Synesthesia
Books by Richard E. Cytowic, M.D.

Synesthesia: A Union of the Senses
Nerve Block for Common Pain
The Man Who Tasted Shapes
The Neurological Side of Neuropsychology
To Stephen
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BECOMING A ROBOT

We touch with our skin, we see with our eyes, and hear with our ears. We take it for granted that each sensory modality is separate at its origin and that we perceive stimuli in them separately within the brain. Yet, of course, we need to cross-refer between modalities, so that we can recognize something in one modality first encountered in another. That we can even do this from birth has been suggested, perhaps controversially, by Meltzoff and Borton (1979), who showed that babies look longer at a pacifier they have just had in their mouths.

The effect of a lack of cross-modal transference is perhaps best shown by the experience of those who, blind as young children, learn to recognize the world through touch and then have their sight restored as adults. Oliver Sacks described one such person who could not recognize objects properly if presented visually unless he was able to feel them with his hands. The most famous and moving example was when he saw a gorilla at a nearby zoo and could only he understand its posture and movements once he had felt a statue of a gorilla. Sacks quotes Richard Gregory’s patient with a similar problem, “Now that I have felt it I can see it” (Sacks 1995). Gregory even suggests that the different senses facilitate and enrich each others’ analysis of the world during childhood, so that, for example, vision is informed by touch.

Not surprisingly scientists have explored these interrelations between the senses further. Jim Lackner, at Brandeis University in Massachusetts, works on movement, vestibular function, and body orientation. In one corner of his lab there is a small circular chamber with a circling floor on which you stand, holding a bar in front of you (Lackner & Dizio 1988). The walls are covered in broad vertical black and white bars. As you walk forward (staying on the same spot as the floor moves under you), Lackner moves the visual bars forward, so that they appear to overtake you, and you think that you are moving backward. The environmental visual flow overpowers both the internal motor command and sensations from one’s body of forward movement.
In a lab in NASA’s Houston Johnson Space Center there is a robot with arm joints homologous to a human. After gloving up with joint sensors you, as an operator, move the robot’s arms by moving your own, the positions and movements of which are computed and used to move the robot’s. Then you don a VR visor and see the robot’s arms. Totally immersed in the VR environment, in less than a minute or so, one becomes the robot. I thought that if I dropped a tool I was moving from robot arm to robot arm it would land on my leg and hurt. Moving and seeing, but not of course feeling, led to a relocation of my sense of my own body into the robot (Cole et al. 2000).

There is a vast literature on these multisensory interaction in perception (for a short recent review, see Driver & Spence 2000). Sound can influence tactile stimulation, while in ventriloquism—and in the cinema—sound localization is altered by visual input. A particular visual input can even make you feel on your skin a tactile sensation delivered to a glove.

Walking direction, body image, sound localization, and tactile perception are just some of the multisensory interactions we perceive. All reflect the need to build up the most comprehensive view of the world and of our internal and external space. Though different sensory modalities may appear pure, they interact at a level before consciousness in a variety of ways in normal circumstances.

THE COLOR OF A KISS

In those with synesthesia sensory interactions are entirely different: stimulation in one sensory modality automatically triggers a perception in a second modality, so that a sound, say, might instantly trigger a blob of color. The condition has been known since Locke’s description in 1690, though, as Richard Cytowic reminds us, the first edition of his Synesthesia: A Union of the Senses was the first book dedicated to the condition. Since then there have been his biographical account of a synesthete,1 The Man Who Tasted Shapes (Cytowic 1993) and Baron-Cohen and Harrison’s multi-author book, Synesthesia (1997).

For this second edition of his book Cytowic has extensively revised and rethought his ideas with a freshness and enthusiasm which is evident throughout. The book combines detailed phenomenological accounts with more speculative theories about the underlying cause and theoretical structure of synesthesia. It has also been informed by the accounts of synesthetes who have written to Cytowic as his interest in the condition has become more widely known.

SEEING PAIN

In such a condition, which is internal, symptomatic, and without external sign, the narratives of individuals are hugely important. Cytowic
concentrates on the experiences and narratives of those with the condition, classifying and grouping them where possible. For reasons unclear as yet, colored hearing is most common, and then colored numbers or letters, with a given letter triggering the same color each time. Such associations are one way, so that color does not lead to sound. Synesthetic experiences must also be reproducible in an individual over time. Though initially synesthetic percepts were considered triggerable only by another sensation, Cytowic has found examples of people in whom extreme emotions can be the trigger, so that anger, kissing, or even orgasms can release shapes, textures, or colors. “Visual” pain is felt by one subject, moving objects by others, while some have multiple triggers.

What seems constant is that the synesthetic perceptions are relatively primitive or unformed. They are perceived as real, but are neither under volitional control or have external agency. For many synesthetes their experience seems to add to perception of the stimulus and enhance their view of the world, rather than the reverse. In fact the additional synesthetic percept can, in some people, lead to an enhanced memory, as in Luria’s famous case (1968). This phenomenological part of the book is rich, detailed, and fascinating. It reflects, in part, Cytowic’s detective work but also the consequences of his and others’ popularizing the condition and enabling synesthetes to write to him.

THE TWO CORNERS

The rest of the book discusses theories of synesthesia. Here, for the first time, he introduces his “rivals” in the fields. In the clear, light blue corner is Simon Baron-Cohen, from Cambridge, a cognitive and experimental neuropsychologist, a data man and, in a correct scientific way, a skeptic. In the green, loud, hot, sharp-shaped corner are Richard and, to a lesser extent, Hinderk Emrich, a philosopher and psychiatrist from Hannover; they are more clinical and patient-led. The two corners agree on the diagnostic criteria for synesthesia, except for one crucial matter: Cytowic stresses an emotional aspect to synesthesia, suggesting that synesthetes have a strong sense of the validity of their percept, with a “feeling of its truth.” This, as we shall see, leads Cytowic to areas Baron-Cohen could not go. While the latter has considered synesthesia primarily due to a malformation, or breakdown, in modularity between cortical sensory systems, Cytowic explores a number of possible explanations.

He uses a myriad of different clinical conditions to suggest what might be the underlying theory, or theories, of synesthesia. He considers phenomena similar to synesthesia, including drug effects, hallucinosis in partial epilepsy, release phenomena (visual hallucinations occurring after loss of sight for instance), and responses to electrical stimulation of the brain. All share a suppression of higher cognitive
brain function and lead Cytowic to suggest, as he did in his first edition, a profound limbic involvement in synesthesia.

He then returns to his experiments on cerebral blood flow (CBF) with a single subject, MW, who tastes shapes. Performed with a xenon inhalation technique in 1987, they showed a profound (18%) reduction in CBF over the left hemisphere. It is fair to say that this CBF result remains controversial. Subsequent PET work by Paulesu et al. (1995) showed increased activation in visual association areas, left posterior inferior temporal, and the parietal-occipital junctions during color-word synesthesia, results broadly compatible with the modularity breakdown theory. Subsequently Frith and Paulesu were careful not to overinterpret their finding of a slight left lingual deactivation (1997). Cytowic, in confronting these differences, suggests more data are necessary and raises the possibility that synesthesia may not be an homologous condition. One should be careful not to build too much from a single experiment on a single person performed with an outmoded technique some years ago.

FEELINGS AND IMPOSTORS

He then considers the limbic basis of synesthesia. Previously he had suggested that synesthesia involves a breakdown in communication between areas within the brain, leading to a release of limbic processes which are, in turn, experienced as synesthetic percepts. He now seems to have retracted this view somewhat and suggests, instead, that the limbic system may act as a bridge to bind the various cortical areas involved in the experience of synesthesia.

What is fascinating for Cytowic, and not for him alone, is the manner in which experience is presented to our consciousness with an emotional valence. Sherrington, the founding father of hard empirical neurophysiology suggested in 1900 that “Mind rarely, probably never, perceives any object with absolute indifference, that is without ‘feeling.’ All are linked closely to emotion.”

Baron-Cohen, writing in 1995, was careful not to dismiss emotion, “since it is clear that we are not ‘cold’ computational devices.” But, lacking a clear theory for it, it is difficult to study.

Since then, it is fair to say, emotions have come more to the forefront of scientific debate, and theory and even some data have been forthcoming (Damasio 1994; Pinker 1997; Griffiths 1997; LeDoux 1999; Rolls 1999). What is not quite clear is the extent to which synesthetic experience is more emotionally valenced that nonsynesthetic experience in a given individual and more important, if the emotional flavor is an unique part of the synesthesia, or reflects a normal “limbic” addition to perceptions.

One way in which emotion may be crucial for normal sensory function may be revealed in Capgras syndrome. In this the affected the
person thinks that relatives and friends are impostors. Ellis and Young (1990) suggest this is because the facial recognition areas of the brain are disconnected from the “emotional valence” areas. Thus a familiar person is recognized but does not trigger an emotional response, and it is this which leads the person with Capgras syndrome, lacking a feeling attached to his wife or friend, to presume the person must be an impostor. Feeling states are, then, part of recognition and perception. Cytowic explores various avenues in groping toward an understanding of the role of emotion in synesthesia.

CONSCIOUSNESS AND THE TAXIMETER

There has long been controversy as to whether we all are synesthetes as neonates. Here views tend to depend on interpretation of ambiguous data, since neonates cannot reveal their experience. What seems undoubted, however, is that neonates—and we adults—do make cross-modal comparisons. After a consideration of this, Cytowic next develops ideas of overlap between metaphor and synesthesia, and how metaphor itself may reveal something of the phenomenal experience and the brain’s underlying function, a theme also considered by Ramachandran and Hubbard (2001). Though the relation of this phenomenon to synesthesia is unclear, Cytowic certainly stimulates and provokes.

In the penultimate chapter the personalities of synesthetes, who appear so normal on first acquaintance, are considered. They are known, despite their good memories, to have comparatively poor math and directional abilities. Cytowic also documents the twilight states of psychokinesis and the feeling of a presence which those with synkinesis sometimes relate. He considers the contribution to their art that synesthesia may have made for Messiaen and Hockney. In Messiaen’s case (the more convincing), one can understand that he tried to join his senses of sound and color, but it is less clear how we non-synesthetes can gain an enhanced perception because of it. And since synesthetes themselves are so heterogeneous it is not even clear how one synesthete can understand another’s experience or aesthetic.

The last part of Cytowic’s book discusses a new way of looking at the phenomenon: microgenesis. This concept, originally defined and explored by Jason Brown (1988), arises from the simple fact that much, most, of sensory input is not perceived. Henry Head (1920) put it thus: “Every recognizable change enters consciousness already charged with its relation to something that has gone before, just as on a taximeter the distance is presented to us already transformed into shillings and pence.”

Thus when we are aware of a stimulus it is presented to consciousness as a formed whole. We know that, for instance, early visual input is coded in cells that respond to wavelengths of light, with center-on
and surround-off fields. As Hubel and Wiesel showed, the primary vi-

sual cortex has cells that respond to moving bars and edges; later color

and movement fields are present. But what we see is a formed, colored,

image. More, we see an object, recognize it and with this an emotional

valence is attached. Showing that a synesthete’s colors are poorly

formed, Cytowic suggests they may represent a precognitive visual

image not usually available to perception.

This is intriguing, though it does not explain why this should occur.

It is not clear from this either if the two sensations of a synesthete in-

teract cross-modally, and how—and if—they are united into a single

percept. The idea is, however, testable. Functional MRI experiments

might show that areas light up during a synesthetic perception that are

not active during perception in controls.

CANDLES AND ROCKETS

At the beginning of this book Cytowic relates how he has always been

an iconoclast, at one stage throwing his neurology notes from a bal-

cony, such was his indignation at its sclerotic thinking. But he is not

simply an image breaker, valuable though those can be. He wants to

erect other, newer, images, images which not all people may appreci-

ate. There is much in this new book I was unsure of, and much that

others may disagree with. But Cytowic will, I suspect, expect that and

indeed relish it. For some people quietly enlarge the envelope of our

knowledge. Cytowic began his career pushing the envelope and is still

pushing it, trying to understand and harnessing data, where he can, to

underpin his ideas. He pursues his ideas with an enthusiasm which

appears to outrun doubt.

Early in this edition he asks why we like fireworks. Might it be be-

cause they are primitive forms of color, normally masked from con-

sciousness? Might they be brief glimpses into our microgenetic brains?

This book has some of the characteristics of fireworks. His phenom-

enological accounts of synesthesia are slow-burning candles, throwing

further and welcome light on the condition. Later come the rockets, as

Cytowic uses data to fuel the upward flight of his theories and ideas.

While the results are never less than entertaining, the measure, as for

all of us, is how many of the rockets will be adopted and brought back

to earth safely. Whatever the future reveals about the neural mecha-

nisms of synesthesia we owe Cytowic a debt for revisiting this fasci-

nating condition and mining its depths once more. It is now up to the

rest of us to match his enthusiasm with further research into tasting

shapes and hearing colors.

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NOTES

1. One does not call people with epilepsy “epileptics.” This is not a blind conformity to being politically correct, but rather a desire to see them as people, as individuals who happen to have and live with a condition. The term “synesthete” is used by Cytowic and will therefore be employed in this foreword. Its use implies, I think, that people with synesthesia are not at a disadvantage and that the aesthete ending implies almost an enhanced appreciation of some sensations.

2. Jason Mattingley and colleagues have recently studied a group of 15 synesthetes with colors after word presentation (2001). Their synesthetic percepts could not be suppressed consciously, but if the words were presented for a very brief time and then masked, so they could not be described overtly or consciously, synesthetic colors were absent. Thus the synesthetic binding appears to occur after initial processing of the visual form, at a level in parallel with or after the stimulus is able to be consciously reported. They also showed that synesthetic experiences can be detrimental to performance of a relevant perceptual judgement.
Understanding our own body and its functions has become in this age a major source of interest, research, and considerable effort. Nowhere is such curiosity in action seen with better clarity than in the work now in progress on the very source of our curiosity, that is, the brain and the mind. A paradox emerges when we try and grasp within an overall view what is now known about the way our brains work as revealed by the veritable avalanche of new facts and ideas discovered by the neurosciences. With superb precision we can now trace, for example, the course of a visual event initiated at the retina of our eye, through all the neural pathways in the brain, and postulate mechanisms for the building of a perception in the visual parts of the brain at the cellular and cell-groups levels. We can also do this for hearing and to some extent for touch and other sensations. We can describe in exquisite detail the workings of our brain systems controlling our motor actions. But nowhere do we find the mechanisms of integration at the highest level to which we can point and ask: Is this how we come to understand? In short, the discovery of how the mind and its conscious (as well as subconscious) functions are organized eludes us even as the sheer number of facts about the detailed workings of the brain threaten to overwhelm the neuroscientist as well as the layperson. Obviously there is a great need for better theories with which some of these data may be organized and better understood.

It is within this context that I find Dr. Cytowic’s book on synesthesia a fascinating and novel contribution. A moment’s introspection will assure anyone that while we easily know that what we see and hear are distinct events, we are simultaneously capable of integrating these events in forming ideas and thoughts about the information such sensory inputs bring to our brains. In most persons, however, this integration is at a level of brain organization of which we remain unaware. In synesthetes, as clearly brought out by Dr. Cytowic, there is a conscious mixing of some of these sensory channels almost as if what is normally a subconscious mechanism is somehow bared to their consciousness. It is not surprising therefore that the cognitive skills of
persons with synesthesia are uneven. Although some may be able to display extremely powerful feats of memorizing and others use their modality-crossing sensations as inspirations for creative work, there is a fair amount of evidence marshaled in this book to support the thought that synesthesia is bought at the cost of some degree of intellectual handicap. This is not to say that synesthetes are therefore doomed to a mildly impoverished extent of personal achievement. The incredible complexity and enormous range of human achievements in spite of physical and mental handicaps far greater than that posed by synesthesia is ample evidence that human minds can find ways to utilize handicaps or, in overcoming them, develop other talents to achieve their goals. While Luria’s mnemonist could not become the concert violinist he wished to be or hold a steady job for long, his extraordinary feats of memory certainly ensured his livelihood and his place in history.

What is perhaps most important about this book is the stimulus it will provide to the imagination of the reader in pondering the rich feast of knowledge about a most fascinating part of ourselves. After all, synesthesia is what we all do without knowing that we do it, whereas synesthetes do it and know that they do it.

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The first edition of *Synesthesia: A Union of the Senses* was the first book ever in English on this fascinating topic, and the first opus of any length to inquire into the neural basis of synesthesia. When I first mentioned the geometrically shaped taste of my proband, MW, to my neurology colleagues over two decades ago, their reflexive response was, "Stay away from it, it's too weird, too New Age. It will ruin your career." They thought I was out of my mind.

As of 2001, neuroscientists in 13 countries have been actively pursuing synesthesia research. I have fielded numerous requests for advice regarding everything from doctoral theses to high-school science projects, I have written entries for the *Encyclopaedia Britannica*, spoken before audiences ranging from NASA engineers to neural networkers to poetry therapists, participated in graduate seminars with novelists and computer scientists, and participated in workshops and colloquia, both on-line and in person, around the globe. In short, we are in the thick of another synesthesia renaissance.

The second edition has been extensively revised to reflect new research that has taken place in the intervening dozen years. It has also been modified to incorporate new knowledge of human brain function and brain development that is germane to synesthesia. A completely new chapter on "spatial extension" explores the Euclidean and dynamic aspects of synesthetic perception, which I had underemphasized previously. Another new chapter on development explores Daphne Maurer's notion that all neonates are inherently synesthetic, and also attempts to tie Lawrence Marks's earlier work on intersensory correspondences into contemporary thinking.

The excisions are noteworthy, too. Thanks to new knowledge largely gleaned from functional imaging, I have been able to delete speculative material. Also gone are lengthy discussions of synesthesia's history, literary synesthesia, and the phenomenon's relation to art, including colored music. These are not without inherent interest, but I judge them to be beside the point in trying to reach a neural understanding of synesthesia. Readers interested in these subjects can consult Kevin Dann's
Bright Colors Falsely Seen: Synesthesia and the Search for Transcendental Knowledge (1998), Jörg Jewanski’s Ist C = Rot? Eine Kultur- und Wissenschaftsgeschichte zum Problem der wechselseitigen Beziehung Zwischen Ton und Farbe von Aristoteles bis Goethe (1999), and the proceedings of the Wolfenbüttel workshop, Synesthesia—Historic and Actual, edited by Hans Adler (2001). I have, however, retained a short discussion of art in chapter 8 only insofar as it pertains to color vision, and I have modified and abbreviated my discussion of composer Olivier Messiaen only to illustrate how a straightforward musicological analysis can predict the colors in Messiaen’s music.

The Internet now offers various sites of interest, some of them interactive, by synesthetes and nonsynesthetes alike. The moderated Synesthesia List is thriving, as are both the American and the International Synesthesia Associations.

All in all, I’m amazed where a casual chicken dinner over two decades ago can lead. It seems it didn’t ruin my career at all.
The idea that the senses can short-circuit and that we can see sounds and taste shapes is inherently fascinating, strains our common sense, and appeals to our belief in magic.

Synesthesia came into my life in 1976, when I read A. R. Luria’s book about a man with a photographic memory. It was called *The Mind of a Mnemonist* (Luria 1968). During my later training in neuro-ophthalmology, I studied illusions and various distortions of vision with great interest. With this preparation, I knew I had stumbled onto something extraordinary in running across two synesthetes within one month. They are VE and MW, 2 among the current 42 subjects of this book. The year was 1979, and I had no idea at the time how far those chance encounters would bring me. I am, of course, thankful to the many subjects who brought their condition to my attention. I am thankful too to the popular and scientific press for showing such an interest in this phenomenon.

Synesthesia has been known to the medical and psychological community for over 200 years. The first medical reference to it was circa 1710, when an English ophthalmologist, Thomas Woolhouse, described the case of a blind man who perceived sound-induced colored visions (Castel 1725, 1735). In 1704, Sir Isaac Newton had tried mathematically to correlate the energy of sound and color, and the first practical application of this appears to be Castel’s *clavecin oculaire* (“ocular harpsichord”), an instrument that plays sound and lights simultaneously. Erasmus Darwin (1790) achieved the same effect with a harpsichord some time later. Correspondences with color are noted by Goethe in *Zur Farbenlehre* (Theory of Colors) (1810). Thus, great minds have turned their attention to synesthesia and we should also note that many had either an artistic or a naturalistic disposition.

Those who know the term *synesthesia* through the literary symbolism of Yeats, Swinburne, Baudelaire, Hart Crane, Edgar Allen Poe, or Dame Edith Sitwell will not find any explication here. We are not talking about sound symbolism or metaphor, but a perception, a literal joining
of the senses. However, the relation of synesthesia to art is discussed in chapter 8.

I start with some historical background and then present synesthetes who tell in their own words exactly what it is that they perceive. They explain what it is like to have, in essence, a sixth sense. A review of theories follows with a new proposal that is consistent with the shift in conceptualization both of neural tissue and of cognitive function. In asking where in the brain synesthesia occurs, we look at things to which it is similar: the perceptions of eidetic memory, temporal lobe epilepsy, release hallucinations, sensory deprivation, and drug-induced synesthesia. Physiologic data are given to support my theoretical position. Following this, the neural substrate of synesthesia is examined in detail. I conclude that synesthesia resides only in the left hemisphere and that the hippocampus is an important node in the neural machinery that generates the parallel perception.

A shift in focus leads me to refute the idea that language has any role to play in the link between senses. It is unfortunate that early psychologists repeated the notion that synesthesia was merely a more intense form of metaphoric speech in which we all engage. This had a tendency, I think, to turn people away from what might be occurring in the brain of someone having a synesthetic experience. Even a partial answer to this question was not possible until the second quarter of the last century, by which time both science and art had lost interest in the subject.

I present and review some familial cases of synesthesia and look into how this unique perception influences personality. We find that artists are not overrepresented among synesthetes and neither does it indicate great intellect or mental dullness. It is simply a rich additional way of perceiving the world.

I end by examining some closely held beliefs and showing that they are in fact illusory. This leads me to the delightful question, What is real? The reader is left to deduce the answer for himself. A disturbing but unintentional effect of analyzing how we create objects (i.e., how we perceive them as being external in the three-dimensional Euclidean space we believe we have around us) has two sides: synesthesia no longer seems so unbelievable, but then reality no longer seems so real.

Why a book on synesthesia now, after so many years of disinterest, and why from a neurological perspective? As I mentioned above, the circumstances are partly accidental. Not long ago, it would have been difficult to give a satisfactory explanation for synesthesia in neurological terms. But we have learned more about the brain in the past 10 years than in the entire history of neuroscience. We have changed both our conceptualization of nervous tissue, as well as our conceptualization of cognitive psychology, so drastically since the heyday of synesthesia that a coherent and convincing explanation of this remarkable
condition is now possible. Reviews of the subject had been published in 1890 in French by Suarez de Mendoza (L’Audition colorée) and in 1927 in German by Argelander (Das Farbenhören und der synästhetische Faktor der Wahrnehmung). But neither was able to approach the subject from a neurological basis. Because this current work represents the only book on the subject, it needs first of all to be addressed to a scientific audience and be as thorough as possible. In this, I think I have succeeded. But it is not beyond the interested layperson or the artist, although lay readers will find parts of this book too technical and reflective while scientists and philosophers will find other places too popular and artistic. Such are the predictable responses to any effort seeking to meet the challenge of writing the definitive work and of saying something reasonably reflective about a subject that has a fundamental appeal.

Although the present volume reflects 10 years of intermittent work, the majority of it was written at the Hambidge Center for Creative Arts and Sciences in Rabun Gap, Georgia. This is a unique facility in beautifully isolated countryside where there is a marvelous opportunity for artists and scientists to live and work together. My thanks for being a fellow in the summers of 1987 and 1988. When I founded a private clinic, Capitol Neurology, in Washington, DC, I did not foresee that research would be something for which we would have a growing reputation. I thank my colleagues and staff of Capitol Neurology for the ability to take time away from the practice and also for accommodating the disruptions of television crews and reporters.

Harry Whitaker was a catalyst to developing this idea into a book. I want to especially thank Rey Aguirre of the Library of Congress for his friendship and valuable help, and Velora Jernigan and Anne Prussing of the Washington Hospital Center Library for helping track down obscure medical references. Thanks to Ray Pierotti, executive director of the Hambidge Center, for insightful discussions and an atmosphere for exchange between artists of all professions.
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Synesthesia
Listening to someone speak seems like a unitary experience. It never dawns on us that the sound of their voice—the mechanical energy of pressure waves pushing against our tympanic membranes being transformed into meaningful language—and the sight of their body language and moving mouth—electromagnetic energy transformed through our eyes into meaningful gestures—are processed in separate locations in our brains. And yet the coupling of these two events appears seamless. Just how tight this intersensory binding is becomes apparent in the less mundane example of watching a ventriloquist. For the life of us, we cannot help but hear the speech as coming from the dummy whose mouth is moving.

So a union of the senses really isn’t new until it turns literal. Most people link different senses only by way of metaphoric speech, saying, for example, that red is a “warm” color, that a certain cheese tastes “sharp,” that so-and-so is a “sweet” person, or that someone else is having a “hot” argument. But a minority of individuals exist who experience the phrase, “I see what you’re saying” as literally true.

What first strikes me is the color of someone’s voice. [V—] has a crumbly, yellow voice, like a flame with protruding fibers. Sometimes I get so interested in the voice, I can’t understand what’s being said.

Spearmint tastes like cool, glass columns. Lemon is a pointed shape, pressed into my face and hands. It’s like laying my hands on a bed of nails.

I enjoy music that has wavy metallic lines, like oscilloscope tracings. My favorite music has movement that extends beyond my peripheral vision. I really like music that makes the lines go up.

I get frustrated by advertisements because the letters and numbers are always in the “wrong” color.

These are examples of the parallel sensation called synesthesia. Although medicine has known about synesthesia for three centuries, it keeps forgetting that it knows. After decades of neglect, a revival of
inquiry is underway. As in earlier times, today’s interest is multidisciplinary. Neuroscience is particularly curious this time because of what synesthesia might reveal about consciousness, the working of nonsynesthetic brains, subjective-objective relations, the neural basis of metaphor, and the relationship between reason and emotion.

The word *anesthesia*, meaning “no sensation,” shares the same root with *synesthesia*, meaning “joined sensation.” It comes from the Greek *syn*, union + *aesthesis*, sensation. It denotes the rare capacity to hear colors, taste shapes, or experience other equally strange sensory fusions whose quality seems difficult for the rest of us to imagine. For example, my voice would be not just something that is heard, but also felt, seen, or tasted. A synesthete might describe music whose sound looks like “shards of glass,” a scintillation of jagged, colored triangles moving in the visual field. Or, seeing the color red, a synesthete might also perceive the “scent” of red.

Synesthetic percepts are neither a conventional perception nor an image. They possess a curious spatial extension and dynamism, and are involuntary, automatic, and consistent over time. Synesthesia is “abnormal” only in being statistically rare. In fact, I will develop the argument that synesthesia is possibly a normal brain process that is prematurely displayed to consciousness in a minority of individuals.

No matter what senses merge in a given synesthete, it is striking how similar the histories of all synesthetes are. One after another, they claim that their lifelong intersensory associations never change over time, and that they have had the trait as far back as they can remember. As children, synesthetes are surprised to discover that the rest of humanity does not see the world as they do; any mention prompts immediate ridicule or disbelief. Despite keeping the experience private and hidden, it remains vivid and irrepressible, beyond willful control.

Present knowledge of synesthesia can be summarized as follows. It runs in families in a pattern consistent with X-linked dominant transmission (with lethality, a qualification explained in §2.8). Female synesthetes predominate by a ratio of at least 3:1. Synesthetes are preponderantly non–right-handed and have additional features consistent with anomalous cerebral dominance. They are mentally balanced and normal—indeed bright—in the conventional sense, and possess excellent memories. Despite an overall high intelligence, synesthetes as a group have uneven cognitive skills. Whereas a minority are frankly dyscalculic, a large proportion exhibit subtle mathematical deficiencies such as lexical-to-digit transcoding, right-left confusion (allochiria), and a poor sense of direction for vector as opposed to network maps. Fifteen percent of the current sample has a first-degree family history of dyslexia, autism, or attention-deficit disorder.
1.1 HISTORICAL DEVELOPMENTS

In examining reports of synesthesia throughout the literature, it is astonishing to find the phenomenon unexamined by neurologists even though, as I indicated in the preface, synesthesia has been known to medicine for about 300 years. After its last heyday, circa 1860 to 1930, it was forgotten, remaining unexplained not for lack of trying, but simply because psychology and neurology were premature sciences at the time. Psychological theory was jam-packed with associations, and concepts of nervous tissue were paltry compared to today’s understanding. What we consider modern neurology was in its infancy in the nineteenth century. Just as concepts of neural organization were becoming recognizably modern, behaviorism appeared on the scene with such draconian restrictions against subjective experience that even acknowledging the existence of an inner life was taboo for a long, long time.

Believe it or not, relating cognition to brain function has occurred only recently. Though it sounds like an oxymoron, neurology has been overwhelmingly indifferent to mental life for the bulk of its history. Freud, who began his career as a neurologist tracing circuits in the brain, is often cited in the argument against this statement. But Freud was antibiological in the extreme and his influence endured a long time. Historically, neurology has been much concerned with movement, spinal reflexes, and other elementary functions while leaving thought and emotion to the realm of psychiatry and philosophy. Even literature “of the 1940s and 1950s expressed considerable ambivalence about the status of the cerebral cortex in mental functioning” (Mesulam 1998).

I mention this history by way of introducing that my study of synesthesia is accidental. I trained at a stroke center at which territory was clearly demarcated. Patients endured a breathtaking barrage of technological interventions only to be told the obvious, that they had had a stroke for which we could do nothing, but that it was their hearts that would kill them. Tuesday afternoon was set aside for an interdisciplinary conference in which all subdisciplines participated: neurology, neuropathology, neuroradiology, neurosurgery, and one of the basic neuroscience sections. The section of neuropsychology rarely presented cases given that it did not have any “real doctors” in it, only PhDs. Such was the intellectual arrogance.

Part of my internship was devoted to ophthalmology, with emphasis on neuro-ophthalmological disorders. It was here that I came to understand that physicians are interested in vision but not blindness, that vision is a psychophysical phenomenon, and that there are limits to organic assessment by Snellen charts, slit lamps, and Hruby lenses.
Visual symptoms that had no visible pathologic changes were ignored or dismissed out of hand. That is, patients “saw things” but the faculty saw nothing. Such complaints were voiced often enough and in such a manner that I sensed both a common thread in their descriptions and a conviction of their reality. Yet I found no references to these unusual specters in standard ophthalmological texts. It is as if these common experiences had been forgotten. A paragraph here and there was enough to pique my interest regarding polyopia, afterimages, and color vision. I particularly enjoyed discovering the physical causes of monocular diplopia, an impossible condition, we were taught, and therefore an infallible sign of hysteria. How surprising to discover its cause to include dislocated lenses, keratoconus, retinal degeneration, cerebral lesions, and migraine (Bender 1945; Fincham 1963; Rubin 1974; Sinoff & Rosenberg 1990).

In neurology, “localizing the lesion” was an end in itself, and often a primary occupation. I thoroughly deplored neurology in medical school. In a fit of pique while studying for an examination, I threw my entire notes off the balcony, proclaiming the subject incomprehensible and that no one should be forced to learn such endless arcane facts that served no purpose.

Two events precipitated my change of heart. One was the transition from classroom to real patients and the influence of a teacher, Dr. William McKinney. He was the first physician I had ever seen sit down on the bed, take the patient’s hand, and actually talk to him. In the clinician’s hands, neurology was no longer a collection of arcane facts but a method. Dr. McKinney suggested neurology would suit me, and later arranged for me to study at the National Hospital for Nervous Diseases in London, an institute more commonly referred to by its address, Queen Square. At the time, the British had a much higher appreciation for cognition than we did in the United States. The second event was my discovery of aphasia and the revelation that one could lose language while preserving the underlying motor functions. It was my introduction to higher cognition and I thought it elegant.

The New York Times music critic Harold Schonberg mentioned that Maurice Ravel had aphasia, so I did what I could to investigate his illness personally. This included correspondence with Ravel’s still-living physician, Theophile Alajouanine (Cytowic 1976b). Perhaps this single event stimulated my interest in how disease affects not just artistic realization but the life of the mind in general, just as learning that Chekhov was a physician began an interest in the relationship between medicine and the humanities (Cytowic 1975, 1976a). The exploration of Ravel led me afield to “the other side of the brain” and split-brain research (Bogen 1969a, 1969b, 1969c). Here, another wonderful paradox was revealed: that the “person” who speaks is not the same “person”
who perceives or solves problems. They are separate but usually uni-
ified by the cerebral commissures.

Critchley’s book on the parietal lobes and MacLean’s papers on sub-
jective experiences in temporal lobe epilepsy, psychosomatic medicine,
and the reptilian brain were again another world, fascinating but unre-
related to what was being taught at the bedside on teaching rounds or in
the conference rooms. The chain appeared broken somewhere and no
one seemed interested in what historical figures taught, nor did anyone
suggest that history might be enlightening. The relevant books had
not been checked out of the library in decades. What was taught was
deemed “new” and the most scientific. This state of affairs was hardly
unique to my medical school, and I coined a private aphorism, “If you
want to learn new things, try reading old books.”

I had read Luria’s *Mind of a Mnemonist* (1968) and already knew of
hyperlexia, hypercalculia, and other elevated functions. No neurologi-
cal explanation for these existed, merely descriptions limited to case
reports. These kinds of perceptual experiences were better explored in
the older non-American literature. It was interesting to read these
works and compare them to the biological model of the National Insti-
tutes of Health that dominated medical thinking at the time. Even the
style and method of classics such as Alajouanine’s analysis of aphasia
in artistic realization (1948) was alien compared to what I had been
exposed to. This is some of the background, then, on the circumstances
that led to my broad interests within medicine.

### 1.1.1 How This Work Got Started

I was chatting with VE one afternoon when my beeper went off, pro-
ducing a series of three shrill tones. Immediately, VE put her hand
to her forehead and gestured for me to silence the device. “Oh, those
blinding red jaggers, turn that thing off!” When asked to explain, she
related that sounds made her see colors and that particularly high-
pitched or loud ones were painful. In the case of my beeper, the three
beeps caused her to see jagged red lines, “like lightning bolts.” A stab-
bbing pain in her forehead accompanied each one.

This was the first instance of synesthesia I encountered. Further con-
versation revealed that she was polymodal, although seeing colored
photisms in response to sound was her dominant experience. An im-
promptu pilot experiment with a faculty member as a control showed
that her drawings in response to spoken Czech words were quite dif-
ferent from those of the non-synesthete, whose drawings at best paral-
leled the rising and falling intonation of speech. She also perceived
color in response to smell and taste. “You know how strychnine smells
pink?” She asked, assuming that I would. “It tastes nearly the same
pink as my angel food cake. Isn’t that remarkable?” This explanation was unhelpful to understanding her experience. Presentation of Luscher color cards and Munsell chips evoked different smells for her and amusement for the rest of us. I made the diagnosis of synesthesia, mentioned its relationship to Luria’s patient, and let the matter rest.

Shortly afterward my new neighbor, MW, who taught theatrical lighting design at the nearby conservatory, invited me to dinner. Our call to table was delayed by the host’s announcement, “It’ll be a few more minutes—there’s not enough points on the chicken.” With that casual remark he turned around, face beet-red. “Oh,” he said with great embarrassment, “you don’t know . . .” Perhaps I would understand, he ventured, because I was a neurologist, but his explanation only seemed to make the situation more bizarre. MW struggled to explain that, for him, flavor had shapes and that he cooked according to the shape of foods rather than their flavor. He was disappointed because the roast chicken had come out “too round” and he couldn’t serve it. He had to correct the seasoning and adjust the sauce to give it a more “prickly” and “pointed” shape.

While his friends ribbed him, I reckoned that I had my second case of synesthesia and that both should be looked into further. Like other synesthetes, MW was astonished to learn that his experience had a name and that he was not the only one in the world who felt things the way he did. Luckily, MW’s undergraduate degree was in botany, so he understood scientific method and the need for experimentation. He graciously consented to undergo the tedious psychophysical experiments, examinations, and invasive procedures documented throughout this book.

1.1.2 History of Synesthesia

Synesthesia’s history is important if we are to understand its neurological basis, because the word has been used to describe diverse phenomena during different eras. Central to my initial approach over two decades ago was a sharp demarcation of synesthesia as a sensory perception as distinct from a mental object like ordinary cross-modal associations, metaphoric language, or even artistic aspirations to sensory fusion. By contrast, the perceptual phenomenon is completely unheard-of in literary and linguistic circles, where the term “synesthesia” is understood to mean rhetorical tropes or sound symbolism (à la Humboldt and Sassure). This is the situation in Oriental cultures, too, where synesthesia is understood to be a literary device rather than a physical perception. The recent interest in “historical” (meaning literary) synesthesia (Adler 2001), and considerations of neonatal development and synesthetic metaphor (chapter 7) make me ponder whether such a sharp demarcation remains warranted.
Much ink has flowed discussing synesthesia in art, music, literature, linguistics, natural philosophy, and theosophy. Two books appeared, Suarez de Mendoza’s in French (1890) and Argelander’s in German (1927). Most accounts emphasized colored hearing, the most common form of synesthesia. By mid-nineteenth century, synesthesia had intrigued an art movement that sought sensory fusion, and a union of the senses subsequently appeared more and more frequently as an idea. Multimodal concerts of music and light (son et lumière), sometimes including odor, were popular and often featured color organs, keyboards that controlled colored lights, as well as musical notes (for a review, see Peacock [1988]). It is imperative to understand that such deliberate contrivances are qualitatively different from the involuntary experiences that I call synesthesia throughout this book.

In such a climate, people were intrigued with the notion that synesthesia might have a direct link to the unconscious. With time, however, attention turned to so-called objective behavior that could be quantified or measured by machines. Humans thereafter became “subjects,” the individual was abandoned, and the mind temporarily became a black box.

Mechanistic explanations have been abundant throughout synesthesia’s history, and the notion of crossed wires turns up especially often. As early as 1704, Sir Isaac Newton struggled to devise mathematical formulas to equate the vibration of sound waves to a corresponding wavelength of light. Goethe noted color correspondences in his 1810 work, Zur Farbenlehre (Theory of Colors). The nineteenth century saw an alchemical zeal in the search for universal correspondences and a presumed algorithm for translating one sense into another. This mechanistic approach was consistent with the then-common view of a clockwork universe based on Newton’s uniform laws of motion. The fact that synesthetes have idiosyncratic responses and that no two of them agree of course undermined this approach.

Today it is possible to take the details of a given synesthete and find similar examples in the classical literature providing, in John Harrison’s words (2001 p 29), “a neat link between the work of scientists a hundred years ago and contemporary efforts to understand and explain the condition.”

1.2 CRITICISM OF EXPERIENTIAL RESPONSES

Science has been traditionally suspicious of introspective accounts because they are often found unreliable. The accounts of contemporary synesthetic subjects, however, are so similar that one gets the persuasive sense of a shared phenomenon. There is a remarkable consistency among subjects, with all of them claiming to have had the experience as long as they can remember, everyone reporting that the secondary
sensations remain constant over time, and all and sundry amazed that others like them exist.

How does science approach the distinction between the first-person understanding of an experience with a third-person one that is supposedly objective? The lack of obvious agreement among synesthetes compounds the apparent difficulty. In fact, this rather glaring problem—that two individuals with the same sensory pairings do not report identical, or even similar, synesthetic responses—has sometimes been taken as proof that synesthesia is not real. But then the implicit question is, Real to whom? To the questioner or the person that has it?

During the twentieth century, physicists successfully eliminated the subjective role of a human observer in gathering empirical data. This is not an unalloyed joy for neuroscience, for whereas a huge knowledge base has come about by physically investigating the brain, it has proven harder to get a grip on mental life. Perhaps we can turn to the nineteenth–century physician, physicist, and polymath Gustav Fechner for guidance, because it is precisely physical absolutism that Fechner meant to transcend. He articulated what every nineteenth century physiologist knew but which became gradually lost in the twentieth century’s zeal to decipher the nervous system, namely, that a mental world exists. Then, as now, the question is, How to do science in such an arena? In a fundamental sense, Fechner’s psychophysics has no substitute: no amount of fiddling with nerve impulses or brain images can substitute for the observer’s report (Regan 2000). Even the current craze of functional imaging starts with the subject’s state of mind.

Many oddities in neuropsychology come to attention by accident and often with considerable coaxing of the patient, who feels embarrassed or ashamed at what he has been taught by authorities is not real—just like the ophthalmology patients who saw things that the professors insisted weren’t there. Verbal responses are the bread and butter of clinical assessment in neurology and neuropsychology. It is the only means in classical neurology to evaluate any sensory quality. Verbal reports often go beyond the capacity of science to analyze and quantity a phenomenon physiologically. For example, testing with the same psychophysical methods with suprathreshold stimuli for orientation, movement, or detection in scotomatous visual fields can yield identical results (sometimes perfect performance) compared to testing in the intact visual field, and yet the subject insists that the perceptions in each test are worlds apart in quality. He “sees” the stimulus in the intact visual field but sees “nothing at all” in the blindsighted field. Unlike the scientist, however, he does not say, “I can make a verbal response to one but not the other,” but insists that the experiences are totally different.
There are other examples where experiential reports alone have changed our concept of neurophysiology. The obvious example is dreaming during the rapid eye movement (REM) stage of sleep. If no one had awakened sleepers during different electroencephalographic (EEG) phases and asked them what was happening, the meaning and clinical correlation of this phasic EEG activity would have remained undeciphered. Worse yet, it might have been assumed to have no meaning at all. Verbal reports are often the neurologist’s Rosetta stone. There are, of course, two sides to that stone. Experiential reports have advanced neuroscience; neuroscience should therefore be able to help us better understand experience. This kind of support is essential to the analysis of synesthesia. Perceptual processes can occur on widely different levels of awareness within an individual. blindsight research, for example, demonstrates that verbal reports severely underestimate visual capacity, whereas work with split-brain patients shows that verbal reports can be actively misleading. Synesthesia can, in principle, be understood just like any common experience, except that there is no shared referent. Different kinds of scientists favor different kinds of data. Psychologists generally prefer to measure behavior, what people do, whereas biologically-oriented types favor physical evidence, especially pictures of the brain.

In our analysis of perception and perceptual deficits that are better understood than synesthesia (or at least better accepted given their familiarity), we will see how aspects of objects—color, shape, movement, texture—can detach and be perceived separately or incongruously with objects from other senses (chapter 9). Although it may be a product of evolution, the human mind actually has become what most of us presume it to be: an ideal entity that exists independently of the world it perceives. When we start looking at what actually happens when we take in the world, our presumptions about the nature of mind and reality begin to break down. We will look at some of these in later chapters.

For example, close investigation of visual mechanisms reveals that it is our brains that construct much of what we take to be objective visual data. Color, for instance, is not due to the wavelength of light reflecting off the surface, as is so often said, nor is it related to any obvious physical quality at a given point on an object. What we see when we look at our surroundings is largely our own invention. Consider the detachment of shape. We have no difficulty recognizing a real tree from an artist’s sketch of the same shape or a photograph of a tree despite the enormously different images that each of these three examples casts on the retina. That we do not rely on “bits of data” from individual photoreceptors in constructing form is a conclusion that can be developed into the premise that shape is detachable from objects. As we
proceed through the chapters, readers may ponder the inevitable thought that objects may not be as objective as they thought.

1.3 SYNESTHETES AS COGNITIVE FOSSILS

No statement of mine has been more misunderstood than my reference to synesthetes as “cognitive fossils.” Notwithstanding, I’ll give it another try. Synesthesia may be more vestigial if one accepts Maurer’s hypothesis that all neonates are synesthetic and the evident conclusion that the majority grow out of it. But I do not want to be misunderstood as considering synesthesia to be more primitive or atavistic, or perhaps even how animals or early humans perceived in their prelinguistic phase. This would confuse us with scale-of-nature questions.

Synesthetes are metaphorically like cognitive fossils because synesthesia is more mammalian than sapient. Synesthesia is more mammalian not because it is somehow primitive but because the sensory percepts are closer to the essence of what it is to perceive meaning than are semantic abstractions. The assignment of meaning is discussed in chapter 7. Ascribing high-level semantic meaning to things is not typical of the superordinate category of mammals, whereas synesthetic perception is. Just as language is species-typical behavior, synesthesia is more phylum-typical.

I believe no general theory of synesthesia is possible without accounting for the characteristic affective state that accompanies synesthetic experience. The experience of affect is understood to depend on the limbic brain. As we discuss in chapter 6, the human brain’s neocortical expanse does not configure itself as a replacement for the emotional limbic brain. The neocortical mantle is not the highest rung on the ladder of cognition, completely suppressing everything below it, but evolved as a detour on the ladder, interposed between brainstem and limbic brain (Cytowic 1996, chapters 3 and 8).

The limbic system in an advanced mammal like the human retains its role for suppressing automatic preexisting biases in favor of newer alternatives to express themselves, and is a locus where value, purpose, and memory are calculated. This organ for calculating valence, to use a more neutral term, could have had either of two fates. It could had been suppressed by neocortex, which is to say that one’s evaluations of value and bias are now to be replaced by higher calculations, a so-called better organ for determining meaning and purpose. That seems to be the quintessential belief of the intellectual. He or she thinks that the goal of thought is to suppress limbic function—to suppress emotion. But the neocortex does not calculate emotion or valence. It just calculates.

The other way the limbic system could have evolved is the way that it did—and this is often misunderstood. The limbic brain has retained
its role as the decider of valence, a function that remains one of the most important processes in order to survive in the world. But it needs better data on which to decide valence—the kind of data beyond those that are immediately at your whiskers or in your mouth. What this brain machinery that is said to make us different from lower animals does is only provide more analytic space about what is going on in the environment so that the limbic brain can decide questions of valence.

If your environment poses the making of correct choices as the problem in life, then you have to have a limbic system. The choices boil down to fundamental ones about what it means to be living organism. People who make their choices emotionally, as we say, are more human than those who make them rationally exactly for this reason. You should permit your intellect only to inform your choices, not to override fundamentally emotional ones. This is a roundabout and romantic way of saying that synesthesia can perhaps be looked on as a shorthand way of calculating valence and salience, of attaching meaning to things.

Heinz Werner (1948, 1957/1978) used the term *syncretic* to describe the class of cognitive phenomenon wherein perceptual qualities are fused, or dedifferentiated, in subjective experience. Three classes of syncretic perception he discerned were (1) the physiognomic, fusing perception and affect, (2) the synesthetic, fusing sensory modalities, and (3) the eidetic, fusing perception and imagery. He saw these fitting within the framework of his organismic-developmental theory and, in pointing to their so-called primitive or developmentally-early standing, suggested that synesthesia could be induced in individuals who were not ordinarily synesthetic (Werner 1934/1978 p 157).
In this chapter we will learn about the world of synesthetes through their own voices. There are many possible sensory permutations, and the range of synesthetic performance in clinical experience is broad. One patient may have a highly restricted form of colored hearing, for example, in which only a particular voice or particular kind of music will elicit photisms. The opposite extreme is the pentamodal patient: stimulation of one sense causes synesthesia in the remaining four. Such a vigorous type is best represented by Luria’s famous patient, S (Luria 1968).

Most often the trait is said to have been in existence as far back as the patient can remember. As children, synesthetes quickly discover that others do not perceive the world as they do. Keeping their special talent to themselves, they retreat into a secret world to avoid ridicule and disbelief, even from their own families. This must have an enormous influence on personality. Despite the emotional burden that being synesthetic imposes, as well as the practical trouble it can cause in school and social situations, synesthetes would not for a moment part with their special ability. They have an unshakable sense of conviction that what they perceive is real and valid, and their synesthetic associations remain constant over their lifetime.

2.1 SYNESTHETES SPEAK FOR THEMSELVES

**MN** I remember most accurately scents. We were preparing to move into the house I grew up in. I remember at age 2 my father was on a ladder painting the left side of the wall. The paint smelled blue, although he was painting it white. I remember to this day thinking why the paint was white, when it smelled blue [figure 2.1].

**OM** Colors are very important to me because I have a gift—it’s not my fault, it’s just how I am—whenever I hear music, or even if I read music, I see colors.

**MW** When I taste something with an intense flavor, the feeling sweeps down my arm to my fingertips, and I perceive that object [weight, shape, texture, and temperature] as if I’m actually grasping it [figure 2.2].
Figure 2.1  “Why was the paint white, when it smelled blue?”

Figure 2.2  For MW, flavor (taste + odor) causes the tactile perception of weight, shape, texture, and temperature.
DS When I listen to music, I see the shapes on an externalized area about 12 inches in front of my face and about one foot high onto which the music is visually projected. Sounds are most easily likened to oscilloscope configurations—lines moving in color, often metallic with height, width and, most importantly, depth. My favorite music has lines that extend horizontally beyond the “screen” area.

Something very strange is going on here. The speakers above are all intelligent, responsible people. They are not being “artistic,” are not on drugs, and are not insane. Yet the incongruous adjectives and nouns come tumbling out with conviction and reflect typical synesthetic sentiments. The speakers have never met, yet their stories are remarkably similar. All apologize frequently. “I know this sounds crazy, but . . .” They also learned to stop talking about their green symphonies, salty visions, and tastes that feel like glass columns long ago in childhood when they realized that they were different, and that no one else understood.

DS My parents thought I was very strange. They thought I was making it up to get attention. Everyone was always jumping in with psychological explanations: I had an overactive imagination, I was spoiled and wanted attention, a whole slew of things.

My mother was the only person that believed me, and I’m sure she was not truly convinced that what I experience is [sic] real.

Other parents may be more sympathetic. When the Russian-born American writer Vladimir Nabokov, as a toddler, complained to his mother that the colors on his wooden alphabet blocks were “all wrong,” she understood him to mean that the colors painted on the blocks did not correspond with his own letter-color associations. His mother understood this because she was synesthetic herself. Nabakov’s account of his and his mother’s synesthesia can be found in “Portrait of My Mother” (1949), and in chapter 2 of his autobiography Speak, Memory (1966).

The appearance of the trait in families indicates that synesthesia is a brain-based condition. The occurrence of synesthesia in contiguous generations, and its occurrence in siblings suggest—at first glance—an autosomal dominant mode of inheritance. Familial cases and population estimates are discussed in §2.8. Penetrance (the relative ability of a gene to produce its specific effect to any degree in the organism of which it is a part) may explain why there is a spectrum of synesthetic performance—from restricted forms in which the stimulus must be highly specific, to the indiscriminate activation of all five senses by a wide variety of stimuli. In a restricted form, the subject may see colored shapes in response to spoken words only, whereas in the polymodal synesthete voice, music, environmental sounds, sights, and smells might all be seen, felt, and tasted:
I heard the bell ringing . . . a small round object rolled before my eyes . . . my fingers sensed something rough like a rope . . . I experienced a taste of salt water . . . and something white. (Luria 1968)

The examples above illustrate two points. First, although any pairing or combination of the senses is possible, the most common yoking is sound with sight, called colored hearing or chromesthesia. The most common form of synesthesia appears to be colored numbers and letters. The second point is that color figures quite prominently in various synesthesias (colored hearing; colored olfaction; word-, number-, and name-color associations; colored taste [Downey 1911]; and colored music). Why this should be so is not clear. The percentages of specific synesthetic combinations culled from 365 case reports are listed in table 2.1.

Two additional points are germane here. First, the dynamic and movement aspects of synesthesia have heretofore not been properly emphasized. I discuss this in detail in the new chapter 5. Second, the disproportion in the types of synesthesia is itself intriguing. The five senses can have ten possible synesthetic pairings. Synesthetic relationships are usually unidirectional, however, meaning that for a particular synesthete sight may induce touch, but touch does not induce visual photisms. This one-way street, therefore, increases the permutations to twenty (or thirty if you allow the perception of movement as a sixth element), yet some senses, like sight and sound, are involved much more often than others are, as table 2.1 shows. To persons endowed with colored hearing, for example, speech and music are not only heard but also a visual mélange of colored shapes, movement, and scintillation.

It is rare for smell and taste to be either the trigger or the synesthetic response. Aside from VE in my original 42-case sample, I have found only one other in whom sight evokes smell; for this man, CLF, “Most things I see or hear have a strong taste as well.” Other than my index case MW, in which taste and smell evoked widespread tactile experience, I have encountered one individual for whom smell triggers touch and another in whom taste induces a secondary experience of color.

Apart from MW’s geometric taste, perhaps the strangest synesthesia is “audiomotor,” in which an adolescent positioned his body in different postures according to the sounds of different words. Both English and nonsense words compelled certain physical movements, the boy claimed, which he could demonstrate by striking various poses. By way of convincing himself of this sound-to-movement association, the physician who described it planned to retest the boy later on without warning. When the doctor read the same word list aloud 10 years later, the boy assumed, without hesitation, the identical postures of a decade earlier (Devereaux 1966).
The following features of synesthetes and synesthesia are now examined in some detail:

- Similarity of stories
- Spectrum of performance
- Synesthesia as an unelaborated sensation
- Validity, constancy, and limits of manipulation
- Personality and psychological stigmata
- Hypermnesia
- Familial cases
I discovered my first two subjects, MW and VE, by chance. The rest brought themselves to my attention via newspaper or magazine articles and radio or television programs that sometimes follow my presentations to professional scientific audiences. I collected cases for 9 years, and here follow the original forty-two subjects of the first edition. I now have well over 100 cases, as do Emrich and Baron-Cohen, and it is fair to say that we have all experienced the same circumstance of events, namely, a geometric progression of cases once the popular press gets wind of our work. This method naturally has selection bias.

For several reasons, but principally because this was the first book in English concerning synesthesia, I have not changed the tabulation of the original 42 subjects, but have included additional examples from new synesthetes as appropriate throughout the text.

The following letter is typical of an unsolicited response:

Dear Dr. Cytowic:

I read the article (copy enclosed) from [a particular newspaper] concerning your work with synesthesia. It’s an affirmation that I am not nuts and whatever my other problems may have been, being crazy was not one of them.

I am a sight/sound synesthete, most often seeing sound as colors, with a certain sense of almost pressure on exposed skin when sounds are very light or colors very bright. [MM] is quoted in the article as stating that it’s sort of like a clear overlay, which is exactly right. You have no idea (or maybe you do do at that!) how exciting it is to read someone else’s description—and from a total stranger—of an experience that I have never been quite sure wasn’t the result of my imagination or being insane. I have never met anyone else who saw sound. When enough people tell you that you are imagining things it’s easy to doubt yourself. I’ve never been quite sure that I’m not crazy.

It’s definitely colors, but I’m not sure that “seeing” is the most accurate description. I am seeing, but not with my eyes, if that makes sense.

I love my colors, can’t imagine being without them. One of the things I love about my husband are [sic] the colors of his voice and his laugh. It’s a wonderful golden brown, with a flavor of crisp, buttery toast, which sounds very odd, I know, but it is very real.

Would it be possible to meet others [synesthetes]? As I said, I have never met anyone else who does these things, and would very much like to, as much for the reassurance as anything else. (RP, 5/1/87)

Table 2.2 summarizes the pertinent demographics, types of synesthesia, presence or absence of certain cognitive characteristics, and pertinent comments for the original 42 patients described in this book. Most have been examined in person. Patients will be referred to throughout this text by the initials indicated in the table. The reader will wish to refer to this table throughout the reading of this book.

2.2 SIMILARITY OF STORIES

Synesthesia has an ineffable quality, one that William James defined in *The Varieties of Religious Experience* (1901): “The subject says that
it defies expression, that no adequate report of its content can be given in words. It follows from this that its ‘quality’ must be directly experienced, it cannot be imparted or transferred to others.”

There is a general social taboo against inner knowledge. Biases exist in our scientific and social systems against examining what society says is not “normal.” It can be difficult to get synesthetes to talk about their experiences because of previously encountered disbelief. “Nobody understands.” “People look at me like I’m crazy.” “I don’t want to be a freak.” True synesthetes are reticent; weirdos and wannabes will talk about their “visions” at the drop of a hat.

The initials identifying the quotes that follow are keyed to the demographic and other data found in table 2.2.

MN  I read with interest the article in the [newspaper] . . . as since early childhood I have thought I was the only person in the world with this.

GG  I realize that I, almost alone, possess this mnemonic device of seeing colors of the alphabet and numbers.

BB  The synesthete BB has simple synesthesia and auras around objects. His synesthesia and dyslexia are discussed in a later chapter.

I have never communicated to anybody of seeing additional colored light. For one, I have failed to understand it myself, and to try to explain it to somebody else would leave me no better off. I was so happy to see that my experience is shared and acknowledged by others. I am 35 years old and work in the construction industry. Fear of ridicule has held my secrete [sic].

DS  I nearly fell over when I saw the article about you in [a magazine]. I ran to my husband, shouting “See! This is me! I told you it’s real. I’m not nuts!”

MM  I see shapes and colors in response to sounds. I enjoy electronic music because it evokes such wonderful shapes and colors in my visual perception area. I feel for the first time that I am not nuts! The colored shape is seen as if I were looking through a plastic transparency which is in front of my eyes. If I shut my eyes, or if it is at night in the dark, then the shapes are the only thing in the field and are therefore more intense.

However, there is a secondary path. Sometimes when I hear words I will see shapes. This second one is the one that makes me feel silly. You will notice the shape which your last name evokes below [figure 2.3]. I’m not much of an artist. This is the first time I’ve written something like this down, but it’s accurate.

I have trouble putting into words some of the things I experience. It is like explaining red to a blind person or Middle C to a deaf person. These connections have been with me essentially since birth and are so natural that they are hard to set down on paper. I find it a wonderful addition to life and would hate to lose it. (10/21/83)

It is striking how Sir Francis Galton (1907), during the previous heyday of synesthesia, should have prefigured most contemporary accounts. His descriptions in Inquiry into Human Faculty and Its Development
Table 2.2  Brief description of current synesthetes

<table>
<thead>
<tr>
<th>Tag</th>
<th>Age (yr)</th>
<th>Race/Sex</th>
<th>Educ</th>
<th>Hand</th>
<th>FMLH</th>
<th>Type of synesthesia</th>
<th>?Proj</th>
<th>?Gmem</th>
<th>?Gmath</th>
<th>?Ggeog</th>
<th>Notes</th>
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<tbody>
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<td>AB</td>
<td>17</td>
<td>WF</td>
<td>12</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
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<td>30</td>
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<td>24</td>
<td>R</td>
<td>N</td>
<td>Number form</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Brother autistic</td>
</tr>
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<td>38</td>
<td>WM</td>
<td>14</td>
<td>R</td>
<td>N</td>
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<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Spelling errors; no synesthesia with LSD</td>
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<tr>
<td>CS</td>
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<td>WF</td>
<td>16</td>
<td>R</td>
<td>Y</td>
<td>Number form</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
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</tr>
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<td>21</td>
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<td>18</td>
<td>R</td>
<td>N</td>
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<td>Y</td>
<td>Y</td>
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<td>Y</td>
<td>N</td>
<td>Y</td>
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<td>N</td>
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<td>Y</td>
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<td>Gender</td>
<td>Relationship</td>
<td>Synesthesia</td>
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<td>M Y</td>
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<td></td>
<td></td>
<td></td>
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</table>

Four generations
Niece is synesthetic; Romance language teacher
Maprotiline: no change; medical illustrator
Voices, music, environmental sounds; geometric colored photisms; “Doesn’t obscure my regular sight”; pilot, computer programmer
Paints; “Always think in colors”
Paints her photisms; sees form constants
Colors have moods
Polyglot; consistent in Latin alphabet
Cousin of MT
Sister synesthetic; son dyslexic; red-green, colorblind
### Table 2.2 (continued)

<table>
<thead>
<tr>
<th>Tag</th>
<th>Age (yr)</th>
<th>Race/Sex</th>
<th>Educ</th>
<th>Hand</th>
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<th>?Gmem</th>
<th>?Gmath</th>
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<td>R</td>
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<td>Visual smell</td>
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<td>Y</td>
<td>Number form</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Sister dyslexic; family left-handedness.</td>
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<td>R</td>
<td>N</td>
<td>Colored hearing</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Music, words have shape and color, “like a transparency”; LSD made more intense.</td>
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<td>44</td>
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<td>20</td>
<td>M</td>
<td>N</td>
<td>Polymodal</td>
<td>N</td>
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<td>N</td>
<td>N</td>
<td>Cannot stand to hear foreign language; marijuana: no change.</td>
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<td>BF</td>
<td>18</td>
<td>L</td>
<td>N</td>
<td>Audioalgesic, smell</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
<td>Three generations; LSD, gender and personality.</td>
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<td>R</td>
<td>N</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
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<td>R</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
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<td>R</td>
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<td>Letters, numbers, music keys</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
<td>No change after ruptured right middle carotid artery aneurysm.</td>
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<tr>
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<td>N</td>
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</table>

Y (yes) or N (no) indicates the presence or absence of the trait indicated in the heading under which it appears. Educ, education (years); Hand, handedness (R, right-handed; L, left-handed; M, mixed dominance); FMLH, family history of left-handedness; Proj, synesthesia perceived externally; Gmem, good memory; Gmath, good mathematical aptitude; Ggeog, good sense of direction.
match current accounts almost exactly. He says, for example, in emphasizing synesthesia’s ineffability that

seers are invariably most minute in their description of the precise tint and hue of the color. They are never satisfied, for instance, with saying “blue,” but will take a great deal of trouble to express or to match the particular blue they mean . . . No two people agree, or hardly ever do so, as to the color they associate with the same sound . . . The tendency is very hereditary. (Galton 1907, p. 107)

2.3 RANGE OF SYNESTHETIC PERFORMANCE

The parallel sense of synesthesia is itself always simple and unelaborated. It is the kind or multiplicity of stimuli and the opportunity for multiple sensations in different modes that can make the synesthesia a compound sensation. It only seems more complex when, failing to find words to describe the sensation, a synesthete resorts to metaphor or analogy. This is how the uncritical mind may erroneously conclude that the parallel sense is a “mere association.”

I call the simplest kind of synesthesia “simple synesthesia.” These are colored auras or blobs that arise spontaneously. The stimulus may not be readily apparent.

2.3.1 Simple Synesthesia and Colored Auras

BB sees “additional” colors bordering objects. They can parallel a boundary, come in “soft splotches” lacking orientation, or appear as a color wash over part of the object. Physical and emotional sensations of numbness, flushing, exhilaration, fear, and happiness accompany seeing the colors. At times they obscure the real object, for example, turning to face someone and “not seeing her but a small white center surrounded by black and a large green masking any feature of this person.”

For BB, a green haze or outline, like a transparency, covers the Golden Gate Bridge (which is actually painted orange). Colors can change with the same object (i.e., the bridge is not always perceived as green).
Flashing light patterns, vivid and clear, seem like snow or halos. The colors he sees are primarily green, red, brown, and amber, singly or in a mixture. They are so subtle that the colors “sort of like float across your eyes.”

Another subject describes her simple synesthesias:

**DS** Sometimes when I am really exhausted I see what I call “sleep designs.” These are involuntary patterns, usually geometric, sometimes floral, always in color and similar to bolts of fabric or bed sheets. They change in different designs without any conscious effort on my part. (3/1/87)

Strong emotions can produce an aura in patients who experience some other somatic synesthesia. I have never seen it in isolation. Anger or the flash of insight may trigger a simple colored aura. Kissing and sexual intercourse are reliable triggers in some subjects, causing colored photisms, tactile shapes and textures, and tastes (DS, DSh, MW, SM, CSc). Since the first edition was published numerous individuals have volunteered to describe the synesthetic qualities of their orgasms; I have not followed up on this systematically.

**DS** People say that anger is red, but I see purple. If I’m really upset at my kids and I’m yelling at them, there will be a purple background behind them. Where their head meets the background, it’s like an aura, a yellow luminescence going into purple. It dissipates slowly.

Figure 2.4 shows JB’s drawing of her simple synesthesia. She has had simple, projected synesthesia all her life. Like Luria’s patient mentioned earlier, she was searching for what to do with her life. Nothing seemed to fit or to be real to her. There was a sense of portentousness that at any time something wonderful or important would happen to her. It was only after the occurrence of unusual experiences as an adult—what some refer to as psychic abilities (see §8.1.4)—that she became an artist late in life. This is the only kind of painting JB does. She is completely self-taught and commercially successful.

**JB** I think I had this from childhood but I thought everyone had it. I never thought about it. One day waiting for the bus I saw little yellow balls jumping all round and I thought “I remember seeing that as a little girl,” but I never mentioned this to anyone.

There is a consistent thing I see on my left side. It seems to be four or five blue squares and it flashes once in a while. This is outside, no question, beyond my eyes. Most of the things are outside.

### 2.3.2 Polymodal Synesthetes

**TP** TP, a 17-year-old dyslexic student, is polymodal. Letters, numbers, and music have color. Food has numbers and falls into “groups,” three representing heavy foods, and one representing thirst and lighter foods. He remembers streets by their color (i.e., the streets, not their names,
are colored). This trait has been present since childhood. His mother wrote down his color associations when he was a child. He reproduced the list without error 10 years later.

MMo MMo, a toy designer, is also polymodal. Sounds and specific words evoke flavor, visual shape, and color. Eights are yellow, for example, a square feels like mashed potatoes, and the name Steve is somehow like poached eggs.
CSc  CSc, a doctoral candidate in music, perceives involuntary tastes and smells when she plays the piano or oboe. This occurs only when she herself plays and not when she is listening to others. She first noticed this at puberty. The tastes and smells can be so intense as to interfere with her musical concentration and she has to stop. She is distressed by this interference and its possible disruption of her profession as a performing artist. Taste and smell do not induce music. However, a kiss produces a visual kaleidoscope intermingled with textures that she feels “everywhere.”

This subject’s experience is reminiscent of the tertiary associations in music cited by Schultze (1912). His subject’s colored music was closely associated with gustatory sensations. Instrumental music produced a sensation first of taste and then of color, as if the stimulus went “from the ear through the mouth to the eye.” He would refer to a mouthful of music (Mund voll Musik) and a perseveration where the taste and color would linger after the music had ceased. Thus he spoke of digesting the music (die Musik verdaut).

MD  MD had severely restricted vision at birth, light perception only by adolescence, and was completely blind by the time she entered college.

For as long as I can remember, each letter of the Braille alphabet has had an assigned color, and that color has never changed. Some letters seem to emit light or, perhaps, to reflect light from another source.

Because she had some useful vision as a child, she did learn the Latin alphabet, and if she

Insist[s] on seeing the same [Braille] word in [Latin] letters . . . then the letters have the same colors as their Braille representations. They are often somewhat odd shades or hues that I would not consciously choose.

In addition to colored letters and numbers, MD sees the white keys on a piano and those of the qwerty keyboard as colored. Months of the year and days of the week are also colored, as are physical streets (not their names) and states. Her geographical maps are obviously colored. She also sees colored shapes when listening to music.

Violins and similar stringed instruments evoke a nice medium shade of green. Piano music is white, and a piano concerto with lot of strings in the orchestral accompaniment evokes a green background with white in the foreground. Mozart’s clarinet concerto is a wonderfully deep shade of blue, and the music of a flute is red. (7/6/01)

Foreshadowing a discussion in chapter 7, I’ll point out that MD’s colors are largely associated with categorical representations. That is, categorical letters, whether Latin or Braille, are colored, as are the
constituent symbols of the Braille code itself. Braille involves 63 different symbols derived from the various combinations of the six dots of the Braille writing cell. For MD, each of these 63 symbols has its own particular color. We just saw that TP, above, perceives food in categorical “groups” and assigns colors to categorical streets just as MD does. The binding of incongruent sensory qualia to categories has heretofore not been commented upon in the synesthesia literature.

I have encountered several blind synesthetes in addition to MD. Starr (1893) suggested that 50% of those who become blind in childhood develop colored hearing. MD recently spoke before a group of “nearly a thousand visually impaired persons,” mentioning her synesthesia for the first time. Six other blind persons from that group reported experiences similar to hers. The development of synesthesia in blind individuals may be more understandable after we discuss sensory deprivation in chapter 4.

2.3.3 Colored Music

MLL When I listen to music I see colored shapes. If I am tired at the end of the day the shapes seem very near. They are always in color. Shiny white isosceles triangles, like long sharp pieces of broken glass. Blue is a sharper color and has lines and angles, green has curves, soft balls, and discs. It is uncomfortable to sit still. I feel the space above my eyes is a big screen where this scene is playing. (9/2/85)

The shapes come, they move, they leave. It lasts for a while and the unpleasant shapes last longer than the pleasant shapes.

2.3.4 Visual Pain and Geometric Hearing

RB As far back as I can remember I have felt pain in shapes, though it seems to me anyone could do so easily. Often, but not always, I hear voices (particularly singing voices) in shapes; I have felt at times I could draw or paint a song. (10/19/84)

The simple shapes are felt, rather than seen, on the surface of her skin, and are never intricate (figure 2.5). She does not have a sense of palpation like MW does. The shapes she usually perceives are blobs, grids, crosshatchings, and geometric forms.

That others should express the least surprise at how she perceives is absolutely incredible to RB:

A person who sings with little phrasing or variation in volume has a straight line voice. A baritone has a round shape that I feel. This is so obvious, it’s all very logical. I thought everyone felt this way. When people tell me they don’t, it’s as if they were saying they don’t know how to walk or run or breathe. (5/6/87)
2.3.5 Colored Orthography That Has Personality

**MT** For MT, any graphic representation of numbers and letters stimulates color. Each letter of the alphabet and each digit has a very specific color that she sees regardless of the typeface, color of the ink, or language (so long as it uses the Latin alphabet). Roman numerals carry the color of the letters that they use. If a letter is spoken aloud, she first visualizes it, at which instance the color is apparent.

The sensation is not like a hallucination but like “an optical illusion that never goes away.”

The sensation is unsuppressible, the colors are always present for me and it is very specific. The colors of the letters don’t overwhelm my ability to read or function. In fact, they enhance my reading, writing, and spelling. Additionally, the numbers and letters seem to carry personality and gender, the same way they carry color. They are “real characters!” (pun intended).

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**Figure 2.5** Drawing by RB of shaped pain following foot surgery. The shape is not constant, but changes with time, just as the experience of the pain is neither constant nor monotonous. Note the simple geometry.
2.3.6 Dysphoria and Photisms with Foreign Speech

MN Since about the age of 3, whenever I hear foreign speech (especially French, Spanish and Italian) I immediately see a blinding goldenrod light, feel a tingling sensation up and down my right side, and experience a “wierd” [sic] sensation in my ears that I can only describe as similar to the sensation one feels when fingernails are scratched on a blackboard. This permeates my entire body and is most uncomfortable. I cannot keep still or concentrate well.

Because I was ridiculed so much about this, told I was spoiled, trying to get attention, etc. (as a child I would put my hands over my ears and squirm until the speaking subsided) I learned to live with it. However, I continue to avoid all foreign films, television shows, etc. (7/7/85)

2.3.7 Colored Hearing in a Polyglot

JM We examine JM in detail because she exhibits many characteristic features of synesthesia.

I had been hoping for a long time to find some information about [synesthesia] or even just a kindred soul. I only became consciously aware of it after reading Vladimir Nabokov’s autobiography Speak, Memory in which, to my great surprise, he describes exactly the same type of synesthesia as mine: a case of colored hearing, i.e. “seeing” every letter of the alphabet and every number in a specific color … My colors are not the same as his.

I too never talked about it, not out of shyness but because I always thought that all people were like that. Only after reading Nabokov’s description of his synesthesia did I realize that this was rather unusual … I enjoy it very much and would be hard put if these colors would suddenly vanish. I don’t think they will; I am 61 now and had it all my life. (11/02/86)

JM is facile in learning languages and has varying fluency in Japanese, Italian, French, and Spanish. In all these languages it is the spelling that determines the color; that is, JM’s synesthesia is grapheme-based as opposed to phoneme-based. She once studied Russian in preparation for travel and found that the orthography of the Cyrillic alphabet had no color of its own but did when she transliterated it to German. “The words would stick out in color phonetically, the way I would spell them in German. It’s simply always there.” JM still thinks to herself much of the time in her native Swiss German.

JM wrote down her color list years ago after she read Nabokov, hoping to find someone like her who saw in colors. She never did, but reading Nabokov made her realize that many of her letters are not “definite colors. It is shades.” Her color list is reproduced in table 2.3.

Note that 10 is white, perhaps because its constituents are white. But all the numbers in the 20 series are red, or mainly red, even though “the other colors are there.” The 30s, 40s, and 50s are all influenced by the first number. The number 164, for example, is white, black, and green. Large numbers are simply the combination of the colors, although it
<table>
<thead>
<tr>
<th>Letter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>strong blue, dark</td>
</tr>
<tr>
<td>b</td>
<td>brown</td>
</tr>
<tr>
<td>c</td>
<td>very yellow, light, almost white</td>
</tr>
<tr>
<td>d</td>
<td>light beige</td>
</tr>
<tr>
<td>e</td>
<td>also yellow, different</td>
</tr>
<tr>
<td>f</td>
<td>yellowishy, but like mustard</td>
</tr>
<tr>
<td>g</td>
<td>gray and sometimes with black outline</td>
</tr>
<tr>
<td>h</td>
<td>dark gray</td>
</tr>
<tr>
<td>i</td>
<td>almost white</td>
</tr>
<tr>
<td>j</td>
<td>orange-red (with yellow in English; not French or German)</td>
</tr>
<tr>
<td>k</td>
<td>pitch-black</td>
</tr>
<tr>
<td>l</td>
<td>grayish, sometimes a little green</td>
</tr>
<tr>
<td>m</td>
<td>brown, different from the b</td>
</tr>
<tr>
<td>n</td>
<td>red rust</td>
</tr>
<tr>
<td>o</td>
<td>white</td>
</tr>
<tr>
<td>p</td>
<td>gray</td>
</tr>
<tr>
<td>q</td>
<td>grayish white</td>
</tr>
<tr>
<td>r</td>
<td>pitch-black, even blacker than the k</td>
</tr>
<tr>
<td>s</td>
<td>bright red, very nice</td>
</tr>
<tr>
<td>t</td>
<td>yellow</td>
</tr>
<tr>
<td>u</td>
<td>whitish</td>
</tr>
<tr>
<td>v</td>
<td>olive green–gray</td>
</tr>
<tr>
<td>w</td>
<td>wine-red</td>
</tr>
<tr>
<td>x</td>
<td>mix of red and brown</td>
</tr>
<tr>
<td>y</td>
<td>grayish white</td>
</tr>
<tr>
<td>z</td>
<td>orange-red</td>
</tr>
<tr>
<td>1</td>
<td>white with black outline</td>
</tr>
<tr>
<td>2</td>
<td>red, light</td>
</tr>
<tr>
<td>3</td>
<td>beige-yellow</td>
</tr>
<tr>
<td>4</td>
<td>dark green</td>
</tr>
<tr>
<td>5</td>
<td>loden green</td>
</tr>
<tr>
<td>6</td>
<td>black</td>
</tr>
<tr>
<td>7</td>
<td>very violent yellow, like lighting</td>
</tr>
<tr>
<td>8</td>
<td>dark red, my favorite number</td>
</tr>
<tr>
<td>9</td>
<td>bluish white</td>
</tr>
<tr>
<td>10</td>
<td>the combination is white; zero is white</td>
</tr>
</tbody>
</table>

Note desaturation and grays, and compare with similar desaturation in achromatopsia. Three days after our interview, JM wrote that she had forgotten to give me the color for j when we met.
does not help JM to remember them “unless there’s an eight in there because I like it so much.”

That a few colors are intense while others are desaturated is a feature that may not be guessed by the frequent reference to “colored” hearing. Even JM remarks that “they’re rather dull colors!” Desaturation of chroma is also common in achromatopsia (Damasio 1985; Damasio et al. 1980), which I discuss in §6.5.

I noted that JM has chromatic-graphemic synesthesia. By contrast, in chromatic-phonemic synesthesia it is sound rather than spelling that determines the color. Accordingly, in chromatic-phonemic synesthesia different languages produce different colors for the same letter because pronunciation differs. For example, in *Speak, Memory* Vladimir Nabokov says, “The long a of the English alphabet . . . has for me the tint of weathered wood, but a French a evokes polished ebony.” In *Drugie berega*, the Russian version of *Speak, Memory*, Nabokov notes that Cyrillic variants are usually duller but similarly hued compared to their Latin letter counterparts. For example, the “unripe apple” green of p differs from the green “gouache” of Cyrillic п. Furthermore, tactile, proprioceptive, and gustatory input—influence far beyond the purely lexical—determine the color of his Cyrillic characters.

Color sensation is formed by palpable, labial, almost gustatory means. In order to determine thoroughly the hue of a letter, I have to savor the letter, let it swell and radiate in my mouth while I imagine its visual design. (tr. Johnson 1985)

I have not personally encountered synesthetes whose native tongue employs an alphabet other than the Latin one. However, GWJ, a native Dane writing to The Synesthesia List, notes that

The Danish letter Æ has a color all of its own (lavender to purple) depending on the exact pronunciation, whereas A is red and E almost white. The explanation is to me obvious: Æ is seen as a single character symbolizing a single vowel, not a diphthong. I don’t even “see” the a-and-e parts of the letter. (5/7/01, my italics)

IW, who is not a native speaker of either Danish or Icelandic (which also uses the Æ letter) comments

To this day I cannot get the Æ to “fuse” into a single color. I see the left half of it as an A (dark red) and the right half as an E (light red). Indeed, I once mistakenly said that the icelandic word “bækur” (“books”) had six letters, because for me it has six colors. (5/5/01)

Heretofore, the synesthesia literature has call attention to sensory-sensory pairings without remarking how synesthesia’s most common expression—colored letters and integers—highlights the association of color and other qualia not with another sense but with categorical knowledge. As already mentioned, I will address this observation in chapter 7.
2.4 SYNESTHESIA AS AN UNELABORATED PERCEPT

Synesthetes do not perceive complex scenes. Because they share their perceptions with us only through verbal labels, this is perhaps how earlier authors came to suppose that language was the link in synesthetic perception.

MW  MW, the gustatory synesthete, perceives shape, texture, weight, and temperature whenever he tastes or smells foods. He describes the taste of spearmint as “cool glass columns.” Such a description can easily lead to the assumption that he is using metaphoric speech or that such a description is a product of imagery. It is not. It is a verbal interpretation of a sensory experience.

When pressed to describe the tactile qualities that he feels, and pressed to explain how it is that he knows it is a glass column, the following occurs: upon inhalation of wintergreen oil, there is a pause of 2 to 3 seconds. His right hand sweeps vertically through the air and he moans pleasurally. He rubs his fingertips together and moves his hand through the air as if palpating an object.

I feel a round shape. There’s a curvature behind which I can reach, and it’s very, very smooth. So it must be made of marble or glass, because what I’m feeling is this incredible, satiny smoothness. There are no ripples, no little surface indentations, so it must be glass, because if it were marble, I would be able to feel the roughness of the stone or the pits in the surface. It’s also very cool so it has to be some sort of glass or stone material because of its temperature. What is so wonderful is the absolute smoothness of it. I can run my hand up and down, but I can’t feel where the top ends. I feel that it must go on up forever. So the only thing I can explain this feeling as is that it’s like a tall, smooth column made of glass. In fact, with the amyl nitrite [an adjuvant that intensifies the synesthesia; see chapter 4], it’s as if there’s a whole row of them and I can stick my hand in among the columns and feel the back sides of the curves. There is this funny sort of feeling of being able to reach my hand into this area. It’s very, very pleasant.

This is a verbal description of a sensation, comparable to explaining to a blind person what it is like to see by use of analogy. What one has in this example of a sensory perception is the formation of contours in a perceptual process (Osgood 1956).

DS  Seeing sound/music does not adequately describe the process. There is a spatial presence that incorporates more than just the sensation of “seeing.” I think that a better description is perceiving, which also includes the sensation of feeling and denotes integration. (3/1/87)

The coloration of the percept is simply that; it can also be associated with shape and movement. Sometimes the color is simply a halo or outline, as in simple synesthesia, or may appear as a wash—a transparent overlay—in which case it is similar to the melting of colors off
object boundaries that occurs in hallucinations. It can be opaque and block out the real object in the environment. Whether a color is opaque or not is hard for patients to describe since they “fill in the gaps.” DS, for example, says that her moving lines block her vision of what is really there even though she “knows” that something is there. This is like filling in the gap in one’s physiologic blind spot, a process that is automatic and unconscious. Even those who know much about the blind spot and how to find it have difficulty, while viewing the scene in front of them, perceiving an empty space where the blind spot should be. We can hold our finger up in the temporal field and see that it disappears from our peripheral vision, but when simply viewing the scene in front of us it is hard, if not impossible, to perceive the blind field that is “really” there.

RP The synesthetic sense is definitely not “in my mind.” It is just sort of there. It is sort of a translucent overlay with depth that I can see through. It is kind of like a heat shimmer, only without the distortion. (9/8/87)

Some patients see the colors one at a time, like the flipping down of a number on a digital clock. Others have a panorama that compels the eye to wander. Letters and numbers flash by them like a ticker tape or sequenced electric sign. HC has a window in which she views six or seven colors at a time as she counts front 1 to 20. MLP (chapter 5) feels that some of her letters and numbers have a “spotlight” on them somehow highlighting them with more light when she looks at them.

2.5 VALIDITY, CONSTANCY, AND LIMITS TO MANIPULATION OF THE PARALLEL SENSE

Patients have an unshakable conviction that what they perceive is real and valid. The synesthesias change little, if at all, over the course of their lifetime and there is little that they can do to intensify or minimize the sense. It is not under volitional control.

SP I have never tried to alter the synesthetic perceptions. They are something that I always considered part of normal functioning—like breathing. I have always accepted the sensations, even in the face of skepticism or ridicule. I know what I see and if others don’t have the facility I consider it to be their loss.

Concentration will tend to intensify the sensations, while distractions will minimize them. (9/17/84)

FKD FKD is a retired romance language teacher who perceives names, nouns, and verbs “as blobs of color with the printed word lightly superimposed.” Sometimes it is so intense that “the printed word will leap out from the page in color.” Note how it is a particular member of a category that triggers the synesthesia.
I was amazed when I realized that other people did not have similar images. The experience comes involuntarily and cannot be altered and is most often the result of hearing the word or thinking of the person so named. (8/7/85)

**MN** I experience the synesthetic sense both in my mind and it is also externalized. It is somewhat like an hallucination. It is very real. Once it begins it doesn’t stop until the speaker stops. (7/7/85)

**GH** A consistent stimuli [sic] will produce a consistent synesthesia. The shapes and colors will be exactly the same if the sound comes from exactly the same source. For example, if you eat a lemon cake baked by one bakery one day and you eat another from a different bakery the next, in both cases you would describe the taste as being that of a lemon cake. But since the cakes are not likely made exactly the same, one would taste somewhat different from the other as described by your taste buds. Now, if a singer sings a song on a record and then live on TV the visual patterns will vary because they’re not exactly alike. If I replay a record over and over, however, I will see the same visual pattern.

I usually see geometric shapes of some complexity that is [sic] ever changing as is the sound that stimulates it [sic]. (4/9/84)

**JM** I can’t stop or start it. I asked my husband, “When I talk to you or when you read something, how do you see it?” And he says, “Not at all.” Anything—I will read your name or read something, immediately it is in all of its colors.

I showed JM a letterhead that featured my business logo, Capitol Neurology, printed in green ink on ecru paper. She was asked whether the color of the ink made a difference. “No, here it is light yellow, then it gets a little gray. O is white, L is sort of gray, N is the worst color, so that it is very dominant and it dominates the others. R is black, then the rest fades out. Immediately it does that when I look at it.”

I asked about meaning and whether the same word in English (e.g., “color”) or German (Farbe) was the same. It is not. The absolute determinant is the spelling. I will say more about color competition and Stroop-type effects in §2.5.2.

As soon as I hear words it is spelled in my mind. You know on Times Square how they have the electric band with the news? That is exactly how it is in my head. Any word that comes in flows right through me in color. That’s exactly how it is. It goes fast, of course, I mean I haven’t got time in a conversation to think of everything—but it’s simply there. If I want to I can stop at a certain word and look at it.

Somebody says to me, “How is your dog?” First I see the word dog in color, then I think of my dog. That’s how it goes. The color always comes first before I can think of the thing.

Subject EF further demonstrates synesthesia’s automaticity and reliance on external stimuli.

When I read slowly, letter by letter, I see each letter in its color. But when reading at “normal” speed, meaning recognizing words at once, mainly the
vowels come out. They are bright and shining, almost like little spotlights. For this reason, I rather notice misprints.

We recently had a spelling reform in Germany. After elementary school children begin learning it, all the newspapers finally changed. Suddenly, it became a new experience to read. (4/17/00)

**DS** I never shift my focus when I see these things. They are always in the same plane—about 6° from my nose. The depth is very important. I get goosebumps even talking about it. It’s like trying to explain to a blind person what green is. If I hear music that goes up there, beyond what I can see, I just can’t listen to it. It’s irritating, I can’t stand opera because they’re always singing up there. I only like what I can see. Too low is the same problem. I’ve never noticed that music goes off the right or left sides of my screen.

The side borders [of her screen] are sharp. It goes there and it stops. It doesn’t go beyond on the sides.

I hate flat lines. Elevator music or Musak [commercial ambient music] is like that. And that irritates me as well. I like music that makes the lines move.

Throughout, one notices that the examples are uneven. Those synesthetes who have colored numbers or letters do not necessarily include all the vowels or consonants; some may not have chromas for all digits from 1 to 10 but may assign colors to several higher random numbers. Likewise, some of the months or days of the week may be missing coloration. The same principle responsible for desaturation of color or the presence of grayish tones may be operative here.

**MT** As a summary of the sense of validity, consider the explanation of MT:

It is not a hallucination but it is hard for me to describe. As I look at a page, I see the colors there even though I see the color of the real ink that’s before me. I know it isn’t there for real, but I still can’t help seeing it. There is still a sensation that the color is there.

I can’t remember when I didn’t have it. It’s not something that I do. It happens all by itself. Letters and colors seems exactly as they are since forever.

Since MT’s stimulus is the graphic representation of letters and numbers, no matter what language the text may be in, obvious questions arise: How does she think? How does she read? Does it not get in the way?

No more than a child learning to read or write and having to look at the letters. After you learn, you take the letters for granted and the individual letters don’t get in the way, because you’re reading words.

She describes her synesthesia as “an optical illusion that’s always there.” Her letter states: “I see pages and pages of color.” Where does she see it? “On the page, wherever the letters are.” So it is not in her mind? “No, it’s on the page!”
2.5.1 Correspondence of Stimuli and Responses

At this point the reader should see general similarities among synesthetes and their perceptions, but perhaps is becoming frustrated at not seeing obvious correspondences among either stimuli or the parallel responses. The search for correspondences was the approach undertaken decades ago, the pursuit of which was fruitless and led to abandonment of the subject.

Even sensory psychologists (Marks 1974, 1975) performing sensory differentials could make little order out of it if they assumed that there were similarities either among the stimuli (such as linguistic or phonological components) or the responses (which presumably shared some psychophysical properties). We show in chapter 3 that a more fruitful analysis involves the way in which synesthetes map sensory dimensions.

Following are examples of colored hearing in which both subjects have equally distinct but different features that serve as a stimulus. One responds to the sound of spoken language; the other is sensitive to the orthography. Yet both have lexical synesthesia.

**EWe** Elizabeth Werth (EWe) is a rather well-known subject studied by the linguists Gladys Reichard and Roman Jakobson (Reichard, Jakobson, & Werth 1949). EWe is a polyglot who learned Serbian and Hungarian as first languages, followed by French, German, English, and Russian. She also reads Latin. The color, shape, and motion synesthesia is essentially the same for sounds in all languages in which EWe can make identifications.

To me the numbers 1 to 10 have colors. I can count and reckon only in Serbian. No other language possesses the proper sounds for my mind, the sounds that include the number color.

Characteristically, EWe feels that the synesthesia and method of memorization is “simple” and “natural,” but the mental contortions she takes in translating numbers and words into another language and her native colors in order, for example, to remember a telephone number are remarkable!

There is no way for me to remember street or telephone numbers except to translate them into Serbian and arrange them in a sequence, eg a serial of diminishing odd numbers intercepted by even numbers occurring at random as in TR8-9051 where there is in my mind a soft curve of 9, 5, 1 plus the two even numbers that tighten the curve to a zigzag line.

EWe enjoys playing with words, listening to new sound combinations, and arranging them in colored patterns. Pronouncing French vowel combinations that she had written out gave her the sensation of
luminous rings”; for others there is texture, sheen, phosphorescence, or sparkling as part of the dynamic of her sounds. The color of a word is dominated by the vowel, which takes on different shades depending on the surrounding consonants. The colors of short English words like "jut," "jot," "lie," and "lay" "simply run together, obscured by the longer words that stand near them."

EWe makes fine distinctions between shades, and many sounds and sound combinations have shape—dots, rings, horizontal and diagonal zigzags, or wavy lines. Some sounds, such as phonetic j, the sound group ji (which does not occur in Serbian), and the English u (ju as in unit), possess form rather than any color at all.

Table 2.4 summarizes a linguistic analysis that Reicbard, et al. (1949) made of Slavic speakers. They concluded that “correspondence is far from regular,” as inspection of the table shows. This point is important and will be brought up again in chapter 6. Suffice it to say here that these eminent linguists and others who have followed them have not found an explanation for synesthetic associations by this method.

DSc DSc is a left-handed speech pathologist whose letter-color associations are determined by orthographic rather than phonemic features. “In Cathy, Charles and cereal, the k, ch and s sounds, all of which are represented orthographically by ‘c,’ evoke a golden yellowish color.” For DSc, the initial letter tends to dominate the overall color of the word. Vowels are also influenced by the context, whereas in isolation they are white with a black shadow or outline. Phonemic and graphemic issues are discussed further in §7.3.

2.5.2 Competition of Color

 Sometimes there is an interesting competition between the color of the synesthesia and the actual orthography or semantic meaning of a word. I mentioned the example of one synesthete’s frustration in seeing advertisement copy printed in the “wrong” color ink. Color competition can occur in a number of situations.

SO I recently mistakenly called a new acquaintance “Diane” instead of “Elaine” because she was dark-haired, and “D” is black whereas “E” is red-orange. If a person has a dark, warm coloring, then I can easily recall their name if it is a dark, warm name. Trying to recall a dark name belonging to a light-haired person is hopeless. (8/19/87)

MLL A young woman named Zayas skated to a piece of music that was green and full of squares. Her costume was totally black; her routine started out with curving motions. It became uncomfortable to me to watch such a mismatch, so I just looked at my hands in my lap. She placed last in her category at the end of the evening’s judging.
Table 2.4  Lack of correlation among speakers of Slavic and Germanic languages

### Vowels

<table>
<thead>
<tr>
<th>Vowel</th>
<th>L (German)</th>
<th>D (German)</th>
<th>S.P. (Czech)</th>
<th>E.W. (Serb)</th>
<th>V.N. (Russian) letters</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>red</td>
<td>red</td>
<td>red</td>
<td>tan</td>
<td>?</td>
</tr>
<tr>
<td>æ</td>
<td>pink</td>
<td>—</td>
<td>(orange)</td>
<td>(tan)</td>
<td>?</td>
</tr>
<tr>
<td>o</td>
<td>blue</td>
<td>red-brown</td>
<td>red-blue</td>
<td>blue-black</td>
<td>ivory</td>
</tr>
<tr>
<td>u</td>
<td>black-brown</td>
<td>black-brown</td>
<td>dark blue</td>
<td>blood red</td>
<td>?</td>
</tr>
<tr>
<td>y(u¨)</td>
<td>gray</td>
<td>—</td>
<td>(gray)</td>
<td>red base with pinkish spots (Hungarian)</td>
<td>?</td>
</tr>
<tr>
<td>ø</td>
<td>light blue</td>
<td>—</td>
<td>(gray-green, red)</td>
<td>(dark blue ground with light blurred spots)</td>
<td>?</td>
</tr>
<tr>
<td>e</td>
<td>yellow</td>
<td>yellow</td>
<td>bright green</td>
<td>yellow</td>
<td>yellow</td>
</tr>
<tr>
<td>i</td>
<td>silver-white</td>
<td>white</td>
<td>canary yellow</td>
<td>white</td>
<td>yellow</td>
</tr>
<tr>
<td>w</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>(steel blue, spreading rings)</td>
<td>dull green with violet</td>
</tr>
</tbody>
</table>

### Consonants

<table>
<thead>
<tr>
<th>Sound</th>
<th>S.P.</th>
<th>E.W.</th>
<th>V.N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>p</td>
<td>dust</td>
<td>light brown, tan, or colorless</td>
<td>apple green</td>
</tr>
<tr>
<td>b</td>
<td>gray-blue</td>
<td>steel blue</td>
<td>burnt sienna</td>
</tr>
<tr>
<td>m</td>
<td>gray-brown</td>
<td>dark tan</td>
<td>fold of pink flannel</td>
</tr>
<tr>
<td>f</td>
<td>violet</td>
<td>purple (with dot-circle)</td>
<td>alder leaf</td>
</tr>
<tr>
<td>v</td>
<td>matte violet</td>
<td>blue</td>
<td>rose quartz</td>
</tr>
<tr>
<td>t</td>
<td>light greenish</td>
<td>no color, but long alternating with diagonal lines</td>
<td>pistachio</td>
</tr>
<tr>
<td>tj</td>
<td>—</td>
<td>gray with diagonal wavy line</td>
<td>—</td>
</tr>
<tr>
<td>d</td>
<td>bright orange</td>
<td>gray or tan</td>
<td>creamy</td>
</tr>
<tr>
<td>r</td>
<td>beige</td>
<td>gray</td>
<td>oatmeal</td>
</tr>
<tr>
<td>η(ŋ)</td>
<td>beige</td>
<td>green (French)</td>
<td>—</td>
</tr>
<tr>
<td>r</td>
<td>—</td>
<td>colorless but tufted (English)</td>
<td>—</td>
</tr>
<tr>
<td>k</td>
<td>lead gray (iridescent)</td>
<td>—</td>
<td>huckleberry (for the letter c)</td>
</tr>
<tr>
<td>g</td>
<td>dark gray</td>
<td>green</td>
<td>vulcanized rubber</td>
</tr>
<tr>
<td>s</td>
<td>“sharply tin color”</td>
<td>gray-white</td>
<td>mother-of-pearl</td>
</tr>
<tr>
<td>z</td>
<td>gray-white</td>
<td>steel blue, darker than f</td>
<td>inky</td>
</tr>
<tr>
<td>ts</td>
<td>“bright white-blue”</td>
<td>no color but a round group of dots</td>
<td>—</td>
</tr>
<tr>
<td>f</td>
<td>blue-silver</td>
<td>gray or colorless</td>
<td>—</td>
</tr>
<tr>
<td>ø</td>
<td>tin color</td>
<td>gray</td>
<td>pale rubbery (letter j)</td>
</tr>
<tr>
<td>tf</td>
<td>“white-blue with some red”</td>
<td>yellow with same form as t</td>
<td>—</td>
</tr>
</tbody>
</table>

2.5. Validity, Constancy, and Limits to Manipulation of the Parallel Sense
In the pairs, a girl and boy wearing lovely flowing pinks and grays, skated to music from “Les Miserables,” that was a broad river of flowing pink. The judges awarded them 10s. The audience agreed.

**RP**  My mother says that I have always used colors to describe flavors. Kiwi fruit tastes green, and there is no other way to describe it. Green grapes don’t taste green, though, so I know that it does not relate to the fruit’s color.

**DSc**  The word butter is blue.

Rizzo and Esslinger (1989) cited case of color competition in a 17-year-old synesthetic boy who had perinatal retrolental fibroplasia. His vision was 20/100 OU and he had normal visual and auditory evoked responses. The durability of his synesthetic responses to musical notes is shown in table 2.5, where one sees that he gives exactly the same responses 5 months after the initial stimulus. Table 2.6 shows his responses to chords. Note that chords do not contain the colors of individual notes. This case is illustrative of absolute versus relative effects of synesthetic responses, as discussed in chapter 3. The presence of color competition is shown in table 2.7. He was asked to remember the color of a Munsell color chip that was presented with a musical note stimulus. He was able to learn this in only one trial compared to controls. The spontaneous response after conflicting color assignment shows that the synesthetic percept is indeed durable and involuntary; the learned association is simply tacked on.

Stroop-type paradigms show how synesthetic photisms are automatic and involuntary. Dixon & colleagues (2000) studied mental arithmetic in their subject, C, with digit-color synesthesia. Her large significant difference \((P < .001)\) between congruent and incongruent reaction times (245 ms) when naming colored squares or colored digits contrasts with the insignificant differences (range 11 to 17 ms) obtained.

---

**Table 2.4 (continued)**

<table>
<thead>
<tr>
<th>Consonants</th>
<th>S.P.</th>
<th>E.W.</th>
<th>V.N.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(d_o)</td>
<td>brown-gold</td>
<td>yellow with diagonal lines alternating with one dot</td>
<td>rubbery (English j)</td>
</tr>
<tr>
<td><strong>r</strong></td>
<td>bluish black</td>
<td>—</td>
<td>sooty rag</td>
</tr>
<tr>
<td><strong>l</strong></td>
<td>watery blue</td>
<td>yellow</td>
<td>limp noodle</td>
</tr>
<tr>
<td><strong>lj</strong></td>
<td>—</td>
<td>yellow, soft gum texture</td>
<td>—</td>
</tr>
<tr>
<td><strong>o</strong></td>
<td>—</td>
<td>steel blue (English)</td>
<td>—</td>
</tr>
</tbody>
</table>


---

40 2. Synesthetes Speak for Themselves
in eight nonsynesthetic controls. That is, naming digits automatically elicited photisms that interfered with her color naming on incongruent trials.

C was next shown simple arithmetical operations followed by a colored square and asked to speak their solution. For example, $5 + 2$ was followed by either a yellow patch—which is congruent with C’s photism color for 7—or a patch of an incongruous color. That automatic

<table>
<thead>
<tr>
<th>Pitch given</th>
<th>Spontaneous response</th>
<th>Response at 5 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>“Bright red”</td>
<td>“Bright red”</td>
</tr>
<tr>
<td>C'</td>
<td>“Bright purple”</td>
<td>“Bright purple”</td>
</tr>
<tr>
<td>D</td>
<td>“Green”</td>
<td>“Green”</td>
</tr>
<tr>
<td>E'</td>
<td>“Sky blue with a little bit of green”</td>
<td>“Sky blue with a little bit of green”</td>
</tr>
<tr>
<td>E</td>
<td>“Blue”</td>
<td>“Blue”</td>
</tr>
<tr>
<td>F</td>
<td>“Yellow”</td>
<td>“Yellow”</td>
</tr>
<tr>
<td>F'</td>
<td>“Dark purple”</td>
<td>“Dark purple”</td>
</tr>
<tr>
<td>G</td>
<td>“Dark red”</td>
<td>“Dark red”</td>
</tr>
<tr>
<td>A'</td>
<td>“Lavender”</td>
<td>“Lavender”</td>
</tr>
<tr>
<td>A</td>
<td>“White”</td>
<td>“White”</td>
</tr>
<tr>
<td>B'</td>
<td>“Greenish white”</td>
<td>“Greenish white”</td>
</tr>
<tr>
<td>B</td>
<td>“Normal purple”</td>
<td>“Normal purple”</td>
</tr>
</tbody>
</table>

From Rizzo & Esslinger (1989), with permission.

<table>
<thead>
<tr>
<th>Chords given</th>
<th>Spontaneous response</th>
</tr>
</thead>
<tbody>
<tr>
<td>G major (G-B-D)</td>
<td>“Pink, blue, and dark red”</td>
</tr>
<tr>
<td>A' major (C-E'-A')</td>
<td>“Lavender, purple, and white mixed with a little blue and green”</td>
</tr>
<tr>
<td>C minor (C-E'-G)</td>
<td>“Orange and celery green”</td>
</tr>
<tr>
<td>F augmented (F-A-C')</td>
<td>“Black, purple, and yellow”</td>
</tr>
<tr>
<td>D diminished chord (D-F-A')</td>
<td>“Green, purple, and black with some red”</td>
</tr>
<tr>
<td>G minor (B'-D-G)</td>
<td>“White, red, and a little purple”</td>
</tr>
<tr>
<td>B major (D'-F-B)</td>
<td>“Regular purple, lavender, and white”</td>
</tr>
<tr>
<td>A' major (C-E'-A')</td>
<td>“Lavender, purple, and white”</td>
</tr>
<tr>
<td>D minor (F-A-D)</td>
<td>“Yellow, green, and greenish-yellowish”</td>
</tr>
<tr>
<td>C major (C-E-G)</td>
<td>“Scarlet red and dark red and a little orange and yellow”</td>
</tr>
</tbody>
</table>

*a Note that chords do not contain the colors of the individual notes.

From Rizzo & Esslinger (1989), with permission.
photisms also appear on mentally calculating arithmetical problems was shown by their interference with C’s ability to name the color of the square on incongruent trials but not on congruent ones. Her large congruent-incongruent difference (236 ms) was 19.3 SD away from the mean difference (1 ms) obtained by the eight controls.

Thus, such experiments demonstrate that synesthetic percepts can be both stimulus-driven and concept-driven, as shown in the example of FDK in §2.5 above. A medical example of a concept-driven symptom would be reflex epilepsy, in which thinking about a certain subject triggers convulsions.

### 2.5.3 Commonality of “I,” “O,” and “U”

The idiosyncratic nature of synesthetic responses is evident, particularly for the colors evoked by words and letters. Baron-Cohen and colleagues (1993) noticed, however, some apparent regularity in response to the vowels “I,” “O,” and “U”. Eight out of nine subjects, for example, reported that “U” was yellow to light brown, “I” was white to pale gray, and “O” was white. This is 88.9% consistent for these three letters. Culling additional samples from the literature, 73% of all responses to the letter “O” were white. The paper cited calculates a probability showing that the chance of eight out of nine synesthetic subjects reporting three letters of the alphabet having the same color is nearly zero ($P < .0000000014$).

I unearthed 14 cases in my own files that had color responses to these three vowels. Table 2.8 shows agreement with Baron-Cohen and col-

<table>
<thead>
<tr>
<th>Pitch given</th>
<th>Original spontaneous response</th>
<th>Conflicting experimental assignment</th>
<th>Spontaneous response after conflicting color assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>“Bright red”</td>
<td>Yellow</td>
<td>“Bright red with a strip of yellow”</td>
</tr>
<tr>
<td>D</td>
<td>“Sky blue with a little bit of green”</td>
<td>Red</td>
<td>“Sky blue with a little bit of green and a strip of red”</td>
</tr>
<tr>
<td>A</td>
<td>“Greenish white”</td>
<td>Black</td>
<td>“Greenish white with a strip of black”</td>
</tr>
<tr>
<td>F</td>
<td>“Yellow”</td>
<td>White</td>
<td>“Yellow with a strip of white”</td>
</tr>
<tr>
<td>C</td>
<td>“Bright purple”</td>
<td>Green</td>
<td>“Bright purple with a little green”</td>
</tr>
</tbody>
</table>

Note: See text for details.

From Rizzo & Esslinger (1989), with permission.

Table 2.7 Conflicting color assignment

<table>
<thead>
<tr>
<th>Pitch given</th>
<th>Original spontaneous response</th>
<th>Conflicting experimental assignment</th>
<th>Spontaneous response after conflicting color assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>“Bright red”</td>
<td>Yellow</td>
<td>“Bright red with a strip of yellow”</td>
</tr>
<tr>
<td>D</td>
<td>“Sky blue with a little bit of green”</td>
<td>Red</td>
<td>“Sky blue with a little bit of green and a strip of red”</td>
</tr>
<tr>
<td>A</td>
<td>“Greenish white”</td>
<td>Black</td>
<td>“Greenish white with a strip of black”</td>
</tr>
<tr>
<td>F</td>
<td>“Yellow”</td>
<td>White</td>
<td>“Yellow with a strip of white”</td>
</tr>
<tr>
<td>C</td>
<td>“Bright purple”</td>
<td>Green</td>
<td>“Bright purple with a little green”</td>
</tr>
</tbody>
</table>
leagues’ observation for speakers of English. Note from tables 2.8 and 2.4 that this association seems not to hold for speakers of Slavic and Germanic languages, however; JM is a Swiss whose native language is German, yet she follows the trend for “I” being white. I cannot explain such concurrence for the color of these three vowels. Marks (1975) tallied synesthetic colors induced by vowel sounds as scores on three opponent-color dimensions, and found that the brightness or pitch of vowels correlates with the brightness of the associated photisms. Accordingly, the vowels “O” and “U,” sounding low-end pitch, are dark, tending toward red or black in color. This discrepancy may be due to phonemic-graphemic differences.

### 2.6 PSYCHOLOGICAL INFLUENCE AND STIGMA

Living in a world of blobs, spirals, moving colors, phosphorescent tastes, and other sensory combinations that the rest of the populace regards as incongruous, to put it mildly, must surely influence the developing personality. Although none of the present subjects or any of the historical ones of which I am aware have demonstrated obvious psychopathology, or either mental dullness or genius, there are some trends that can be seen among synesthetes as a group.

**DS** For DS, both pain and pleasure evoke visual and spatial perceptions that are also in color. She was recommended for psychological
counseling in high school when she told the assistant principal that “when I kissed my boyfriend I saw orange sherbet foam.”

**RP** As a child I once mentioned my colors to a teacher, who promptly told my parents I was schizophrenic. That ended my telling anyone about it for quite a while.

I am so used to my colors making me different from others who can’t see them. I am both afraid and eager to know what it is like for people who share the trait, to know how different or the same we are. Did the others you studied just shut up about it, and not worry, or did the synesthesia and the difference it created become a part of their definition of themselves?

I know that it was very much a part of my life as a child, a sort of test of friendship, to see how others reacted when I told them. If they didn’t believe me, I didn’t want to be their friend.

**BB** BB, one of the few males with this trait, describes the heightened emotion and portentiousness that seeing his color auras create. The stimulus seems to come from people themselves, who have colors around them. “It feels like an emotional bond. The feeling lasts a few seconds. When I realized that others didn’t see this, I worried what was wrong with me. I thought it was stress related.”

One particular person comes to mind. There was a very strong feeling and she was surrounded by a dark blue-green aura. It wasn’t because she was sexually attractive. I don’t know what the emotional feeling was due to because I had only met her twice. But there it was. I think there was some sort of bond or something. I’m not sure which comes first, sometimes I think I see the color and react emotionally; others it may be reversed—I get an emotion and then see this color. I’m not sure. And I don’t know what makes it happen. (4/2/86)

At times, a scene that is quite ordinary will take on a special perception of clarity, “as if locked in time, looking as a masterful painting, at other times of being part of a motion picture,” or a very heightened feeling of merging with the ambient environment while never losing contact with the ongoing stream of consciousness.

**DS** DS also has color auras associated with people. An intuitive suspicion that something about a person is not good will produce a “color spike” around them. She feels it is entirely based on her feelings.

My husband was going to hire someone and I had bad feelings, but it turned out I was dead wrong. She’s fabulous for the job. Initially, it was that she had lightning bolts—not like grand Zeus—it’s zigzag static. I call this my static line. When I meet someone who has this static, small lightning bolts, metallic, silvery, bronzy, I don’t like them. I don’t see them with this person any more.

**MN** Other synesthetes were well aware of the negative consequences that revealing their synesthesia could cause. This is a source of distress.
I tend to describe/analyze in colors, feelings, and sensations, however, I tried not to do this (especially in school) because I wanted good grades and grades were not given out for colors, feelings and sensations. I have always had to make a conscious effort to simplify what I was teaching in my work (former high-school teacher) in order to be understood. (7/7/85)

**MMo** I feel strangely apart from the world. Perhaps this contributes to my incomplete fences separating modes where the to-and-from schloschings form the soup into which inventions are born. (9/12/84)

**GG** Rarely, the synesthetic sense can interfere with rational thought. This was particularly severe in Luria’s patient, S, whose inability to suppress his synesthetic percepts was often so severe as to make it difficult for him to attend to the semantic and meaningful qualities of a discourse. His images would guide his thinking, one association leading to another, rather than thought itself being the dominant element. Such interference is found in only a few of the current patients, where it tends to be mild.

GG, a medical illustrator, describes that while preparing an outline for an article she was to do for a professional publication, she found herself going back over and over every sentence to understand what she was trying to say. In school, short answers on exams were no trouble, whereas she found difficulty with essay answers because all the colors got mixed up and I didn’t have a clear idea. Writing is very slow for me. I read a lot and that seems to go ok, even though the colors are definitely there when I read. But writing is difficult, so the synesthesia can be troublesome for me.

**MM** Sometimes speech will dominate perception and I will not be able to understand what someone is saying for the “clutter.” This doesn’t happen too often, thank goodness. The only real problem is that when I am driving and a very loud sound comes on such as loud music or the Alert Test tone and it is hard to see. The image intensity is directly proportional to the sound level. People laugh when I say “turn that down, I can’t see where I’m driving.”

**JM** JM reads every night and her synesthesia does not interfere with understanding. However, it does influence her feeling toward a person, place, or subject because of the color. For example, her niece was expecting a baby and wrote that they would name it Paul if it was a boy. JM was distraught because the name Paul is such an ugly color, its [sic] gray and ugly. I told her “anything but Paul.” And she couldn’t understand why and I said “it is such an ugly color, that name Paul.” She thought I was out of my mind. At last I thought it really isn’t my business and she can do what she likes. The name probably isn’t that bad, but in my mind it’s very awful. And that influences how I feel about people.
On the other hand, if a name has a color that JM loves very much, then the name can be beautiful. She feels that the color of the name has much more influence on her likes and dislikes than the sound of it. For example:

I like blue not that much, but the blue in the A is very nice. So names like Alex and Alexandra—I always call myself Alexandra among my family. I hate the name [her name]. My mother was American which is why I have that name. The name Alexandra is such a pretty color and that’s why I like it and that’s why I always use it.

JM finds it odd that her favorite color, red, appears only once in her whole alphabet, the bright red of the s. Moreover, all words starting with s are not automatically appealing. It all depends on the combinations.

Despite their high intelligence, synesthetes can exhibit lacunae of abstruseness. They can be remarkably dense in some areas, usually linguistic, such as dialectic or poetry. Many remark that they have trouble “getting it.”

MT I do sometimes have trouble “getting it” but I think I’m both intuitive and analytical. The difficulty I have in “getting it” arises either from the difficulty of hearing language—“things” often sound like other “things”—or from the way many people string words together sort of needlessly. All I mean is that I have difficulty hearing, but not from a lack of ear power. (12/10/86)

DS I’m always knocking over salt cellars and water glasses because I have to use my hands, not really to talk but to think! I need as much support as I can get to think.

Sometimes I have no idea what people are saying. There is a lot of junk in my mind that makes it hard to pay attention.

Psychological parameters are discussed further in chapter 7.

2.7 WHAT IS SYNESTHESIA GOOD FOR?

Synesthesia is a rich way of feeling, highly enjoyable for those who possess it. To lose it would be a catastrophe, an odious state akin to going blind or not being alive at all. Synesthetes have a well-developed innate memory that is amplified by use of the parallel sense as a mnemonic device.

2.7.1 Word and Number Memory

DI For DI, the color of a word is unpredictable from the colors of the individual letters, but once she “sees” a word she thereafter easily remembers the color of it and thus the spelling or the context associated with it.
This may be one reason for my ability to remember things better than most people. I can visualize pages and then read what is on them. I use my synesthesia to remember names and words to the point where I remember actually saying "I don’t remember the name but I think it’s blue or something."

But note the inconsistency. What kind of memory is this in which the important element—the actual name—is forgotten? Although synesthetes will commonly volunteer that the added sense enhances their memory, it is more often the memory for the sense itself that is memorable, not the content.

DI has competition among letters for the overall coloration of the word, prompting her to “wish that this color synesthesia [sic] was a little better. My feelings about the word or subject can also ‘shade’ the overall color of the word.” An example is given with my name:

\[
\begin{align*}
  R &= \text{green} \quad \text{Richard is remembered as green (with white)} \\
  i &= \text{white} \\
  c &= \text{yellow} \\
  h &= \text{brown} \\
  a &= \text{red/brown} \\
  r &= \text{green} \\
  d &= \text{red} \\
  C &= \text{yellow} \quad \text{Cytowic is remembered as yellow with black because of the influence of the } w \\
  y &= \text{green} \\
  t &= \text{darker green} \\
  o &= \text{white} \\
  w &= \text{black} \\
  i &= \text{white} \\
  c &= \text{yellow}
\end{align*}
\]

How this helps her remember my name is not clear, since there must be many green and yellow names. If she subsequently meets me and sees yellow and green, how does she know that my first name is green rather than yellow? This issue bears further analysis. A partial explanation may be that when confronted by someone previously met, a color appears. Being associated with a letter or combination of letters thus helps to jog the memory for the actual name. But I suspect it has to do with color being bound to a particular element in a category.

We see from this and other examples that for those persons with colored letters and words, given elements may determine the predominant color. For some the leading letter is the only determinant; for others it is an amalgamation; in still others the vowels can dramatically alter the coloration of a word.

2.7. What is Synesthesia Good For?
GG When asked what good her synesthesia does her, GG responds that it is a boon to her memory, particularly remembering numbers—"they're chromatically arranged. I can recall it much more easily because I'm given a hint. If I knew it before I know it doubly." A list of her colors shows that there is not, in fact, a chromatic arrangement for the 10-digit series. "Isn't that a rainbow arrangement?" she asks with surprise. The notion of chromaticity cannot serve as a method for her remembering the 10 digits nor for larger integers.

The spelling of synesthetes is usually good because the word is visualized; the color will tell, for example, whether a word has two i's or an e.

2.7.2 Topographical Memory

Excellent topographical memory is another common claim of synesthetes. If they want something they can visualize it exactly in a drawer, for example, and go right to that drawer and find it exactly as they have pictured it. This item may be one that they have not used for many months.

2.7.3 Hypermnesia

There is a relationship between hypermnesia and synesthesia. As shown in the example of BB, above, considerable affect may also accompany the reminiscence.

MW Years after experiments were begun on MW we were discussing feature detection neurons and their sensitivity to highly specific attributes of a visual scene. On learning about feature detection neurons MW volunteered a specific childhood memory about the way the sunlight hit the daffodils at his home. He specifically remembers the "angle" of the sunlight. His profession as a lighting designer, requiring knowledge of visual effects related to beam angles of incident light, probably has nothing to do with this childhood memory. The point here is that he has a highly crystallized memory of a perceptual event that occurred on an annual basis. He would observe daily until the luminance was "just so," which it was for a brief period only.

On a specific morning in April, I could plot it year to year, April 7th or 9th I don't recall what day exactly. It was a particular way the sunlight hit on our driveway on the daffodils and it was very vivid and I would look forward to it every year at the same time of the day to be exactly the same way. It was the beginning of Spring for me. I knew it was here. I loved it. It was wonderful. It was beautiful and the beginning of Spring. It was not going to be cold any more. I couldn't wait until that day when the light arrived. (12/16/86)
RB Memory for conversation is excellent, an asset to a court reporter. I can recall dialogue from movies and books.

MLL My memory is best for things I’ve seen and pictured; also which side of the page to find a previously seen passage. As a volunteer pot mender for the Smithsonian, I could remember part of a pot assembled one year when I found more pieces the following year. I can remember things from age 3.

MM The images I see are like really seeing and are stored as regular memory and are therefore available for recall. The things I “see” are therefore just about as real as anything I can remember. I can recall them in sequence at any time.

My memory for faces is very strong. I can remember scenes, and then looking at the memory of it, read a sign on the wall, describe a texture, etc.

Many such comments regarding elevated memory of course suggest eideticism, a topic considered further in §4.3. Also note the strength of affect present in synesthesia in contrast to the relatively neutral valence we nonsynesthetes experience. How many of us take special enjoyment in, say, reckoning? Yet MD states, “I see the numbers from 1 through 100 at a glance in a set colored pattern. I can do mental mathematical computations accurately and with pleasure.” Likewise, can anyone imagine a woman named Jean changing her name to Alexandra just because she likes the letter A so much? But this is precisely what JM tells us: She changed her christian name because “the blue in the A is very nice . . . [and] the name Alexandra is such a pretty color” (§2.6). The same can be asked of the less-common vile affect associated with colors, names, and so on. Nonsynesthetes do not have such violent emotional reactions over such trifling matters.

Some recent researchers have proposed that synesthesia results from cross-wiring between two sensory cortical modules. Having pondered the phenomenon for over 20 years, I have come to appreciate both elevated memory and affect as key features of the experience that need explaining. I have until now under appreciated the role of categories in synesthesia. For example, synesthesia’s most common manifestation, colored letters and numbers, is based on category. Chromatic-graphemic synesthetes will see A as the same color whether uppercase, lowercase, cursive, italic, or whatever because they recognize it as an instantiation of their prototypical category “A.” Here, synesthesia depends on the ability to categorize shape, not just perceive it as an object.

Many attributes that induce synesthesia—such as graphemes, phonemes, gender and personality (as applied to letters and numbers), time units, days-of-the-week and other ordinal concepts—do not really fit into any of the standard modalities. Furthermore, such categorization is also affect-laden. For example, speaking of her colored streets, the blind synesthete MD says:
I find it easy and satisfying to picture street maps and am a good navigator. The maps that I see are colorful, and perhaps that’s what makes map visualization both easy and pleasurable.

WW, a professor of neuropathology and the son of subject EW, has chromatic-phonemic synesthesia and number forms (discussed in chapter 5). He comments on how synesthesia helps him remember various categories:

Let me say that this is a delightful trait to have. I tend to use it consciously and unconsciously to help me remember correct sequences of numbers, words, phrases, letters, to help me remember names and locations of anatomical structures (especially neuroanatomical structures—you should see the beautiful array of colors in the brain!) and neuropathological classifications. I could go on and on, but those will serve as a few examples. (10/10/85)

2.7.4 Olfactory Memory

MG, a 24-year-old man, illustrates the memory-like qualities of synesthesia in his visual smell. He smells objects that are seen on TV or in advertisements—cigarettes, bleach, and foods, for example. Thus, although there is a synesthesia between sight and smell, the smell is always specific to the object seen and seems to be qualitatively different, therefore, from the more generic perceptions in other modes—such as visual blobs and lines, smooth or rough textures, elementary tastes, or general somatic sensations. One might speculate that this is because smell is such a low-gestalt sense, or because smell is so intimately related with the anatomical structures serving memory.

Personal experience tells us that smell is particularly apt to evoke memories; but memories and sensations rarely, if ever, evoke the vivid memory of a smell. The smell MG perceives is not a memory but a real sensation. His memory is excellent. “I remember sights, sounds and scents from [age 3]. Usually I can remember all experiences vividly in its [sic] entirety.” (11/24/85)

The ability to remember a smell, surely a rare capacity, is found among synesthetes more often than expected by chance. Smell is examined in more detail in chapter 4, in the analysis of MW (the gustatory and olfactory synesthete), and in chapter 5, §5.6, in which smell is intimately related to memory in SdeM, a fact demonstrated by a change in memory following loss of smell as a result of a pituitary tumor.

The memory for scents is not necessarily related to the stimulus for synesthesia, however.

DS My sense of smell is very important. I cook by taste and smell. I can’t follow a recepie [sic]. I have to put in what I want to put in. I can remember scents—the smell of a strawberry, or the musty scent of my grandmother’s basement. It’s not the memory—I remember the smell.
I lost my sense of smell for 2 months while I was sick. And I was miserable. During this time, I seem to recall that the synesthesia was the same.

2.8 FAMILIAL CASES

Several of the current subjects have first-degree relatives who are also synesthetic (EW, SO, FKD, MT, LH, NM, and SP) (see also Laignel-Lavastine [1901]). The presence of familial cases serves the argument that synesthesia is a brain-based condition, that is, it is inherited rather than purely learned.

Two synesthetes serve as examples. Vladimir Nabokov (VN), although not personally studied by me, is used because he was the first familial case of which I was aware. EW, whose family has the trait over four generations, is used from the current subjects.

VN In “Portrait of My Mother” (1949), Nabokov related spontaneous synesthesia as well as a fine case of colored hearing. Perhaps “hearing” is not quite accurate since the color sensation seems to be produced by the very act of my orally forming a given letter while I imagine its outline.

The “a” of the English alphabet has for me the tint of weathered wood, but the French “a” evokes polished ebony. This black group also includes hard “g”—vulcanized rubber—and “t”—a sooty rag. Oatmeal “n,” noodle-limp “l” and the ivory-backed hand mirror of “o” take care of the whites. Passing on to the blue group, there is steely “x,” the inky horizon of “z,” and huckleberry “k.” Since a subtle interaction exists between sound and shape, I see “q” as browner than “k,” while “s” is not the light blue of “c” but a curious mother-of-pearl. In the green group, there are alder-leaf “f,” the unripe apple of “p,” and pistachio “t.” Dull green, combined somehow with violet, is the best I can do for “w.” The yellows comprise various “e”s and “i”s, creamy “d,” bright-golden “y” and “u,” whose English alphabetical value I can express only by “brassy with an olive sheen.” In the brown group, there are the rich, rubbery tone of soft “g,” paler “j,” and the drab shoelace of “h.”

One can enjoy the metaphoric adjectives attached to Nabokov’s colors. “Such confessions must sound tedious and pretentious to those who are protected from similar leakings and drafts by more solid walls than mine are.” His mother seemed to find this perfectly natural. As a 7-year-old, he remarked to his mother that the colors were “all wrong” on the alphabet blocks he was using to build a tower. He discovered that she possessed the trait and that “some of her letters had the same tint as mine and that, besides, she was optically affected by musical notes.” Unfortunately, Nabokov does not list his mother’s colors.

Nabokov also had an unusual aptitude for mathematics as a child, and when sick with a fever “I felt enormous spheres and huge numbers swell in my aching brain . . . Such were the mathematical monsters that thrived on my delirium . . . Beneath my delirium [mother] recognized
sensations she had known herself and her understanding would bring my expanding universe back to a Newtonian norm.”

**EW** EW is a cultural affairs correspondent for a newspaper. She became aware that her synesthesia was unusual when she took a college psychology course. “Professor,” she asked “doesn’t everybody do that? I thought they did.” In his 35 years of teaching, the professor had not encountered a case before her. He urged her to go home and ask her parents if they had it. “My mother didn’t know what I was talking about, but my father thought, as I had, that everybody saw things that way.”

EW has a “photographic memory” and her number forms, which are also shared by the family, are discussed in chapter 5. Her son, WW, the neuropathology professor, comments:

I have had a long-time fascination with our particular “quirk of the mind” and have kept records from time to time regarding consistency of my “colors,” sometimes comparing my colors to my mother’s; she did that with her father over some years before his death in about 1950. There are a few other aspects to our synesthesia including certain spatial relationships of series of numbers (which also appear in color, of course). I am quite convinced that “it is in the brain and not in the mind” as I believe the newspaper article stated you seem to think. The apparent transmission of the trait from one generation to another in our family lends support to that idea.

### 2.8.1 Pedigrees

Nearly everyone since Galton (1907) has commented on the heritability of synesthesia. As Bailey & Johnson (1997) point out, however, few studies have attempted to gauge the population prevalence of synesthesia or even to report the family history of those with the condition. As a literature search spanning the past century shows, it is faintly peculiar that those interested in synesthesia were more concerned with the trait’s characteristics than in the persons who manifested it, and even less interested with the reasons for its appearance in a given person. This omission is slowly being rectified. In performing population estimates and family analyses it is important, of course, to distinguish between idiopathic synesthesia and that which is acquired.

Bailey & Johnson provide such a thorough review of possible as well as plausible modes of inheritance in synesthesia based on the clinical data, that I have omitted much of this discussion from the current edition, choosing instead to record here the pedigrees of my 11 families and Baron-Cohen’s six families that have been studied to date (figures 2.6 and 2.7). For many years the likely—but unproven—contender for synesthetic inheritance has been X-linked dominance, and this remains the case, although Bailey & Johnson added the possible modifier “with lethality” to this presumed mode of inheritance.
2.8.2 Linkage Analysis and Population Estimates

Table 2.9 combines my demographic data with that of Baron-Cohen et al. (1993, 1996) and Emrich et al. (2001). We all find a preponderance of female synesthetes, ranging from 1:1 to 1:20, determined by a number of differing estimates and methods. For example, one of my ratios of 1:1, based on a 1994 on-line Prodigy survey, likely suffers selection bias due to more males than females having computers and on-line subscriptions at the time. Baron-Cohen et al.’s 1993 ratio of 1:20 results from the 565 individuals who responded to a radio broadcast but who
were not necessarily tested. The more reliable ratios from the three research groups range from 1:3 to 1:6.

Our estimates of population prevalence differ as well, from about 1 in 500 to 1 in 25,000, as table 2.9 details. Partly due to nonrandom inclusion but largely for unknown reasons, our subject populations differ appreciably. Whereas I obtained a good number of polymodal individuals or those whose synesthetic unions are other than chromatic-lexical, the British and German cohorts are composed overwhelmingly (>90%) of individuals with chromatic-lexical synesthesia. Given our different methods and disparate cohort populations, I believe the prevalence for any type of synesthesia is likely 1:2000 or less.

Figure 2.7 Pedigrees of synesthete’s families.
In collaboration with neurogeneticist Bill Johnson of Rutgers University, I studied eleven families with 177 members, of whom 46 had synesthesia, in preparation for a neurogenetic linkage analysis. We found the trait at least 2.5 times more common in females and also found that transmission is common, except for male-to-male transmission. Indeed, we found no confirmed case of male-to-male transmission, either historical or in our own data.

Regrettably, all 137 persons from whom blood samples were required would not cooperate, so we were unable to perform an actual mapping analysis seeking a marker locus on the X chromosome. However, we had sufficient data to run a simulated linkage analysis. The well-known simlink program for finding marker loci yielded an average lod score of 5.02 for these families (max 8.51, any family, 2.74), more than enough to prove linkage had we had sufficient blood samples. (For a clearly X-linked disorder, a lod score \( b^2_2 \): 0 is required.)

Although Baron-Cohen et al. (1996) did not attempt a linkage analysis to prove the means through which synesthesia might be acquired, both our data are consistent with and highly indicative of an X-linked dominant mode of inheritance.

Bailey & Johnson (1997) have proposed an intriguing qualification to X-linked dominant inheritance, namely “with lethality,” if there actually is an extremely high sex difference among synesthetes, because a
female-male sex ratio higher than 3:1 simply cannot be explained by straightforward X-linked transmission.

Theoretically, however, if hemizygous males carried no normal allele, then the synesthesia gene would be lethal to 50% of the male fetuses of synesthetic mothers. (Baron-Cohen and colleagues’ female-male offspring ratio of 18:9 within six families matches this; in our eleven families the figure is also 50%—but in the opposite direction, with a female-male ratio of 8:15).

A further prediction of Bailey & Johnson’s suggestion is an increase in miscarriages among synesthetic women. (As a baseline, it is received wisdom that 25% of all concepti spontaneously abort, a figure necessarily higher than the proportion of known, or obvious, miscarriages.) Further research can clarify the possibility of lethality in synesthetic inheritance.

I should note that a single male-to-male transmission would disconfirm X-linked inheritance of any mode inasmuch as males must inherit their X chromosome from their mothers. In other words, all synesthetic males must have synesthetic mothers. At first glance, the pedigree of Vladimir Nabokov would appear to be the disconfirming instance, given that Nabokov’s son Dimitri is also synesthetic (colored letters). Whereas it is well-known that Nabokov’s mother was synesthetic (indeed, he wrote about it twice, in 1949 and 1966), it is far less known that Nabokov’s wife, Vera, was also a synesthete. Thus, Dimitri has two synesthetic parents. Because it is impossible to determine now from whom he inherited the trait, Nabokov’s pedigree remains consistent with X-linked dominant inheritance.

Parenthetically, Dimitri Nabokov compared his own letter-color list with that of his parents and found no congruence at all “except for the ‘M’ which in my father is pink, blue in my mother, and for me a shade of lilac or mauve as if it were a blending of the two.” He told this anecdote during a television documentary in which both Baron-Cohen and I participated (“Orange Sherbet Kisses,” Horizon, BBC 2, December 13, 1994). He also read from the diary in which the father recorded Dimitri’s color associations at age 7; 40 years later the son finds no change. Initially, in the 1940s and later, linguists approached Nabokov’s synesthesia more as a metaphor than a perception. According to Dimitri, however, “my father regarded his own phenomenon of synesthesia with the same rigor as that of a scientist studying lepidoptera.”

Lastly, Baron-Cohen has wondered if the synesthesia gene might be maladaptive. Among nearly 200 contacts I have not encountered more than a handful of synesthetes for whom the condition is unpleasant or disabling, and then only once in a while. Even when my proband case with taste-touch synesthesia (MW) claimed to be sometimes “overwhelmed” by the shapes, textures, and movements that he felt, it was, upon closer inquiry, no more than a matter of distractibility. Much like
the gourmand who doesn’t want to be disturbed while savoring his foie gras, MW sometimes wished to ignore ongoing events so he could attend to a particularly pleasurable synesthesia. But MW was never perceptually confused about what he sensed.

In contrast, Baron-Cohen’s case JR, presented in the above-mentioned documentary (see also Baron-Cohen et al. 1996) does exhibit perceptual interference. A female music teacher, JR has colored hearing in both directions, that is, seeing colors on hearing sounds and hearing sounds upon viewing colors. (JR has been tested extensively to confirm consistency in both directions and does appear to experience a stressful mélange of notes, sounds, and colors in visually busy or noisy environments, such as Piccadilly Circus at night with its panoply of lighted signs, and thus she lives a relatively restricted life.)

“it may be, then,” speculates Baron-Cohen, “that whilst milder cases of synesthesia carry no selective disadvantage, certain forms of synesthesia are indeed maladaptive.” That is, to those who believe in cognitive modularity, this strategy may have been selected for its fidelity in sensory processing whereby persons can be certain rather than confused whether they saw or heard something.

Against Baron-Cohen’s speculation based on JR, however, I must cite the composer Olivier Messiaen, who also had colored hearing in both directions (though only for music). Based on his voluminous autobiographical accounts and interviews, Messiaen was neither confused perceptually nor distressed psychologically by his bidirectional synesthesia. The predictability of Messiaen’s colors through blind musical analysis is discussed further in §8.2.2.1.

2.8.3 Genetically Mediated Psychological Characteristics of Sensory Functions

Some general comments regarding the heritability of sensory functions will conclude this chapter. Many people believe that whereas most physical characteristics are inherited, psychological or behavioral traits are not. In fact, genetic endowments (genotype) do indeed make individuals prone to specific talents or personality traits just as it drives them to become smart or stupid, tall or short, blond or dark.

As an example of a simple hereditary sensory ability, the capacity to taste phenylthiocarbamide (PTC) as bitter or tasteless is well understood. In most populations taste thresholds (e.g., for hydrochloric acid) have gaussian distributions. But PTC does not follow a normal distribution, the proportion of nontasters ranging from 20% in African populations to 30% in European descendants. The ability to taste PTC as bitter is highly specific in that the substance can be recognized by a “taster” only when dissolved in his own saliva. The trait is not related to overall taste acuity, although it does correlate with responsiveness to
bitter noncarbamides (such as quinine). Since carbamides are manmade synthetics, it is difficult to fathom what adaptive function a taster gene might serve.

It is not naive to seek a single-gene determinant of synesthetic ability. Single-gene determination of complex mental phenomena occurs in Gilles de le Tourette syndrome (Robertson 1994), several types of X-linked mental retardation (Neri et al. 1994), and color blindness (Vogel & Motulsky 1992). Genetic factors are important in both hereditary deafness and many forms of blindness. Little work has been done regarding genetic differences in the sense of smell, although scattered reports indicate hereditary factors in selective anosmia (the inability to detect specific odors [Amoore 1977]). Conversely, the presence of “noses” in families of parfumeurs and cognac industrialists is legendary. A number of data sets (from twins and other family members) suggest that heritable components mediate susceptibility to selected visual illusions, eidetic or photographic memory, spatial orientation, afterimages, and the ability to detect flicker in a source of light (flicker fusion frequency). Since most studies have used small samples and have done little to control for prior experience, they require cautious interpretation.

One talent that shows a strong tendency to run in families is, of course, musical ability. The pedigree of Johann Sebastian Bach is a prime example, though not a unique illustration. Data gathered from the Julliard School of Music show clear heritability in 50% to 75% of parents of opera singers, instrumental virtuosos, and music students. Noteworthy musical aptitude appears to emerge early in life and improve steadily among the gifted, even without practice and in a variety of settings. Such findings point to a maturation in the gradual unfolding of the genotype.

A similar sensory unfolding may be gleaned from synesthetes’ comments about having the trait “as far back as I can remember,” in contrast to a minority of patients who noted it in their adolescence, around puberty, after which it became more intense. As mentioned earlier, hormonal influence on synesthesia has not yet been studied systematically by anyone.

A situation analogous to synesthesia may be the familial and genetic aspects of perfect pitch (Profita & Bidder 1988), which also shows a high familial incidence, occurs predominantly in females, and invariably manifests at a very early age. A related question is whether musical tone perceptiveness is an aptitude that varies continuously between the extremes of marked insensitivity in the so-called tone-deaf to the acumen of those with excellent relative pitch. Profita & Bidder concluded that “perfect pitch is a unique and innate trait possessed to variable degree by a subpopulation of humans.”
Perfect pitch is similar to synesthesia in four aspects:

1. It is all-or-nothing. The talent is either present or it is not.
2. The skill appears naturally without necessity to develop it through the practice that characterizes acquisition of other musical skills.
3. “Most of our subjects with perfect pitch recalled their astonishment on learning that everyone did not have this capacity” (Profita & Bidder 1988).
4. It manifests at an early age: 5 (26%) of Profita & Bidder’s 19 subjects recognized the capacity by age 5, 89% (17/19) by age 10. Pedigrees are compatible with autosomal recessive inheritance; that 80% of those affected are female suggests that the trait is sex-related.

Perfect pitch localizes to the left planum temporale (Schlaug et al. 1995).

Other studies implicate hereditary musical ability, whether measured by some global score or by instruments with various subtests. For example, musical quotients based on tests of musical intelligence have shown identical monozygotic twins to be more alike than dizygotic fraternal twins. Several models try to account for the transmission of musical ability: single-gene action with incomplete dominance, a single or small number of recessive genes, or several major genes with multiple alleles. None of these account completely for the available data.

Sir Francis Galton, in *Hereditary Genius* (1969), presented the first clear quantitative evidence that genius, as measured by outstanding accomplishment, tends to run in families. Since that time, others have questioned how much education and opportunity (environment) are responsible for the great differences in individual achievement. We believe today that genius (which Galton distinguished from talent both quantitatively and qualitatively) is a function of both heredity and environment.

Galton himself gave little weight to environment, a point of contention today mostly due to political correctness. Numerous studies have shown that within wide limits, long exposure to a common environment does not seem to make people more similar in intelligence; equally numerous studies clearly demonstrate the role of heredity in intelligence among humans and animals. The estimate for genetic determination in human intelligence is about 80%, and it is unlikely that the genotype contributes less than 50% of the variability.

Thus, both general IQ and specific component ability seem to be heritable, some specific talents being more dependent on genotype than others. The synesthete’s ability is inborn and appears early in life, but does not seem to be highly—if at all—modifiable by environmental influences. In familial cases wherein affected individuals are encouraged to speak openly and, in a sense, practice their skill, synesthesia may appear robust at an early age.
The fact that synesthesia exists is established; what is not established is how or why synesthesia occurs. One of the most glaring problems in trying to fathom a mechanism for synesthesia is the lack of consensus among synesthetes regarding the parallel sense that they perceive. That is, when individual synesthetes compare associations, they find little or no agreement.

An expectation for homogeneity among synesthetic perceptions is a presumption stemming from the consensus regarding perception of everyday objects. Everyone agrees that roses are red and violets are blue, that a square looks like a square, and that a banana tastes like a banana. Anyone can recognize a piano by its sound and not mistake it for a trumpet or a baby’s cry. However, a look at everyday illusions that are taken for granted illustrates that consistency in perception is hardly absolute.

A prime illusion is the perception of an object’s constant color despite the varying illumination of daylight. I discuss color constancy and colored shadows in detail in §9.2. For now, it is sufficient just to cite an example. Because the brightness and spectrum of daylight both differ markedly from sunrise to sunset, an object viewed in the morning reflects more blue light than the same object seen toward evening, when it should appear redder, given that it reflects more red light. Instead, we perceive its color as constant despite broad variations in both intensity and wavelength of the incident light. The color we attribute to an object is different from what physical optics tells us it “really is,” the latter being described by immutable and impersonal laws of nature. Nonetheless, what we actually perceive is different from what the physical properties of the incident light lead us to predict. The question then should not be, Why don’t all synesthetes agree? but rather, Why do the rest of us agree so well in our mutual illusions?

Experiential phenomena can shed some light on this duality. Among its many sequelae, a seizure discharge originating in the temporal lobe produces subjective experiences that are similar to synesthetic perception. Considerable evidence shows that experiential phenomena are
positive manifestations of either limbic seizure discharge or deliberate limbic stimulation (Gloor et al., 1982). The fact that such experiences can be evoked by stimulation without warning but not evoked by warning without stimulation, and that they arise only from specific anatomical structures (particularly the amygdala) leaves no doubt concerning their cerebral origin. That the phenomena are described in very similar terms further suggests that patients do not embroider their responses nor elaborate a story—that is, they are not verbally dressing up a vague sensation as opposed to describing an actual fragment of experience.

Similar to the circumstance of synesthesia, criticism about inconsistent responses has likewise been leveled at the nature of experiential phenomena, whether they arise naturally as part of a temporal lobe seizure or are deliberately evoked by electrical stimulation of the brain. That is, they demand that stimulation of point x in all brains must elicit the experience y. However, Halgren & colleagues (1978) argued that experiential responses are “individualized,” and that the types of mental phenomena elicited are related more to the patient’s personality than to where in the limbic system the stimulation is applied. That is, they argued that who is stimulated is more important than where the stimulation is applied to the brain. Subjective experiences verbally communicated by the patient cannot be put to the same objective analysis that a finger movement elicited by stimulating the motor cortex might be. The variety, vividness, and compelling emotional coloration of these reports might incline the hard-nosed to question whether they represent true cerebral responses when compared, for example, to phosphenes or buzzing elicited by stimulation of primary (unimodal) sensory cortices.

Similar analysis can be applied to the experience of synesthetes, who volunteer similar descriptions of unelaborated sensory perceptions. There is little if any self-referential material woven into their reports compared to the temporal lobe epilepsy (TLE) patients. The synesthesias assume a compelling immediacy similar to reliving past experiences, which TLE patients liken to actual events. In both sets of individuals, however, there is never any doubt that these phenomena are occurring out of context, incongruously superimposed on the ongoing stream of consciousness.

Cumulative data show that stimulation of limbic structures at point x does not produce experience y in all brains. Rather, it results in a mélange of perceptual, mnemonic, and emotional components that reflect the function of the stimulated area while simultaneously incorporating elements of the individual brain’s past experience. Analogously, a given stimulus evokes disparate perceptions in different synesthetes. Just as there are consistencies in the mechanism producing experiential
responses, so must there also be consistencies in the experience of synesthesia. (Marks has shown the latter case to be so [1978, 1987].)

An abiding criticism against synesthesia is that it is subjective, knowable only through the experiential reports of the subjects themselves, a psychophysical phenomenon without measurable objective manifestations. Such criticism is empty. Many established medical conditions are entirely subjective, such as headache and all pain syndromes, dizzy spells, and TLE. TLE is the best example from this short list because although TLE patients rarely have convulsions, they do have all sorts of peculiar subjective experiences, such as disordered time sense, a sense of leaving one’s body (autoscopy) and other dissociative states, and distorted perceptions. They occasionally experience synesthesia.

TLE is such a common and well-known entity (1:9600) that a physician can diagnose it by the history alone; can confirm the diagnosis by prescribing anticonvulsants and causing the symptoms to resolve; and, finally, can prove the diagnosis by demonstrating characteristic waveforms on the EEG. The word “dia-nosis” literally means “through knowledge,” and the diagnosis of synesthesia is made just as any other diagnosis is. Although synesthesia is rare the stories of synesthetes are so similar that it can be diagnosed by the history extracted from the patient; confirmed by meeting certain clinical criteria; and proved by objective tests that separate synesthetes from nonsynesthetes.

Localization is fundamental to neurology. Now, other scientists increasingly try to relate formally defined cognitive operations to anatomy. Some techniques used in such attempts are imaging, the molecular biology of receptors, and the analysis of time-locked electrical and magnetic oscillations. The underlying assumptions of such disparate methods, however, are often different. The necessary shift among conceptual frameworks that so often plagues the newcomer is the distinction between top-down and bottom-up approaches to any academic discipline.

Bottom-up approaches are usually easier to grasp. Students in a given science enter the field and are trained in its basic framework. As they work away and eventually approach the controversial frontiers, they may be struck by deep, baffling, conceptual problems that they have come upon from the bottom up.

Someone like a philosopher, on the other hand, confronts the same problem from the top down. A philosopher’s education emphasizes broad questions about history, a methodology for science, and a theory of what theory is in general. All this gives the philosopher a particular approach to problems. Confronted with a quandary in biology, for example, someone with a philosophical background ponders it with a
frame of mind quite unlike that of a biologist who encounters the same problem from bottom-up training. A broad education lets the philosopher come down on it and see it in a different way. We're all looking into the same room through different windows. But the view is tilted by the assumptions and methods of the viewer.

3.1 CLINICAL DIAGNOSIS

In 1979, when I encountered my proband MW, no one was studying synesthesia and no one was interested in doing so. Indeed, none of my neurological colleagues had even heard of the term and their uniform verdict was that I was wasting my time with such silliness. Synesthesia just didn’t fit their tidy worldview. “Stay away from it. It’s too New Age,” they advised. “It will ruin your career.”

In the first edition I understandably dedicated a lot of ink to the entire objective-subjective debate (read perceptual-metaphoric here if you wish) and to criticisms questioning synesthesia’s reality, given the lack of obvious external manifestations measurable by a third-person observer, as well as the lack of obvious agreement about the extra perceptions that synesthetes themselves experience. Since those early times, however, scientists in 13 countries have investigated some aspect of synesthesia. Numerous websites now devoted to it are listed in the appendix; even a moderated “synesthesia list” exists to disseminate news and hook up interested synesthetes and scientists around the globe.

Concomitant with the exploding interest in perceptual synesthesia, there has been a growing interest in historical or what I think is more accurately called metaphorical synesthesia. The German musicologist Jörg Jewanski, for example, has compiled an extensive bibliography on colored music (Jewanski 1999). Recently, I participated in workshops at the University of Chicago regarding “Synesthetic Education and the Cultural Organization of the Senses” (Stafford 1999) and at the Herzog August Bibliothek in Wolfenbüttel, Germany entitled “Synesthesia—Historical and Actual” (Adler 2001). Documentaries worldwide, feature articles, and fresh encyclopedia entries are proceeding apace; this gives some idea of the renaissance of interest in synesthesia.

Today, three individuals predominate in perceptual synesthesia research. They are Simon Baron-Cohen, an experimental psychologist in England; Hinderk Emrich, a philosopher turned psychiatrist and head of the clinical psychiatry department at the medical school in Hannover, Germany; and myself, an American neurologist and neuropsychologist (with a smidgen of British training).

We each approach synesthesia from the differing viewpoints of our basic disciplines. I am not trying to draw battle lines, only to point out how we look into the same room through different windows. Simon is an experimentalist rather than a clinician, meaning that he is skeptical
of subjects’ stories and more trusting of experimental protocols, method, statistics, and the like. He and fellow psychologist-collaborator John Harrison devised the test of genuineness and urge its faithful use. Simon resists speculation regarding synesthesia, preferring objective facts and what is firmly accepted. He also subscribes to cognitivism and the proposal a la Fodor, that both cognition and the brain are modular.

Hinderk is foremost a clinician, as am I, meaning that our emphasis is first on the patients—what they say, what they do, how they behave. We are trained not to take anecdotes and appearance at face value but, rather, to be alert to discrepancies among the saying, doing, and behaving. We try to explain symptoms and behavior in terms of brain function. As a psychiatrist, Hinderk is taken with the feeling state of synesthesia and identifies particularly with the Einsamkeit, the sense of loneliness and isolation that synesthesia imprints on an individual. “All my life,” the synesthete says, “no one has understood,” or “I always felt as if I was the only person in the world with this.” How, Emrich asks, does this profound sense of alienation and singularity affect their mind, their personality? Here, perhaps, we hear an echo of Luria (1968), when he explored how synesthesia affected the personality and day-to-day psychology of his famous subject, S.

Emrich is interested, as am I, in, What is it like? We are interested in the qualitative aspects of the experience. His attempts to reproduce externally what the synesthete perceives on his or her screen has yielded interesting results but show how difficult it is for synesthetes to convey exactly what it is that they experience. He asked a subject who sees music as moving colored shapes to draw the relative shapes and colors that he experienced upon listening to a rather simple piece, a Gymnopodie by Erik Satie. According to the synesthete, the result was 45% accurate at best. Somewhat later, a computer simulation was able to incorporate more subtle movements, scintillation, and the fading color as the notes progressed and decayed. This was an impressive demonstration to watch but, even here, the results were only 50% to 70% representative of what the synesthete perceived internally. No wonder synesthetes get so frustrated trying to explain themselves. As Galton first noted a century ago, their perceptions are highly peculiar (Galton 1907). Baron-Cohen, Wyke, & Binnie (1987) also commented on the difficulty their proband had in satisfactorily conveying the exact nature of her experience.

It is notable how often those interested in explaining synesthesia instead focus so much on trying to reproduce an external model of a given synesthete’s visualizations.

Representing neurology, I emphasize how clinical neurology approaches patients in a different manner from other branches of medicine. For example, the mysterious maneuvers of the neurological
examination and the seemingly arcane questions that go hand in hand actually conceal the very intellectual process through which a diagnosis is obtained. Diagnosis involves inference, deduction, and integration of all possible interpretations, followed by selecting the one interpretation most compatible with all the facts.

The clinical method is Cartesian in its approach in that neurologists work with small bits at a time—description, anatomical localization, level of the neuraxis involved, and so on—finally synthesizing the entire problem from myriad simpler elements. We are first interested in description, which is similar to saying history. Taking a history, however, is more than passive listening: one extracts details and actively guides the patient without interjecting leading questions.

Do not confuse clinical judgment with actuarial judgment, the latter being based on statistics and probabilities gleaned from large groups of patients with the enviable advantage of hindsight. Powers of reason and deduction avail us nothing unless observations are accurate and we can separate observation from judgment.

The clinical method in neurology focuses on the concept of the level of the lesion. For example, we segment the nervous system into vertical bits (created functionally, anatomically, or developmentally from phylogenesis) starting at the myoneural junction where nerve and muscle join, up to peripheral nerve, on through several layers of the spinal cord, to the brainstem and cerebrum proper, ending at the level of neocortex on the brain’s surface and its 52 Brodmann divisions. The German anatomist Korbinian Brodmann (1868–1918) first provided a physical footing for the concept of localization. Brodmann studied the architectural arrangement of neurons throughout the cerebrum and carved both gray and white matter into 52 distinct parcels that we now refer to as Brodmann areas (see Cytowic 1996, pp. 44–49, and §6.2.5 of this book). Today, however, some of the anatomically defined Brodmann areas have been replaced with other divisions that are defined functionally or physiologically. The discipline is in flux.

History of the clinical method’s approach hopefully clarifies why neurologists are more inclined to perform an examination and thoughtful history before running off to obtain laboratory tests, scans, or shoving their patient into the latest machine. From the above description of the clinical method, it should be evident that laboratory tests and diagnosis of nervous system disease is always preceded by a clinical examination. Experiments and laboratory tests can only be directed intelligently by clinical information; to reverse these processes is unintelligent and wasteful of medical resources.

Having emphasized these differences in approaches, let us move on to synesthesia’s diagnostic criteria, which are clinically derived. Table 3.1 summarizes differences between synesthetic perception and ordinary intermodal associations.
3.2 Diagnostic Criteria for Synesthesia

Five features define the idiopathic synesthesia as discussed in this book, and also serve to distinguish it from acquired synesthesia—such as drug-induced synesthesia, epileptic synesthesia, and synesthesia due to acquired brain lesions, which are discussed in subsequent chapters.

1. Synesthesia is involuntary but elicited. Synesthesia is insuppressible but cannot be conjured up at will. It happens to someone, automatically, in response to a discrete stimulus (Dixon et al. 2000). Even a number rendered invisible through lateral masking will induce synesthetic colors. If subjects are deeply engaged, the synesthesia may be attenuated, whereas focused attention on it in a relaxed state may make it seem more vivid. For example, “When working at my computer I am oblivious to everything around me, and so I’m not really aware of the colors the clicking of my keyboard makes as I type.” Otherwise, the individual cannot suppress the synesthetic percept even when its appearance is detrimental to task performance (Mattingly et al. 2001). That, too, synesthetes report an ability to go back to or look at a portion of a percept that interests them, browsing as it were, implies some degree of voluntary manipulation. However, synesthetic perception is never deliberately produced de novo.

The trait is often said to have been in existence as far back as the person can remember; sometimes it is not noted until puberty or else becomes intensified at the time of puberty. This raises the possibility of hormonal influence (volume transmission) which those interested in synesthesia haven’t even begun to address, let alone study systematically.

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Table 3.1 Synesthetic percepts compared to intermodal associations

<table>
<thead>
<tr>
<th>Synesthesia</th>
<th>Intermodal associations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Stimulus-responsive</td>
<td>Conditioned by a question</td>
</tr>
<tr>
<td>2. Not confirmable</td>
<td>Confirable (in large samples)</td>
</tr>
<tr>
<td><strong>Intrapersonal variance</strong></td>
<td></td>
</tr>
<tr>
<td>3. Very small</td>
<td>Average to large</td>
</tr>
<tr>
<td><strong>Interpersonal variance</strong></td>
<td></td>
</tr>
<tr>
<td>4. Large</td>
<td>Small to average</td>
</tr>
<tr>
<td>5. Absolute assignment, context-free, passive</td>
<td>Relative assignment, context-dependent, active</td>
</tr>
<tr>
<td>6. Rare</td>
<td>Common</td>
</tr>
<tr>
<td>7. Not yet explicable</td>
<td>Largely understood</td>
</tr>
<tr>
<td>8. ? Left hemisphere</td>
<td>Right hemisphere</td>
</tr>
</tbody>
</table>

Translated from K.-E. Behne (1992), with permission.
2. **Synesthesia is spatially extended.** This is a clarification from the first edition, in which I said synesthesia is projected. By “projected” I meant that the percept is assumed to exist “out there,” and not in the imagination. For example, if visualized, the synesthesias are projected on a “screen” in front of the subject’s face; if felt, they are within range of the immediate grasp. Projected synesthesias are experienced close to the body within reach of the limb axis, never farther away. The same is true for the kinetic sense that often accompanies synesthetic percepts: the perceived movement is close to the body. Heretofore I have tended to focus on color and tactile qualities while unintentionally underplaying the kinetic and dynamic aspects of synesthesia. Remember that the percepts appear for a short while, then decay.

For their subjects with colored hearing, Harrison & Baron-Cohen (1995) determined that color was neither in the visual field nor was it mentally imagined, the only two loci of visual experience possible in non-synesthetes. Whether or not synesthesias are distinctly sensed as external, they do have a spatial reference that is neither imagined nor retinally derived.

3. **Synesthetic percepts are consistent and discrete.** The associations for an individual synesthete are consistent over his or her lifetime. If a sound is blue, it will always be blue; the context of the stimulus does not influence it. This has been affirmed repeatedly by testing individuals without warning up to 46 years apart with the same stimuli. Synesthetes who experienced several modalities do not experience different sets of modalities in different situations. Rather, the pattern remains the same.

This indelible quality of synesthesia is, in fact, the basis for Baron-Cohen’s test of genuineness (Baron-Cohen et al. 1993). In this test, subjects are asked to describe the color sensation experienced on hearing items from a list of 130 words, phrases, and letters. The experimental group was not informed of any retest, which took place without warning more than 1 year later. A control group (n = 9) matched for IQ, memory, age, and sex were read the same list and asked to associate a color with each list item. They were forewarned at the time of testing that they would be retested on a sample of items from the list a week later. When retested 1 year later, 92.3% of the responses of the experimental group were identical to those originally given compared with only 37.6% of control subjects’ responses (retested 1 week later). This confirmed the genuineness of these nine cases.

Given the explosion of interest in synesthesia and the public exposure to it, it is presently important to weed out synesthesia wannabes. Because most experiments have assumed that synesthetes are a homogeneous group (a shaky assumption), it is important for future research that a test of genuineness be performed to ensure that the subjects
reported actually have the condition. The demonstration of Stroop interference, which reveals synesthesia’s automaticity, can also be used as a test of genuineness (Odgaard et al. 1999; Mattingly et al. 2001).

Synesthetic percepts are generic and restricted. Given choices on a matching task, synesthetes pick only a few, whereas nonsynesthetic controls distribute their choices over the available range. The generic nature of percepts is demonstrated by the fact that synesthetes never see complex scenes. The percepts are unelaborated: blobs, lines, spirals, and lattice shapes; smooth or rough textures; agreeable or disagreeable tastes such as salty, sweet, or metallic. Replication, with radial or axial symmetry, is common. Synesthetic percepts never go beyond an elementary level. To do so would turn them into figurative hallucinations.

Discrete also refers to signatures of distinctive stimuli. We all recognize the distinctive sound of the piano because it sounds like a piano—not a vacuum cleaner or a dentist’s drill. As DS explains,

The shapes are not distinct from hearing them—they are part of what hearing is. The vibraphone, the musical instrument, makes a round shape. Each is like a little gold ball falling. That’s what the sound is; it couldn’t possibly be anything else.

4. **Synesthesia is memorable.** Perhaps because of their semantic vacuity, synesthetic percepts are easily and vividly remembered, often better than the original stimulus. “She had a green name—I forget, it was either Ethel or Vivian.” In this example, the actual names are confused because they are green, but the synesthetic greenness is recalled. There is a strong link between synesthesia and hypermnesia. Many synesthetes use their synesthesia as a mnemonic aid. The relationship between synesthesia and memory is well depicted in Luria’s *The Mind of a Mnemonist* (1968). His subject’s memory was limitless and without distortion, and was largely so because of the synesthesias that accompanied every sensation.

5. **Synesthesia is emotional.** Synesthetes have an unshakable conviction and sense of validity that what they perceive is real. They trust their synesthetic perceptions. A “eureka” sensation, as when the light bulb of insight goes off, often accompanies the parallel sense. The common presence of strong validity feelings implies limbic brain contribution to synesthetic experience. The limbic system provides the emotional valence and sense of conviction that people attach to their neocortical ideas and ideals. Moreover, it is in this part of the brain where anatomical opportunities exist for joining information from the various senses.

Consider the degree of affect that polymodal synesthete CLF endures. For him, letters and numbers have color, smell, gender, and personality whereas auditory and visual stimuli produce sensations of taste, touch, shape, and color.

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3.2. Diagnostic Criteria for Synesthesia
I navigate through a rather incredible world. It’s matter-of-fact in that it’s always been that way, but it is not matter-of-fact in that new and strange synesthesiae always surprise me. The emotions in synesthesia are invariably strong and I take care to coordinate with them. Overload is a problem for me.

I have a full emotion for every color. I am careful to wear the colors of clothes that accord closely with my actual emotions at the time I put them on. If my mood changes during the day, I feel lopsided, out of sync between my own emotions and the emotions of the colors I am wearing or surrounded by.

(5/6/01)

3.3 WHAT AND WHERE IS THE LINK?

All theories of synesthesia assume a “link” between the sensory stimulus and the synesthetic percept. To the extent that you believe that all psychological phenomena have direct physiological correlates, then some type of physiologic theory must be correct. Past research has focused on semantic mediation as a possible mechanism for synesthesia, a view that simply makes it a subset of the more general phenomena of cross-modal associations due to shared connotative meaning (D’Andrade & Egan 1974; Marks 1975; Osgood 1960; Riggs & Karwoski 1934; Vernon 1930; Wheeler & Cutsforth 1922). These studies typically investigate connotative meaning through such devices as the semantic differential (Osgood, Suci, & Tannenbaum 1957), anthropological measurement of artistic and linguistic emotional expression, and phonetic symbolism.

Such studies show that synesthetic percepts tend to follow conventional trends of connotative meaning. In colored hearing, for example, both synesthetes and normals match low pitches with large, dark photisms; high pitches with light, small photisms; and louder sounds with brighter and larger photisms (Karwoski, Odbert, & Osgood 1942; Marks 1974; Ortmann 1933). The difference is that synesthetes report seeing an external photism, whereas normals imagine that these “go together” appropriately. This relationship of mapping sensory dimensions explains one small aspect of synesthesia, and only those types in which a vision plays part. So restricted a view does little to explain other modes of synesthesia or its other characteristics. There are surprisingly few direct comparisons between the distinctive perceptual processing of synesthetic and nonsynesthetic subjects. In synesthesia, the precipitating stimulus repeatedly evokes a specific percept, or a narrow range of them at most. Synesthetic percepts are characteristically real, vivid, discrete, consistent, and memorable.

In showing only that synesthetic percepts follow some conventional lines of connotative meaning, therefore, these studies do little to clarify the underlying mechanism of synesthesia itself, except to suggest that it may simply be a more intense form of ordinary connotative association. Many aspects of perception that could be entertained as an explanation...
for synesthesia are amenable to experimental study. Following are some of these brain mechanisms and how experimental data might verify or disprove them. Curiously, this had not previously been done. Rather, existing papers have largely addressed the durability of synesthetic percepts following a retest interval of years (Devereaux 1966; Gengerelli 1976; Luria 1968; Rizzo & Esslinger 1989), made lists of associations in search of common patterns, or probed how synesthesia varies with alterations in stimulus amplitude or interval.

### 3.4 THEORIES OF THE MECHANISM OF SYNESTHESIA

It should not surprise readers that most references to synesthesia are old as well as being reports based on the introspection of subjects. In the 50 years between 1881 and 1931, Marks (1975) lists more than seventy papers, whereas in the 42-year span between 1932 and 1974 only sixteen papers appeared. There can be no doubt that the advent of B. F. Skinner’s behaviorism, which precluded reference to mental states, contributed to this decline. Only in the last two decades have mental states again become acceptable topics of scientific inquiry.

Both antique and modern thought on the mechanism of synesthesia can be divided into the following categories:

1. Undifferentiated neuronal activity: sensory incontinence analogous to synkinesis in infants
2. Linkage theories
   a. Neural specificity
   b. Polymodal combination
   c. Vestigial connections, persisting from birth
3. Abstractions theories
   a. Cognitive mediation
   b. Aristotelian common sense

#### 3.4.1 Undifferentiated Neuronal Activity

Popular in the nineteenth century, undifferentiated theories speculated that synesthesia was caused by an immature nervous system and likened synesthesia to the normal syn-kinesis (“joined movements”) observed in all infants. A baby reaching for a toy, for example, exhibits involuntary overflow movements of the trunk and extremities. Only when corticospinal and cerebellar motor pathways have matured and acquired their myelin insulation, is a human capable of finely isolated dextrous movements that do not spill over to other muscle groups. Labeled the degeneracy theory (Bleuler & Lehmann 1881) or the compensation theory (Downey 1912; C. A. Myers 1911), these theories suggest...
that synesthesia is a form of atavism or sensory incontinence since "there is a level in the development of animals at which no sense differentiation takes place." Empirical evidence does not support this idea and no one seriously argued the point in modern times.

Undifferentiated theories predict an impairment of intellect and an indiscriminate perceptual response to a stimulus—characteristics opposite the actual specificity of synesthesia and contrary to synesthetes' usual high intelligence.

The gustofacial reflex (Steiner 1973) bears an apparent similarity to synesthesia. It is a well-differentiated motor reaction of the facial muscles to taste stimuli. Controlled by neural structures of the brainstem, it is a rigidly fixed behavior. The neural apparatus of gustation is well developed and functional long before the gestational term. The adult form of the human taste bud is clearly visible in histologic preparations of the human embryo in the fifth gestational month.

Ethologists such as Peiper (1951) and Lorenz (1965) call the gustofacial response and innate behavior, an inherited motor coordination. Characteristic of such innate behaviors is its rigidly fixed appearance, resistance to exhaustion by repetition, and homologous distribution among lower mammals.

In the gustofacial reflex, different tastes produce fixed facial expressions (sweet = smile; bitter = disgust with tongue protrusion; sour = pursing of the lips). Any resemblance to synesthesia is superficial. The gustofacial reflex is universal with identical responses across individuals. Such is not the case with synesthesia. This observation suggests that the neural mechanism for synesthesia must lie above the level of the brainstem.

The striking point of the gustofacial reflex is the ability of the pontomedullary region of the human brain to discriminate between sensory signals and "decide," if you will, that some events shall be welcomed by the organism while others must be rejected as harmful or noxious. People are often inclined to believe that discrimination between good and bad is a cognitive function based on life experience, conditioning, learning, and an emotional attitude. This is not the case.

### 3.4.2 Linkage Theories

Linkage theories are based on the assumption that something is different with the circuitry of synesthetic brains compared to nonsynesthetic ones. The assumption of crossed wires, short circuits, or crosstalk is the intuitive explanation for synesthesia among laypersons, but the logical consequences of such an assumption are again contrary to fact. Linkage theories would especially support universal correspondences, which cannot be found.
The premise of neural specificity is that inflexible hard-wiring mediates between a sensory stimulus and a synesthetic percept. To use colored hearing as an example, the basic hypothesis in all attempts to construct a parallel pitch-color scale is that if \( aN, bN, cN \ldots \) represent the vibratory frequencies in a musical scale, then the multiple of \( aNM, bNM, cNM \ldots \) will predict the spectral wavelength of the synesthetically induced color. Among others (see Ortmann [1933] for a review), Isaac Newton (1730), and Erasmus Darwin (1790) proposed such theories. The elder Darwin, a proponent of colored music, built a harpsichord-lightbox device in which colored lanterns could shine through a shutter apparatus controlled by the keyboard. Because colored-hearing synesthetes have an idiosyncratic relationship between color and pitch, this scheme fails.

None of the proposed sensory reflex theories can be taken seriously today. These theories proposed two monosynaptic afferent-afferent limbs instead of the usual afferent-efferent ones (Donath 1922; Downey 1912; Hilbert 1895; Pierce 1912).

The synesthesia that occasionally occurs with lysergic acid diethylamide (LSD) and other anti-serotonergics is relevant here because the perception of visual hallucinations is facilitated by sensory input from other modalities (i.e., synesthesia). Suppression of neocortical activity with relative activation of deeper structures suggests that emotional meaning might be a relevant linkage to synesthetic percepts, a suggestion that is empirically testable. The LSD data are discussed in chapter 4.

Such considerations repeatedly raise the question of how the different sense modalities keep to themselves. In contemporary terms this is the binding problem. That is, I see an apple as a unity, not as something red and round, or I perceive honey rather than something yellow and sweet. The binding problem has so far remained unsolved. As Emrich pointed out in the Wolfenbüttel workshop (Adler 2001; Emrich 2001), the past fifty years has seen the concept of so-called grandmother cells come and go. It was thought that all distributed cognitive content converged on highly specialized cells that summarized distributed concepts: female human being, mother of the mother, old, etc. = grandmother. Diverse reasons led to the rejection of this concept. Next followed the idea of oscillations at 40 Hz that were supposed to bind different aspects of perception into a unified whole such that representation was not in a particular area but within the waveform process itself. This concept too has not panned out and who knows what the next fashion will be.

Synesthetes are just as capable as other individuals of making intermodal associations; their peculiarity, however, is an additional binding that leads, for example, to a sound resulting in a visual representa-
tion that is experienced not as additive but as integrated. Emrich calls this hyperbinding. I will say more about this in §§4.9.9 and 4.9.10 when I discuss supporting evidence for the anatomical localization of synesthesia.

If all neonates are synesthetic and lose their synesthesia by 6 months, as Maurer (1993) proposes, then vestigial remnants could explain synesthesia in the adult. Generalizing the results of Paulesu and colleagues’ study (1995) of chromatic-lexical synesthetes, Baron-Cohen proposes “unusual connectivities” between the association cortices subserving the joined sense modalities in question. There is no doubt that in the functional studies to date, cerebral metabolism is greatly perturbed beyond what is expected for the modality of the stimulating sense. The question remains, What is the nature of the proposed connection? Baron-Cohen proposes corticocortical connections, whereas Emrich and I favor a vertical, lower-level linkage via corticolimbic projections.

3.4.3 Abstraction Theories

The two main versions of the abstraction theory of synesthesia both involve a filtering out of specific sense elements until one is left with either an abstract emotional or an abstract perceptual residue that serves as a synesthetic mediator. Marks (1978) has consistently argued that synesthesia is fundamentally perceptual in its nature. Perceptions without language can have meaning. Indeed, Marks has demonstrated that cross-modal associations in nonsynesthetes and cross-modal metaphors in language derive in part from some of those same sensory processes that underlie synesthesia. That is, even in cross-modal perception by nonsynesthetic persons, language only modulates but does not wholly mask or replace the underlying and prior sensory relations. In nonsynesthetic children, cross-modal similarities are stronger perceptually than verbally (Marks, Hammeal, & Bornstein 1987). This is why semantic mediation as a synesthetic go-between has never panned out.

Those theories lumped under the rubric of cognitive mediation stress the importance of secondary and subsidiary meanings. The association theory (Langfield 1926; Wheeler & Cutsforth 1922) explains synesthesia as the operation of chance associations: if A suggests B, then A and B have been experienced simultaneously at some previous time. The naiveté of this premise speaks for itself and has more to do with a psychological notion than with the facts of synesthetic perception.

The emotional tone theory (Calkins 1895; H. L. Smith 1905) emphasizes intrinsic associations inasmuch as the affective (connotative) component of a stimulus is an integral part of its quality. Its claim that synesthesia and its stimulus have a common emotional background neglects the corollary that synesthesia should be ubiquitous, since emotional
coloring is an attribute of all ordinary sensation and not restricted to any particular sense. One should expect a pleasant color to evoke not only a mellifluous sound but also an ambrosian taste, a warm feeling, or the fragrance of a rose. Such a general spread, although logically imagined, it not at all characteristic of the specific response of synesthesia.

Aristotle’s common senses form the second category of polymodal abstraction. Most twentieth-century writers have fallen back on Aristotle’s common senses to serve as abstract perceptual residues that mediate connotative meaning and hence synesthesia. All theories that propose language as a synesthetic mediator also fall back on Aristotelian common sense and suggest that synesthesia is simply a more intense form of the metaphoric speech that everyone uses. The following discussion explains why linguistic theories cannot be correct.

Historically, Democritus taught that all mind events were events of the soul (psyche) and could be predicted by the shape of the soul’s atoms. All sensation was therefore reduced to motion. Plato stressed the need to appreciate the idea of a sensation as well as its physical attributes. From this, Aristotle (De Anima, books II and III) spoke of the particular and common senses.

By an object peculiar to a particular sense, I mean one that cannot be perceived by any other sense, and in respect of which no deception is possible. Thus color is an object peculiar to sight, sound to hearing, and flavor to taste ... Each sense judges the objects peculiar to it and is never deceived as to the existence of the color or sound that it perceives. (Quoted by Wheelwright 1951, p. 134)

We can be aware of certain aspects of the world around us in more than one way, however. We can see as well as feel the sizes and shapes of bodies, see and hear the motion of bodies from one place to another, and can even tell whether that motion is slow or fast. The common sensibles include movement, number, rest, size, figure, and length. The common senses are not perceived via a special sense organ, but rather indirectly (kata symbebêkos) through the particular senses.

Aristotle believed that although the senses come from outside us through different channels of the sense organs, they do not remain separate in our sense experience. The world that our senses gives us is one of bodies of various sizes and shapes, in motion or at rest, and related to one another in space in a variety of ways. Our sense experience of these bodies also includes a wide variety of qualities—the colors bodies have, the sounds they make, the roughness or smoothness of their surfaces, and so forth. We receive these sensations passively through our sense organs but are more active than passive in putting together the seamless fabric of our experience. While sensation comes from the outside, sense experience that arises from our perception of that outside world involves memory and imagination on our part. A unity results
from the simultaneous perception of different qualities in one object, “as bile is at once bitter and yellow. This explains why we may mistake a thing, because it happens to be yellow, for bile” (*De Anima*, book II, ii; Wheelwright 1951, p. 138).

On discrimination, Aristotle wrote:

Each sense has its own type of sense-object. Residing in its own sense-organ, it discriminates the specific differences of the sense-objects proper to it. Thus sight discriminates between white and black, taste between sweet and bitter, and so on. But we can also discriminate between white and sweet, and in fact between any two sensible qualities. By what means do we perceive generic differences? . . . [It is not] possible to discriminate between white and sweet by means of a different sense for each of them; there must be some one sense to which both of the compared qualities are discernibly present. Otherwise it would be like trying to establish a difference between two objects on the ground that you perceived one of them and I the other. Objects can be differentiated only where there is a single faculty to discriminate between them. In the case of white and sweet, as they are recognized as distinct, there must be a single faculty to affirm the distinction and hence a single faculty which thinks and perceives them both. We conclude from this that different things cannot be discriminated by a separate organ for each. (Wheelwright 1951, p. 140)

To pursue Aristotle’s argument, one is forced to say that the same faculty that *discriminates* white from sweet may also either fail to discriminate them or perceive them as synonymous based on shared qualities—hence synesthesia.

Research in the last century, therefore, focused on shared meanings as the link and suggested that synesthesia occurred at the highest levels of abstract processing in the central nervous system (CNS).

### 3.5 PROPOSAL FOR A SYNESTHETIC MEDIATOR

A variant of the linkage theory, entertained and tested below, may be called *polymodal combination*. Heretofore, all recent theories of synesthesia have invoked Aristotelian common sense as a mediator of connotative meaning and therefore as a rudimentary mediator of synesthesia. On reflection, however, an Aristotelian common sensible is not like a synesthetic percept at all (figure 3.1). An Aristotelian common sensible, such as roundness, cannot be learned by touch alone; it is a concept common to several senses. It is not a cross-modal association or an additive phenomenon but a filtering out of abstract residues, a subtractive attribute that amounts to a superabstraction. By contrast, synesthesia adds elementary percepts (e.g., sound and color) to form complex ones without losing the identities of the elementary constituents.

Cross-modal associations per se are familiar enough from everyday life. Even young children can recognize as identical an object seen alone and then palpated in the dark (Ettlinger & Blakemore 1969; Popper &
Cross-modal abstractions are requisite to speak, as Geschwind (1964) pointed out:

The ability to acquire speech has as a prerequisite the ability to form cross-modal associations. In sub-human forms, the only readily established sensory-sensory associations are those between a non-limbic (i.e., visual, tactile, or auditory) stimulus and a limbic stimulus. It is only in man that associations between two non-limbic stimuli are readily formed and it is this ability which underlies the learning of names of objects. (p. 155)

At one extreme, for example, the concept of “quantity” is a polymodal abstraction (a nonlimbic-to-nonlimbic association). My current hypothesis proposes that synesthesia is a polymodal combination that is concrete instead of abstract. Based on theory alone, therefore, language should have little to do with synesthesia. This conclusion is supported experimentally by semantic differentials between subjects with colored hearing and the gustatory synesthete MW that show no common meaning between words describing either the stimuli or the synesthetic responses.

It is worth taking a short detour to examine the semantic differential before proceeding further.
3.5.1 The Semantic Differential

Osgood and colleagues (1957) identified meaning as a representational mediation process and developed a particular kind of measurement operation, the semantic differential. They postulated a semantic space, Euclidean in nature, of unknown dimension. Semantic scales, each defined by a pair of polar adjectives, are assumed to represent a straight-line function that passes through the origin of this space.

A subject “differentiates” the meaning of a concept when judging it against a series of polar scales. For example:

```
FATHER
Good: x: Bad
Fast: x: Slow
Hard: x: Soft
```

Each judgment represents a selection along a set of given alternatives and localizes the concept as a point in the semantic space.

Even in subjects who have considerable linguistic sophistication, almost half the total variance in meaningful judgments is accounted for by only three stable factors: evaluation, potency, and activity. A pervasive evaluative factor in human judgment regularly appears first. Namely, is it good or is it bad? Next, the potency factor is concerned with power and things associated with it—size, weight, toughness, and so forth. Third, the activity factor is concerned with quickness, excitement, warmth, agitation, and the like.

These three major factors of evaluation, potency, and activity are empirically rather than theoretically derived and appear in a wide variety of judgmental situations. Furthermore, the relative weights of the factors are constant, evaluation accounting for double the variance due to either potency or activity, and these two in turn carrying double the weight of any subsequent factors. A large portion of the total variance remains unaccounted for, however, and Osgood suggested that there must be a large number of relatively specific semantic factors.

The semantic differential is a generalizable technique of measurement. There are no standard concepts and no standard scales, the concepts and scales used in a particular study depending upon the purpose of the research. Single words serve most often as a unitary semantic concept (e.g., *fraud*), but nonverbal concepts such as Rorschach pictures, representational or abstract paintings, sculpture, and even sonar signals have been used (Osgood et al. 1957).

It is precisely because the semantic differential taps the connotative aspects of meaning more immediately than the highly diversified denotative aspects that it might be applicable to aesthetic studies and concepts such as synesthesia.
The history of the semantic differential in relation to synesthesia is of some interest. The use of polar adjectives to define the termini of semantic dimensions grew out of research on synesthesia by Karwoski & Odbert (1938). These researchers related synesthetic perception to thinking and language in general and assumed that any difference from the general population was one of degree rather than kind. Whereas synesthetes might picture fast, exciting music as bright, angular, red photisms, nonsynesthetic listeners would merely agree that words like “red-hot,” “bright,” and “fiery,” as verbal metaphors, adequately described the music. Osgood et al. (1957) said “the relation of this phenomenon to ordinary metaphor is evident,” a conclusion that is not, in fact, adequately justified. They did show that stimuli from several modalities—visual, auditory, emotional, and verbal—may have shared significates or meanings. Showing this, however, does little to clarify the underlying mechanism of synesthesia itself, nor is it justified to conclude that semantic mediation or shared linguistic meaning is the link in synesthesia (Marks 1978).

In explicating the logic behind the semantic differential, Osgood et al. (1957) cited Karwoski and colleagues (Karwoski, Gramlich, & Arnott 1944; Karwoski & Odbert 1938; Karwoski, Odbert, & Osgood 1942; Odbert, Karwoski, & Eckerson 1942) and pointed to their diagram of “synesthetes” illustrating a rising and falling tone (figure 3.2). They showed that “practiced synesthetes” (a term undefined) and trained nonsynesthetes (an oxymoron) rendered similar graphic representations, and thereby argued for cognitive similarity.

My objections are that (1) their subjects are clearly not synesthetic but are using imagery, (2) their controls were trained to make specific cross-modal associations, and (3) that what is being drawn, as appears obvious from examining the figure, is not any synesthetic sense of the sound but rather the underlying concept of the stimulus: namely, a rising and falling tone. Their subjects are drawing the abstract concept, not the sound or an idiosyncratic synesthetic response to the sound. Osgood et al. (1957) stated “that these practiced synesthetes are not exercising a ‘rare’ capacity was shown in two subsequent experiments: in one, subjects who had never even thought of ‘seeing things’ when they heard music were played the same stimulus selections and told that they had to draw something to represent each stimulus—exactly the same types of productions were obtained” (p. 22). Figure 3.2 shows the drawings of “photistic visualizers” versus controls. There is little qualitative difference between the two. Many are either line drawings or solid forms whose increased thickness corresponds to the increased intensity of the stimulus. The representations of the soft parts of the stimulus appear as the directly opposite characteristic used by the subjects to represent the loud central part. Karwoski et al. (1942)
believed that these symbols seem “conceptually adequate to represent the stimulus.”

*This is not synesthesia.* Although “the same types of productions” were elicited, one needs to ask whether their subjects routinely saw such representations whenever they heard a rising and falling tone (a crescendo-diminuendo) or—to give a more naturalistic circumstance—the Doppler effect of a passing siren. If so, one would rightly suspect that such subjects were synesthetic. Yet the information is lacking for the reader to judge. Did subjects who rendered these graphic representations for the experimenters render the same drawings when challenged at a later time with the same stimuli? There are no data to show whether these associations are consistent over time as is typical of idiopathic synesthesia.

Karwoski et al. (1942) thought that the ease with which translation from the auditory to the visual might be reduced to verbal terms, and the fact that the translations nearly always occurred in related pairs of opposites, suggested a close relationship to language. This led them to differentiate visual and mood poles of music and further suggest that the form element in colored hearing is “very closely related to common factors in our culture,” such as “light or heavy music, thin strings and thick bass.” They satisfied themselves that there was a “great repertoire of similes and metaphors for translating sound into sight” and that language was the key to this translation.
What are their so-called synesthetic subjects actually responding to? I think the correct analysis is that they are giving a graphic representation of a concept—an abstract principle—rather than giving a graphic representation of the parallel sense they might experience if they actually were synesthetic. Karwoski and colleagues’ conclusion may have contributed to the opinion of their contemporary colleagues that synesthesia was not so rare. Karwoski claimed to relate synesthesia to thinking and language in general. Rather than being a freak phenomenon, Karwoski & Odbert (1938) estimated that colored music synesthesia was “indulged in” by 13% of Dartmouth college students, “often as a means of enriching their enjoyment of music.” Even larger numbers were reported to have such experiences occasionally. Their conclusions are unfounded, but it is easy to see how this fostered the notion that semantic meaning could be the link in synesthesia.

The high agreement among 100 nonsynesthetic subjects regarding the most appropriate visualizations of music yielded Karwoski & Odbert’s conclusion that “the capacity to appreciate music in visual terms exists in a considerable portion of the population.” I think no one would argue with this, but appreciating music in terms of verbal metaphor is quite another thing from experiencing an involuntary synesthetic photism.

Osgood et al. (1957) relied on Karwoski and colleagues’ synesthesia investigations in formulating the theoretical background for the semantic differential. It is ironic that use of the same instrument 30 years later should demonstrate no correlation between the semantic meaning of the stimulus and its synesthetic response.

In 1979 Frank Wood and I (unpublished data) applied the semantic differential to subject VE and three controls. A sound-color matching task revealed that notes she perceived as high generated predominantly pink responses whereas low notes were predominantly blue (see figure 3.10). We used 10 colors (black, blue, brown, green, orange, pink, purple, red, white, and yellow) as the concepts, and differentiated them across the 25 scales of pleasant–unpleasant, strong–weak, familiar–strange, good–bad, high–low, fast–slow, delicate–massive, fragrant–foul, animated–listless, large–small, clean–dirty, mellow–sharp, full–empty, nice–awful, sharp–dull, regular–irregular, active–passive, light–dark, sacred–profane, open–closed, angular–round, light–heavy, hard–soft, soaring–earthbound, and voluminous–sparse.

Differentiating the 10 colors over 25 scales failed to show any similarity in the semantic space between pink and those notes that were perceived to be high, or between blue and those notes that were perceived to be low. In fact, blue was judged to be high, good, somewhat passive, and neither potent nor weak. Pink was judged to be neither high nor low, neither good nor bad, neither active nor passive, and only slightly potent. We concluded that whatever caused VE to
perceive high notes as generally pink and low notes as blue, it was not on the basis of any shared meaning.

The semantic differential did not consistently explain the three controls’ associations either. Control A seemed to have a clear relational effect in matching red, yellow, and pink to high notes. These were all perceived to be good, relatively potent, and passive, while all being high. Control T showed no consistency in semantic meanings of colors that were associated with high and low notes, and control L was inconsistent. We did not pursue linguistic meanings further, having failed to show any semantic parallelism.

Osgood (1960) studied cross-cultural generalities of visual-verbal tendencies (which he called “synesthetic”) and explicitly stated that his bipolar dimensions used in semantic evaluation derived from the bipolarity of dimensions obtained from the study of synesthesia. This is why, more than any other reason, falling back on linguistic mediation as an explanation for synesthesia seems a circular argument. Osgood’s own explication of his theory is that meaning consists of a process of mediation whose connotative components correspond to the dimensions obtained via semantic differentiation. The mediation processes themselves are treated as learned representations of responses that become attached to their signs through learning (reinforcement). More important, the representational components are complex rather than simple responses and are derived from several kinds of reaction besides language.

Recalling our discussion of Aristotelian common senses, it is clear that we can perceive an object as light or heavy by the sound of its fall or can, for example, estimate the number of pins knocked over by a bowling ball by the sound as it crashes into them. Such cross-modal linguistic associations may be cognitive shorthand that conveniently serves to highlight important sensory attributes that are held in common. However, these attributes are qualitatively different from the parallel sense of synesthesia and should not be confused with it.

3.5.2 Polymodal Combination

Based on the above, I believe that the place to go fishing in the brain for an explanation of synesthesia is not at the top (in the neocortex where symbolic language resides) but lower in the pond, at an earlier stage of neural processing.

Testing the first class of theories, that of primitive loss of differentiation, is infeasible on a priori grounds, but testing the latter two categories—linkage and abstraction—is plausible. Experiment may distinguish between the two theories in the following way. The proposed model applies to all types of synesthesia.
Figure 3.3 shows three possible levels for linking a stimulus to a synesthetic response or responses. A high level of semantic mediation implies a broad range and richness of the ultimate perceptual domain: If the associations are mediated through semantically abstract shared meaning, then the precipitating stimulus should engender a group of percepts that share the same meaning, and the range of synesthetic associations should be as broad as nonsynesthetic controls. On the other hand, a direct, low-level one-to-one link suggests an extremely limited range, quite specific as to the particular stimulus-percept combination. If the neuronal-specificity linkage theory is correct, there should be virtually no variability in the stimulus-to-percept associations of a synesthete, unlike normals, who are already documented to mediate via shared connotative meaning. Presumably, a middle possibility exists that stresses a small range of associations through a fairly low-level, relatively semantically impoverished mediating structure.

In terms of CNS processes, semantic mediation would stress that synesthesia flows through the highest levels of neocortical processing, whereas neural linkage would stress direct linkages between various
sensory channels, at quite low levels of brain integration. An interme-
diate position might stress a relative attenuation of cortical associative
processing with a corresponding enhancement of “lower” associations.
*Polymodal combination* would, by definition, invoke a lower level of as-
sociation than the classic polymodal abstraction theories. Hence, the
range of synesthetic responses would be different according to the two
theories. Polymodal combination implies a more restricted range than
polymodal abstraction.

Within this class of lower-level associations, the direct linkage theory
can be further distinguished from the intermediate position by a con-
sideration of relative effects in the psychophysical function relating
synesthetic perception to the precipitating stimulus. Like the hard-wired
knee jerk reflex, the lowest level associations would show no relative
effects: a given stimulus would evoke the same percept regardless of
the context of the stimulus within a set of recent stimuli. Purely cog-
nitively mediated percepts might be especially sensitive to relational
effects (Marks, Szczesiul, & Ohlott, 1986). The intermediate position
should show a combination of both types of effect.

### 3.6 OPERATIONALIZING THE THEORIES OF SYNESTHESIA

The alternative theories of synesthesia have been discussed above. His-
torically, no direct comparisons of characteristic perceptual process-
ing between synesthetes and nonsynesthetes were made in the past. A
number of issues in making such comparisons lend themselves to ex-
perimental tests. Briefly, the fundamental question is the level at which
the synesthetic association is mediated. A low level of association pre-
dicts a restricted range of perceptual responses to the same stimulus,
whereas a high level of association predicts an extensive range of asso-
ciations to the eliciting stimulus, all of which are presumably mediated
by a shared, high-level cognitive or connotative meaning.

A second experimental issue addresses absolute and relative effects
in a psychophysical stimulus-response mapping experiment (see figure
3.3). A very low-level linkage should show no context effects; that is, a
given stimulus should always evoke the same percept, just as the knee
jerk reflex always produces the same twitch. This is called an absolute
effect. For example, if a given stimulus were the highest of a group
presented repeatedly to the subject, it would evoke exactly the same
response as if it were the lowest of another set of stimuli presented to
the subject. A purely relative mechanism, by definition mediated at a
higher cognitive level, would predict that the stimulus would elicit quite
different percepts, depending on its context within a set of stimuli. In
both of these phenomena, range of associations and context effects, there
could obviously be an intermediate level, suggesting a corresponding
intermediate level of stimulus-response mapping.
The following experiments investigate the psychophysical functions of two synesthetes, each compared to three controls, with specific attention to the question of range and context effects.

3.6.1 Experimental Subjects and Procedures

Beyond a willing subject who consents to undergo the tedious process of a mapping experiment, one needs a reliable and easily administered stimulus that will consistently produce some synesthetic response. The response should be scorable along a variable dimension and the arrangement of the mapping task should be flexible to permit investigation of absolute and relative effects as discussed above.

3.6.1.1 Subjects  

Two synesthetic subjects, one who perceives vivid geometric shapes and textures in response to tastes and smells (MW) and another with colored hearing (VE), served as the experimental subjects.

MW, the gustatory synesthete with geometric taste, is a lighting designer who feels, rarely sees, and otherwise perceives geometric shapes whenever he tastes or smells foods. His parallel sense is most vivid and sensuous with novel flavors and smells (i.e., those sampled for the first time), although the synesthesia does not fatigue with repeated samplings or familiarization. With repeated inhalations his sense of smell will fatigue and the accompanying synesthesia might be absent because “I can’t smell anything.” But after a pause, when his olfactory neurons have recovered, the synesthesia is present as before. Having discovered that others do not taste shapes, he habitually keeps his synesthetic perceptions to himself to avoid ridicule and disbelief, although the perceptions themselves are impossible to ignore.

Shapes are felt mainly in the face, hands, and shoulders, in the trigeminal and dermatomal distribution of C2 to T2. There is often a sense of grasping or manipulating the shape, of palpating its texture or temperature. At times, the thumb or middle finger will feel more intensely than the other digits. Years after experimentation with MW began, he was shown a dermatome chart and immediately explained, “So that’s why it feels like it’s sweeping down my arm into my hand!” Despite the sensation of movement down his arm (spatial and temporal summation), I have never been convinced that he ever perceived in a true segmental distribution. His synesthesias are almost always pleasurable; rarely, they may be a “slap” or “burning” in the face. His obligation to attend to the synesthesia can sometimes be noted by others in his company through his lapses in conversation, his manual gestures, or his nonverbal behavior that indicates satisfying pleasure. This behavior is nothing like the staring spell or aura of an absence or limbic seizure.
MW has a vivid memory for what he calls “sensory experiences.” By this he means an ability to conjure up highly detailed visual images and past emotional states. A pilot study showed that he is able, in fact, to form accurate eidetic images after the method of Haber & Haber (1964; see also Haber 1969). Of interest is his lack of source memory for a synesthetic percept, although other experiments showed that he can recognize instantly a stimulus he has had before. His hobby of cooking, for example, is guided by a method that I call the “unknown template,” in which he has a nonverbal “idea” of what the final dish must “feel” like. Written recipes are not satisfactory to achieve the final desired result. He adjusts seasonings, often by trial and error, to alter the taste’s shape, making it “rounder,” giving it more “inclination,” “sharpening up” corners to give more heft to the vertical component, or giving the overall shape some “points.” A “eureka” conviction of recognition overcomes him when the taste of the actual dish matches his unknown template. “Unknown” here simply means unavailable to semantic expression. This is just a version of the general instance of knowing what you are looking for only when you find it.

VE, the auditory synesthete, has all her life seen splotches of color whenever she hears music. Occasionally, environmental sounds such as beepers, voices, or clattering machinery will evoke photisms. Her habit is to ignore these percepts except in cases of shrill and loud sounds, where their vividness makes them impossible to neglect. At this level, they may be accompanied by a stabbing pain in the forehead. She is also synesthetic in other modalities, although less regularly so. For example, smells have color and strong chroma evokes smell. As a young child she had an especially vivid pictorial as well as verbal memory and could easily memorize long passages from poems and plays.

At the time of these experiments MW was 36 years old and VE, 38. The three nonsynesthetic gustatory controls were a 40-year-old chef (control J); a 33-year-old carpenter (control S); and a 43-year-old academic administrator (control W). A fourth gustatory control was eliminated because he insisted that there was no logical way for taste and shape to go together. The three nonsynesthetic auditory controls were a 28-year-old visual artist with strong scientific and mathematical interests (control L); a 24-year-old medical student (control T); and a 54-year-old professional portraitist and muralist, widely read in the classics and philosophy (control A). All six controls were chosen not so much for rigid age-sex match as for their various experience with and professional response to taste, sound, shape, and color.

### 3.6.1.2 Construction of Appropriate Response Domains

For MW, a pilot study determined if certain shapes were appropriate as responses with which he could describe the percepts arising from various tastes. For this purpose, 10 tastes were used in solution: (1) salt, (2) sucrose, (3)
anise, (4) citric acid, (5) Campari, (6) menthol, (7) Angostura bitters, (8) vanilla, (9) quinine, and (10) Karo syrup. The responses were developed to permit choices ranging from completely round (spherical) to completely angular (cubic). The response set thus represented a circumplex dimension, and the answer sheet is shown in figure 3.4.

Stimuli were presented in 10 blocks of 10 trials each arranged in a Latin square counterbalancing sequence. The subject chose one of the shapes on the circle for each of the 100 taste trials and the results showed an orderly distribution of shape choices matched to taste stimuli. In general, simple tastes (such as sweet or sour) elicited a more restricted range of responses than did the complex tastes (such as anise or Angostura bitters), and there was noticeable differentiation in the shape-to-taste mapping.

This pilot experiment also revealed that regular solids radially symmetrical in three dimensions were inadequate as a stimulus set, since the subject often reported percepts that were linear, columnar, or pointed. Consequently, a revised response sheet was prepared so that it would incorporate some of the reported percepts for those for which the subject was unable to find satisfactory matches on the original response sheet. This revised answer sheet is shown in figure 3.5. It has an even more complex dimensionality to it, so that shapes can sometimes differ from one another along more than one orderly series of intermediate forms. This figure-eight organization did seem to reflect the response domain as described by the subject: Most members of this
figure-eight domain, in both the upper and lower half, were included in the subject’s description of his percepts in the pilot study.

Pilot studies with VE, the auditory synesthete, demonstrated that verbal labels were quite as satisfactory as actual color chips (see also Williams & Jackson 1968). An answer sheet was constructed in the following manner. An alphabetized list of color adjectives was printed in left-to-right order on a single line for each of 144 trials in a given sound-color matching experiment:

BLACK BLUE BROWN GREEN ORANGE PINK PURPLE RED WHITE YELLOW

3.6.1.3 Procedure Table 3.2 summarizes the taste and sound stimuli.

Gustatory Synesthesia For the shape-taste experiment the stimuli consisted of 13 solutions ranging from pure 0.2 M sucrose for solution 1 to pure 0.2 M citric acid for solution 13. Three different experiments were conducted as follows:

Figure 3.5 Revised circumplex for the actual taste-shape matching experiments. See text for further details. (From Cytowic & Wood [1982b] with permission.)
Experiment I utilized solutions 1 (pure sucrose) through 7 (50:50 sucrose-acid), and involved seven sets of the seven tastes arranged in a Latin square counterbalancing table so that each taste occurred in each serial position once and followed every other taste once. After 0.25 mL of solution was squirted by syringe into the subject’s mouth, he circled on the answer sheet that shape that best represented the percept, either synesthetic or imagined (for the controls), that resulted from the taste. Tastes were applied at the rate of one every 20 seconds, with breaks of 10 minutes between experiments.

Experiment II was identical to experiment I except in using solutions 7 (50:50 sucrose-acid) through 13 (pure citric acid).

Experiment III likewise had seven sets of tastes but explored the whole range of available tastes by using odd-numbered solutions only.

**Auditory Synesthesia**

Sound stimuli for the test of auditory synesthesia consisted of single piano notes recorded on tape. Three different tapes were prepared as follows (refer to table 3.2).

| Tape I (A-440) Low | D\(\text{\#}\) D E E \(\text{\#}\) F F\(\text{\#}\) G A\(\text{\#}\) A B B C |
| Tape II Extended range (4 octaves) | D\(\text{\#}\) F A \(\text{\#}\) \(\text{\#}\) 220 D\(\text{\#}\) F A \(\text{\#}\) \(\text{\#}\) 440 D\(\text{\#}\) F A \(\text{\#}\) \(\text{\#}\) 880 D\(\text{\#}\) F A \(\text{\#}\) \(\text{\#}\) 1760 |
| Tape III (A-880) High | D\(\text{\#}\) D E E \(\text{\#}\) F F\(\text{\#}\) G A\(\text{\#}\) A B B C |

From Cytowic & Wood (1982b, p. 41), with permission.

Experiment I utilized solutions 1 (pure sucrose) through 7 (50:50 sucrose-acid), and involved seven sets of the seven tastes arranged in a Latin square counterbalancing table so that each taste occurred in each serial position once and followed every other taste once. After 0.25 mL of solution was squirted by syringe into the subject’s mouth, he circled on the answer sheet that shape that best represented the percept, either synesthetic or imagined (for the controls), that resulted from the taste. Tastes were applied at the rate of one every 20 seconds, with breaks of 10 minutes between experiments.

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**Auditory Synesthesia**

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Tape I consisted of 12 sets of 12 notes, each set containing the half-notes between C-sharp (adjacent to middle C) and C (one octave above middle C). All 12 notes appeared in each set and, across sets, a Latin square counterbalancing table assured that each note followed every other note once and occurred in each serial position once. Sets were ordered randomly, as was the order of tapes. A note was sounded for 5 seconds and followed by a 10-second pause on the tape, during which the subject was instructed to record on the answer sheet the visual...
percept seen or imagined. A new note sounded at the end of the 10-second pause and the cycle was repeated until all 12 notes were played.

Tape II also consisted of 12 sets of 12 notes counterbalanced as in tape I, except that the 12 notes were not adjacent half-notes but were separated by a major third interval and ranged four and a half octaves, from C-sharp below middle C to A two octaves above middle C.

Tape III was identical to tape I except for being one octave higher.

The line of color adjectives is described above. Twelve such lines, corresponding to a single set of 12 notes, appeared on a single page. Thus, 12 pages constituted the answer booklet for a single tape. Subjects were instructed to circle the color perceived or imagined as seen in response to the tone on the tape.

Subjects worked at their own speed, taking breaks between sets as needed but no breaks within the set. Each subject completed the three tapes across 5 days of testing. Subjects worked in a quiet room but otherwise had no restrictions on the environment in which they worked.

3.6.2 Results

The results of the mapping experiments show the presence of both absolute and relative effects but are closest to the lower level of linkage. Synesthetes clustered their responses in restricted areas of the response domain while controls spread their choices out over the available options. The synesthetic absolute effect is present in only one part of the stimulus field. Furthermore, there is a prominent relational effect in which the response mapping of the entire range is reproduced in one segment of the stimulus range. These conclusions are examined in greater detail below.

The psychophysical function for MW, the gustatory synesthete, is difficult to describe in view of the circumplex dimensionality (figure-eight form) of the response domain. The results are presented as though the shapes were ordered in a single linear dimension, even though this is to some extent a distortion and oversimplification. The reader should therefore refer often to figure 3.5 in interpreting this set of results. The frequencies of shape choices for particular taste stimuli for the gustatory synesthete and his three controls are shown in figures 3.6 through 3.9. Similarly, the color responses to specific tones are shown for VE, the auditory synesthete, and her three controls in figures 3.10 through 3.13.

The obvious tendency of the synesthetic responses to cluster in restricted areas of the response domain is of special interest. This tendency was tested by a $\chi^2$ analysis, collapsing across stimuli, of the departure from the assumption of uniform distribution of responses
across the response domain. This $\chi^2$ was calculated for each set of counterbalanced stimuli for each subject. The relevant $\chi^2$ values were significant at $P < .001$ for all three sets for both synesthetes, beginning at 86.0 ($df = 10$) to 108.0 ($df = 22$). The same was true for two of the controls (W in the gustatory series and A in the color series), where the $\chi^2$ values exceeded $P < .001$ for one set per subject. Reasons for departure from uniformity are discussed below.

On inspection, there are apparent qualitative differences between these particular controls and the synesthetes in respect to the distribution of responses in the different parts of the range. In contrast to the controls, both synesthetes show a unique constriction of the response set at one end of the domain, with a similar and broader range applied both across the whole domain and across the other part of the domain. These tendencies are not subjectable to formal statistical tests, but are considered further in the discussion below.
3.6.3 Discussion

Inspection of the various figures relating synesthetic percepts to eliciting stimuli shows some common features for both synesthetes that are indeed distinct from the nonsynesthetic controls. Compared to controls, the most notable feature of the synesthetic percepts, for both the gustatory and the auditory synesthete, is their greatly restricted response repertoire. The frequency distribution of synesthetic responses in various categories is greatly restricted compared to that of controls.

A second clear feature, shared by both synesthetes but by none of the controls, is a distinct asymmetry of responses in respect to the range of choices that are available in various subsets of the response domain (see figures 3.14 and 3.15). Both synesthetic subjects use an extremely restricted response repertoire in one particular part of the response domain under study. The gustatory synesthete, in responding to various concentrations of sucrose versus citric acid, showed his restriction of
responses in the acidic half of the stimulus domain. There were essentially only three shapes that he employed, all some type of pointed and angular shape. These are conceptually close to one another in the response dimension. The auditory synesthete showed the greatest preponderance of blue and pink responses in the high single octave.

In contrast both synesthetes showed a full range of responses in the other half of the stimulus domain, quite similar to that shown when they were responding to the extended range of stimuli between both extremes of the stimulus dimension under study. Thus, there was a prominent relational effect whereby the response mapping of the entire range was reproduced in one segment of that range; but there was an absolute effect as well, whereby the other end of the stimulus domain elicited a very restricted range of responses.

The six control subjects employed a variety of strategies in their taste-shape and sound-color matchings. Most of them spread their choices out over the available response domain, giving a very diffuse, although
Figure 3.9  Distribution of shaped choices for control W. (From Cytowic & Wood [1982b] with permission.)

Figure 3.10  Frequency distribution of colors for VE, the auditory synesthete. The dashed lines on the low (tape I) and high (tape III) octave histograms mark those parts of the stimulus domain that also occur in the extended range (tape II). (From Cytowic & Wood [1982b] with permission.)

3. Theories of Synesthesia: A Review and a New Proposal
Figure 3.11  Distribution of color choices for control L. (From Cytowic & Wood [1982b] with permission.)

Figure 3.12  Distribution of color choices for control T. (From Cytowic & Wood [1982b] with permission.)
Figure 3.13  Distribution of color choices for control A. (From Cytowic & Wood [1982b] with permission.)

Figure 3.14  Collapsed frequency distribution of MW’s shape responses for the low (f₁), high (f₂), and extended (f₃) range of taste stimuli. (From Cytowic & Wood [1982b] with permission.)
not bell-shaped, and rich set of responses to a stimulus. One control of each in the gustatory series (W, the academic administrator) and the auditory series (A, the professional muralist) showed a restricted and essentially bimodal distribution of choices that was dominated by relational effects and lacking in appreciable absolute effects. This relational effect has been shown previously in nonsynesthetic subjects (Ries 1969). Control W explained that he decided to use shape 17 for sweet tastes, which were “best represented by the concavities of this figure.” Accordingly, his range of most to least sweet encompassed shapes 16 through 19. Those for most to least sour were numbers 7, 8, 9, and 23, the sourness “represented by the complexity of the faceted cone.” He apologized during testing: “I hope this isn’t boring you because I’m being niggardly in my choices. Basically, if it’s sweet I’m choosing these [round] shapes, and if it’s sour, I pick these [conical].” Control A claimed to have no logical scheme for choosing his colors but, like the others, “I just pick whatever comes into my head.” It does not need

Figure 3.15  Collapsed frequency distribution of VE’s color responses for the low, high, and extended range of sound stimuli. 1, black; 2, brown; 3, blue; 4, green; 5, orange; 6, yellow; 7, purple; 8, pink; 9, red; 10, white. (From Cytowic & Wood [1982b] with permission.)
emphasizing that the controls, even those who show a bimodal distribution, are making conscious choices in their matches and experientially deny having synesthesia.

In relation to the theoretical issues considered earlier in this chapter, it appears that synesthetic percepts show two things: (1) a generally restricted range of responses and (2) a combination of absolute and relative effects. Martino & Marks (2000) recently posited the existence of both strong and weak forms of synesthesia, a proposition that may partly explain the context effects observed in matching experiments. According to the theoretical considerations discussed, therefore, one can conclude that synesthesia is a distinct phenomenon, unlike ordinary intermodal associations. Its distinctiveness appears to involve an intermediate level of stimulus-response association in which the stimulus-response mapping is neither completely one-on-one nor richly one-on-many. A combination of absolute and relational effects exists, lending further support to the notion of an intermediate level of stimulus-response mediation.

Regarding the brain basis for a process whose sole characteristics are behaviorally described, it is at least possible to indicate that the synesthetic mechanism does seem to occupy an intermediate place in the range of concrete-to-abstract, one-on-one to one-on-many, and therefore simple-to-complex brain mechanisms.

The neurological level of this mechanism is taken up in the next chapter; the neural basis for synesthesia is addressed in chapter 6.
With a few theoretical considerations behind us, we can now zero in on the level of the neuraxis at which synesthesia occurs. Our first question is, To what is synesthesia similar?

The mapping experiments and theoretical issues revealed two fundamentals: (1) a restricted range of responses from the available choices and (2) a combination of absolute and relative effects. The bridging across senses is neither at a one-to-one correspondence as it might be if the link were hard-wired at some low level of the CNS, nor is it one-to-many as might occur at a higher level of abstract processing. It therefore seems to occupy an intermediate place in the range of concrete-to-abstract and simple-to-complex brain mechanisms.

So where is it? I will argue that synesthesia (1) is asymmetrical in being a left hemisphere phenomenon, (2) is not localizable as a so-called higher cortical function in the conventional, hierarchical sense, and (3) draws on temporal lobe–limbic structures.

My method in this chapter begins with reasoning by analogy. This may annoy those readers who are eager to get on with it, who want to be able to point to a spot of brain tissue and say, “this is where synesthesia happens.” These folks would rather hook patients up to the latest brain-imaging technology without much thought as to what question the effort supposedly answers, and then labor over what the results mean.

I have already made plain my distaste for what is typically an American approach to medical technology—namely, a fishing expedition that produces computer-generated images supposedly showing the brain anatomy underlying the cognitive task in question. But such images are already a highly abstracted construct of countless data points, with little understanding behind what they actually represent. They are neither a representation of reality nor a model of actual histology. Yet we continue to stand back, look at the pictures, and marvel. (Lest I be widely misunderstood let me state that there is a relationship but no identity.) I am no Luddite, but I prefer technology to either confirm or disconfirm a hypothesis—not be a tool for casting about in
search of something interesting. A hypothesis can be carved from theoretical considerations, clinical ones, or a combination of both. It is the approach and the thought that goes behind it that matters.

I also have a pat answer for those who ask the most common question about synesthesia, namely, “Is it real?” “Real to whom,” I respond, “To you or to those who have it?” The question itself belies a widely held belief in a supposed objectivity behind an essentially subjective experience. The insistence on a third-person verification, often technological, before accepting the validity of any subjective experience indicates how addicted we have become to the technical and the objective, how poised we are to reject our own experience.

I want to iterate that science is creative, an exercise in human imagination. It has different philosophies and points of view. It isn’t a monolith. Science has value, especially respect for the use of evidence and logical reasoning. It is also honest, curious, and open to ideas while remaining skeptical when valuing new claims. Yet, as Lewis Wolpert points out (1993), the scientific enterprise means only to produce verifiable knowledge—that is all. Still, most people think it the final word on everything. That of course is not my approach to revising this tract on synesthesia. I don’t expect to have the final word on anything, just the pleasure of relating 20 years of fascinating and enjoyable work.

4.1 PHENOMENA SIMILAR TO SYNESTHESIA

In trying to fathom first the anatomical and then the functional basis for synesthesia, we can gain a first approximation by examining a number of phenomena to which it is similar. These include:

- Drug-induced synesthesia (LSD and other hallucinogens)
- Eidetic imagery, other forms of hypermnesis (e.g., Luria’s patient S)
- Simple synesthesia
- Sensory deprivation hallucinations, release-type and otherwise
- Hallucinosis of temporal lobe epilepsy
- Mesencephalic hallucinosis (peduncular hallucinosis of Lhermitte)
- Electrical stimulation of the brain (ESB)

Some of the methods used to approach these ideas will include:

- Influence of drugs on synesthesia
- Regional cerebral blood flow, cerebral angiography, and magnetic resonance imaging (in both single subjects and homogeneous groups)
- Neuropsychological assessment
- Evoked potential studies
Scientific inquiry activity into LSD and similarly acting drugs boomed during the 1950s and 1960s, but just as quickly was aborted when adverse effects appeared and when it failed to prove itself the therapeutic tool that psychotherapists had promised. LSD and other antiserotonergics sometimes produce synesthesia. It is not a universal effect of the drug as many assume from their impressions of 1960s counter-culture, nor does LSD induce synesthesia every time it is ingested even if it has once done so.

Regrettably, much of our contemporary knowledge regarding LSD is anecdotal, with variation of response unreliable and complicated by factors such as dose inconsistency, purity, and chemical identity of illicit street preparations. Such problems can never be resolved, and the more reliable laboratory work done with both animals and humans will never be repeated. We have no option but to rely on what data we have. Reference to self-experimenters such as Aldous Huxley, Timothy Leary, and Carlos Castaneda is beyond the scope of this book, and interested readers may turn to Grof et al. (1973) and Grof & Halifax (1978).

Synesthetes perform in some ways reminiscent of nonsynesthetic volunteers under the influence of LSD (1) in their tendency toward concreteness (Fanchamps 1978; Hollister 1968; Silverstein & Klee 1957), (2) decreased productivity (Zialko 1959), (3) emotional significance (Finkel 1976), (4) vividness of percepts, and (5) vivid memory for the perceptual experience itself (Hollister 1968; B. L. Jacobs 1977; Siegel & West 1975). This vivid memory of dreamlike experiences and a marked emphasis on detail is evident in subjects’ drawings and recollections of their drug-induced perceptions.

The drug’s effect on visual perception and CNS integration is most interesting. The colored visions themselves seem paradoxical in view of increased thresholds for axonal responses beyond thalamic synapses, until you appreciate the facilitating effect of sensory inputs from other modalities on the evocation of visual hallucinations (i.e., synesthesia). Almost all measures of color perception are affected in humans given LSD. Particularly noteworthy is the increased elicitation of subjective colors by stimuli that only rarely evoke color percepts (flicker fusion) or usually never do (pure tones). The combination of flicker and pure tones greatly increases visual effects, both patterns and colors, compared to flicker alone (Hartmann & Hollister 1963). The visual image suppresses alpha rhythm (Shirahashi 1960).
LSD is principally a serotonin antagonist. Inasmuch as serotonin is primarily an inhibitory neurotransmitter, inhibiting its inhibition on a given cell by LSD allows the next neuron in the chain to elude inhibition, so to speak. The brain concentrations of its receptors are maximal in hippocampus, basal ganglia, thalamic nuclei, and cerebral cortex (Renkel 1957).

In general, serotonergic function, especially in the raphe, is conceived as dampening overactive neurons to various stimuli (external and internal). The result of inhibited function is to decrease the filtering of cognition, perception, and feeling. Therefore, mental and physical events are presumably experienced in a novel and less processed manner.

LSD has differential actions on central synapses: facilitation of primary evoked responses and inhibition of the recruiting responses (Purpura 1956a, 1956b, 1957). Purpura has explained this based on anatomical differences in synapses between the two neural arrangements. LSD facilitates the primary afferent axosomatic synapses while inhibiting corticocortical association and nonspecific mesodiencephalic axodendritic pathways. This may underlie the intellectual and behavioral disorganization so evident clinically inasmuch as LSD inhibits human cortical dendritic potentials in a manner similar to that recorded in cats (Purpura et al. 1957).

Electrodes implanted in both animals and humans reveal regional differences in EEG activity: (1) desynchronization in neocortex, suggesting arousal, and (2) synchronized, paroxysmal discharges in hippocampal gyri, amygdaloid nuclei, and septum (Bente, Itil, & Schmid 1957; Ingvar & Soderberg 1956; Monnier 1959; Vogt, Gunn, & Sawyer 1957). In humans, these subcortical paroxysmal discharges, which are not reflected in the surface electrodes, coincide with emotional change or perceptual distortion (Monroe et al. 1957). Perhaps a stimulated limbic system in the face of disinhibited neocortical integration results in a subject who cannot discriminate but who is prepared to respond emotionally (Bridger 1960). As some of the earlier theories suggested, emotional meaning might be a relevant linkage in synesthetic perception.

Physiologically, LSD induces a suppression of corticocortical connections with corresponding facilitation of the direct lower-level specific afferents (Purpura 1956a, 1956b, 1957; Purpura et al. 1957). The antiserotonergic action of LSD may be plausibly related to its effect of rendering the cortex less responsive to reinforcement, and thus more responsive to external stimuli (S. Cohen 1970; Hollister 1968; Messing et al. 1978; Weil-Malherbe 1977). The negative action of increased brain serotonin in interfering with learning and in disrupting memory consolidation, dream recall, and novel task performance might account
for the memorability of the synesthetic percept (Essman 1977; Fibiger, Lepaine, & Phillips 1978). At present, fourteen types of serotonin receptors are known.

As table 2.2 in chapter 2 shows, five of the current subjects have taken LSD in the past. Only one (MM) had his spontaneous synesthesia intensified while under the drug’s influence. Three subjects experienced no synesthesia with the drug. Although LSD did not induce synesthesia in a fourth patient (MW), he feels that he was “hypersensitive” to it, experiencing “sensory overload” on one-fourth the dose considered standard (in 1971) among his confreres. MW has vivid memories of the three occasions when he ingested the drug. Compared to his pleasurable synesthesias, however, LSD made him dysphoric, which is why he avoided it.

Because ideas about possible neurotransmitters involved in synesthesia are deductions based on historical and animal work, they are speculative.

4.3 HYPERMNESIS

The vividness and memorability of synesthetic percepts, two of its defining characteristics, make them resemble eidetic imagery and other forms of hypermnesia—that is, mental reminiscences that revive the original percept with realistic clarity. Specifically in this regard, eidetic images, so easily and vividly remembered, are precisely so on account of their semantic vacuity. That is, they carry little semantic or emotional baggage, but rather are reproducible in their original form.

4.3.1 Luria’s Patient, S

An interesting aspect of eidetic imagery is that it has some percept-like qualities and some memory qualities, and yet is qualitatively distinct from both. The relationship between synesthesia and elevated memory is especially familiar in Luria’s classic case of S (1968). (See also the subject by Reichard et al. (1949), who came to those authors’ attention via a class assignment on the topic, “How I Memorize.”) S was unavoidably synesthetic for the experiences of daily life. No distinct line separated vision from hearing, or hearing from a sense of touch or taste. He could not prevent the translation of sounds into shape, taste, touch, and color.

Presented with a tone pitched at 2,000 cycles per second and having an amplitude of 113 decibels, S said: “It looks something like fireworks tinged with the pink-red hue. The strip of color feels rough and unpleasant, and it has an ugly taste—rather like that of a briny pickle … you could hurt your hand on this.” (Luria 1968, p. 23)
This same synesthesia enabled him to visualize vividly each word or sound that he heard, whether in his own tongue or a foreign language unintelligible to him. The thing to be remembered was automatically converted into a visual image of such durability that he could remember it many years after the initial event. So specific was his ability that the same stimuli would invariably produce the same synesthetic response, although the synesthetic experience itself was always secondary to his recall. There was no limit to the capacity or durability of the traces he retained. As Luria put it, his memory was limitless and without distortion.

... I recognize a word not only by the images it evokes, but by a whole complex of feelings that image arouses. It’s hard to express ... it’s not a matter of vision or hearing but some over-all sense I get. Usually I experience a word’s taste and weight, and I don’t have to make an effort to remember it—the word seems to recall itself. But it’s difficult to describe. What I sense is something oily slipping through my hand ... or I’m aware of a slight tickling in my left hand caused by a mass of tiny, lightweight points. When that happens, I simply remember, without having to make the attempt. (Luria 1968, p. 28)

S’s inability to suppress these synesthetic percepts was often so severe as to make it difficult for him to attend to the semantic and meaningful qualities of a verbal discourse. An earlier example of synesthesia was of this man, S, seeing a yellow voice with protruding fibers and being so overwhelmed by the perception that he could not understand what was being said to him. He became “trapped” in a synesthetic tangle of evoked percepts, mostly visual, whenever he heard a story. His images would guide his thinking, one picture leading to another, rather than thought itself being the dominant element. Although he could easily manipulate his eidetic images, he was quite inept at abstraction and generalization, at converting encounters with the particular into instances of the general, enabling one to form general concepts even though the particulars are lost.

Perhaps this occurs because the details of a visual experience are essentially unrepeatable, constituting a single episode, whereas the semantic abstractions from a given story are part of the currency of language and can easily be interfered with by subsequent events of daily life and living. Thus it is precisely the concrete level of intellectual processing, a level of encoding conceptually lower but richer sensorily, that appears to facilitate the vivid and long-lasting memory for discrete episodes.

There are sensory memories that can be evoked in hypnagogic reveries (Kubie 1943; Kubie & Margolin 1942). These memories merge into the kind of memory mediated by verbal symbols of past events, rather than through vivid sensory images. This is another example of how the semantic abstractions are part of the currency of language. Such memories are necessarily not concrete or vivid because, semantically, they
are generalizations. They stand nicely in contrast to the vividness of synesthesia, eidetic memory, and the “recollective hallucinations” of Penfield, what he also calls forced experiential responses to electrical stimulation of the brain.

Luria summarized S’s memory as

a striking example of spontaneous recall. Granted that he imparted certain meanings to these images which he could draw upon; he nonetheless continued to see the images and experience them synesthetically. He had no need for logical organization, for the associations his images produced reconstituted themselves whenever he revived the original situation in which something had been registered in his memory. (Luria 1968, p. 63)

### 4.3.2 Eidetic Memory

Most of the studies of eideticism are German. The German-born American neurologist Heinrich Klüver (1928, 1931, 1932, 1965) has been the principal reviewer of this work and Jaensch (1930) systematized its study. Few papers are cited after 1937 until the subject was revived by the Habers (Haber 1969, 1979; Haber & Haber 1964) who concluded that “no serious doubts were raised about the validity of eidetic imagery as a phenomenon, even though the methodology of assessment has been both poorly described and poorly executed. Eidetic imagery just ceased to excite scientists.” Also present was a climate of behaviorism that was against introspective topics.

Haber & Haber (1964) established criteria for determining eidetic images. Using colored squares on a neutral background, the examiner demonstrates afterimages so that the subject can distinguish an afterimage (which moves with eye movement) from an eidetic image (which does not). Unlike eidetic images, afterimages fade rapidly, require long fixation to create, and show negative (complementary) coloration. The Habers’ criteria for eidetic images are that an image (1) must be reported, (2) must be positively colored, (3) is projected onto the easel rather than being located in the head, (4) is described in the present tense, and (5) is associated with eye movements appropriate to the location of objects in the scene.

Many reports on eideticism are in children, and the Habers estimate some degree of eidetic ability (structural or typographic) in 8% of American elementary school children; they estimate the prevalence of strong (typographic) eideticism in adults at 0.1% My proband synesthete, MW, can form eidetic images after the method of Haber & Haber. Subjects MT, SdeM, and MP are also eidetikers.

Although eidetikers have excellent recall of visual detail, their performance is not necessarily discontinuous from the distribution of control subjects (Furst, Fuld, & Pancoe 1974). The same might be true of synesthesia.
Like synesthetes, eidetikers describe their images with spontaneity and conviction, giving the impression that they are genuinely seeing a stable, externally projected display. Gengerelli (1976) found stability of eidetic images in two subjects after 46 years. An example of verbatim eidetic recall is perhaps the best way to convey this. Pollen and Trachtenberg (1972) studied alpha rhythm and eye movement in Stromeyer and Psotka’s (1970) patient. While viewing a print of Chagall’s *My Village*, no alpha rhythm was present. Alpha rhythm was prominent and convergent eye movements were present when she described details from her eidetic image of the print. “The subject described the painting with a speed that could scarcely have been exceeded had she been looking directly at it.” Her description was as follows:

Horse and green man facing each other. Horse or cow. The man has a yellow hat with a red band. The horse is mostly pink and white except he’s blue in the neck just above the necklace he’s wearing. And under his eye is someone milking a cow. Up above this is another sort of sphere like thing. Heading back is a green man carrying a hoe, I think, and a girl standing on her head. Behind them are more houses. The one on the left is yellow. It’s upright. Then there is a red one upside-down, a blue one upside-down, a blue one right side up, and then a yellow one right side up. There’s a moon over that. The centre of the picture has a red sphere in it. Down in the bottom centre is a tree of some sort in a triangular shape with some little green blobs and a bunch of brown blobs in the branches. In the bottom left hand is mostly reds and pinks. Bottom right there’s some yellow and blue. The sky at the top is black. Anything else? (p 110)

This description was produced in 68 seconds, about the time it takes to read it. The subject made saccades in the direction of objects she described. She had normal alpha rhythm that blocked appropriately to eye opening or tasks requiring visual attentiveness. Of interest is the presence of large-amplitude posterior alpha rhythm when she scans or reads text from an eidetic image. Pollen & Trachtenberg noted that her speed and detail of recall indicate considerable concentration and mental effort, and cite their own work in noneidetikers showing that alpha blocking occurs with visual tasks that recall resolution or search for the finest detail rather than the fine detail itself. They suggested that the subject’s alpha rhythm during eidetic recall was understandable either if that recall did not require the finest details or if her access to fine detail did not require much searching of her memory.

The few attempts to discriminate eidetic from noneidetic subjects by strict laboratory methods have been remarkable. For example, Stromeyer & Psotka (1970) used Julesz’s random-dot stereograms—so well-known to vision researchers interested in depth perception—to test for clarity and duration of eidetic images (Julesz 1964, 1995). The subject must look monocularly in succession at two patterns of dots that fuse in stereopsis to produce an object that appears out of the viewing plane.
Noneidetic observers are unable to perceive the stereoscopic object when the two dot patterns are projected as little as 150 ms apart. Stromeyer & Psotka’s eidetic subject could accurately report the figure in detail when the interval between monocular observations was so great as 24 hours. She found the test “ridiculously easy.” The patterns are presented monocularly and the two eidetic images are fused to produce the stereoscopic appearance of a third image. Patterns with $10^4$ elements were employed at intervals up to 3 days, and patterns with $10^6$ intervals up to 4 hours, in a double-blind experiment. Reports of binocular rivalry support Stromeyer & Psotka’s interpretation that an eidetic image is represented before binocular fusion. Both Jaensch and Klüver found binocular color rivalry in an eidetic image built up from presenting a particular color chip to one eye and a different color chip to the other eye.

Stromeyer & Psotka’s eidetiker is also cited as being able to hallucinate “leaves on a barren tree, or a page of poetry in an unknown foreign language which she can copy from the bottom line to the top line as fast as her hand can write. These visions can often obscure a real object.” There is a report that the visual and auditory evoked responses are blocked during hallucinations, but the methodology is questionable (Schatzman 1981). It is known in neurology that one cannot perceive and hallucinate in the same visual coordinates (§9.5.3).

Stromeyer & Psotka’s subject examined the dot stereogram part by part, “frequently shutting her eyes to see if she has a good image of the part.” Luria’s patient used the same technique in making eidetic images of numeric tables. What an eidetiker actually does during eidetic recall is not clear. Stromeyer & Psotka’s subject recalled the image part by part rather than as a gestalt, some of the stereoscopic images taking up to 10 seconds to construct. Nor is it necessary for the stimulus images to be in sharp focus, an observation reminiscent of Land’s 2-squares-and-a-happening experiment for edge detection (figure 4.1) (Land & McCann 1971). As a perceptual trait, “edge” implies discontinuity and is an Aristotelian common sensible not restricted to vision. Recall how DS spoke of her photisms going off the edge of her “screen” and that MW spoke of his shapes receding past the edge of a tactile “plane” stretched before him. When we speak of spatial extension in chapter 5, recall that edge is as much concept-driven as it is stimulus-driven.

What makes the Stromeyer-Psotka data appealing is that electrophysiologic evidence supports the experimental reports of Klüver, Luria, and other neuropsychologists. Similarly, the eye movements recorded by Pollen & Trachtenberg support the observations by others of saccadic movements when subjects read an eidetic image of text.

Some, like Gray & Gummerman (1975), object that eidetikers simply use more intense imagery than that possessed by the majority of people. Haber (1979) reviewed the conflicting interpretations. Miller &
Peacock’s (1982) otherwise good review fails to criticize Gray & Gum-merman for using a scaled-down version of the Julesz dot stereogram as a so-called objective measure of eideticism. Eidetikers identified by Haber’s criteria failed this simplified task, which was then cited as evidence that eideticism does not exist. Julesz (1964, pp 357, 360–361) cautioned that stereopsis is hard to obtain when superimposing coarse gradient patterns with few pixel elements.

4.3.2.1 Eideticism and Synesthesia Seventy-odd years ago, Jaensch (1930) discussed both eideticism and synesthesia under a rubric he termed the “integrated” personality type. Glicksohn et al. (1999, 1992) have more recently studied the relationship between synesthesia and eideticism, suggesting that both groups have the common characteristic of cognitive dedifferentiation (what Baron-Cohen et al. [1993] called

Figure 4.1 Land’s 2-squares-and-a-happening experiment. Place a pencil over the boundary between the two gray areas. The right-hand paper reflects 80% of the light; the left-hand one 40%. A light at the left of both casts twice as much light on the center of the 40% paper as on the center of the 80% paper, producing a linear gradient across the papers. The reflected luminances at corresponding points of the papers are equal. Yet the left 40% paper looks darker than the right 80% one.

When a narrow object, a “happening,” obstructs the boundary, the two appear to have the same lightness. The only alteration is the viewer’s obscuration of the edge. The change in luminance at the junction between areas constitutes an edge and leads to a visual difference between the whole two areas. Although the word “edge” suggests a sharp in-focus boundary, a boundary severely out of focus looks the same. (From Land & McCann [1971] with permission.)
“a breakdown of modularity”). For example, synesthesia entails the
dedifferentiation of sense modalities, whereas eidetic imagery entails
the dedifferentiation of imagery and perception. Using a technique pre-
viously employed for identifying child eidetikers (Harris & Richardson
1986), they screened twenty-nine adults for both dispositions. In seek-
ing a common psychological attribute that might lead to both traits,
they found that psychic absorption was marked in the experience of
both topographic and structural eidetikers, but not in the experience of
colored-hearing synesthetes. Individuals scoring high on the absorption
scale showed a negative correlation between structural eidetic imagery
and color-mood synesthetic differentiation. Prudent interpretation of
these results is in order given the researcher’s reliance on question-
naires and the lack of a verification mechanism for either the synes-
thetic or eidetic trait.

Dann (1999) explored the eideticism of Vladimir Nabakov in detail.
Nabakov is comparable to Luria’s S in being both synesthetic and
hypermnestic. Nabokov’s writings about alphanumeric chromaticism
are so voluminous as to leave little doubt that he is synesthetic. First
appearing at age 7, his trait is automatic, durable, memorable, spatially
extended, and pleasurable (Johnson 1985). Nabokov’s novels are noto-
riously autobiographical, so it is small surprise that he endows several
fictional characters with synesthesia. Among them is Van in Ada who
describes how color and number forms help him remember. “Synes-
thesia, to which I am inordinately prone, proves to be a great help in
this type of task” (Nabakov 1969, p 584).

As Dann points out, “I see myself,” “I see,” “I note,” and “I distin-
guish” are recurring phrases in Nabakov’s lexicon—and note the use
of the present tense, an eidetic characteristic. Nabakov’s eidetic recall
is a recurring subject in his autobiography, Speak, Memory, where he
explains, “I witness with pleasure the supreme achievement of mem-
ory, which is the masterly use it makes of innate harmonies when
gathering to its fold the suspended and wandering tonalities of the
past.” In passage after passage, the past comes back to him in the same
spatial-temporal perspectives as when he first experienced it. Chess
games, for example, are repeatedly recounted with visuospatial specific-
ity in his novels. He refers to eideticism throughout his works, such
as in the poem “Pale Fire” where he claims that he can “order” “pho-
tographs” to be taken, and can “reproduce” their exact image later on
(Nabokov 1962, p 34). For Nabakov, letters possessed not only hue
and luster, but also personality in a manner similar to MT and other
subjects.

MP’s “memory maps” (to be discussed in §5.7) at first seem impres-
sive examples of spatially extended number forms until one appreciates
that her mental “card catalog” is in fact a collection of concrete eidetic
images. The noted autistic veterinarian Temple Grandin (1995, p 25) reveals much the same limitation in discussing her mental catalog of Great Danes, namely, that “there is no generic, generalized great Dane,” but that her mind is full of specific exemplars. Thus, a concrete specificity seems to be common to autism, eideticism, and synesthesia.

Based on various sources, Dann concludes that “what makes the eidetic image so powerful is that the original affect is also restored to the viewer, who re-experiences the emotional quality that infused the earlier perception of the scene, person, or object” (1998, p 143).

Conceptually, both synesthesia and eideticism represent a collapse of categories. In synesthesia, a perception exhibits two or more qualia at once, whereas in eideticism memories are seamless, with no past, present, or future. Dann cites numerous instances wherein Nabakov portrays eideticism in his writing. For example, in describing the capture of his first butterfly in Speak, Memory, he begins with the creature’s perch on a honeysuckle at his family’s summer home in 1906 and ends on a dandelion beneath an aspen in Colorado two decades later. Even so noted an objectivist as Francis Galton commented on the dissolution between past and present when discussing his own eidetic memory. “In short, this experience has given me an occasional feeling that there are no realities corresponding to Past, Present, and Future . . . I suspect that you have felt the possible truth of this so vividly as it has occasionally appeared to my imagination through dwelling on these ‘Memories’” (Galton 1909, pp 277–278).

The difficulty distinguishing between reality and memory is precisely what Luria’s S complained of. “To me there’s no great difference between the things I imagine and what exists in reality” (Luria 1968, p 146). Reality was a fluid entity: the taste of restaurant food changed with the music being played, or he could not eat and read the same time because the food’s flavor intruded into his perception of the written words. Purdy (1936) also reports the same confusion in a woman who is both synesthetic and eidetic. Perceptual confusion has also been noted in polymodal or bidirectional synesthetes who are not eidetic (Ulrich 1903; Baron-Cohen 1996).

S lived in a concrete world. Because homonyms sounded alike and therefore evoked the same synesthetic associations, he could not distinguish them. Synonyms confused him for the same reason: how, for instance, could “distinguish” and “discern” mean the same thing when their sounds produced such disparate sights, smells, tastes, and touches?

4.3.3 Synesthesia and Memory in Current Patients

One of the defining characteristics of synesthesia is that the parallel sense is memorable. Inspection of table 2.2 in chapter 2 shows that 37 of
42 subjects judge their memory to be above average or excellent. Commentary regarding the utility of synesthesia as a mnemonic device were related in chapter 3.

Four of the current subjects studied with the revised Wechsler Memory Scale scored in the superior range (DS, 101; JM, 143; MT, 135; MW, 143). Reasons for the average score of DS are discussed below in her results of neuropsychological testing. An additional subject, MLL, happened to be a normal volunteer in the study of memory performance and aging at the National Institutes of Health. At age 50 years she scored in the superior range on a name-face association test (including delayed recall), recognition of faces (with 40-minute delay), a misplaced objects recall, a news story recall, and a delayed nonmatching task.

4.3.4 Memory of Synesthesia

In chapter 1, I related the anecdote of how MW’s comments that the roast chicken did not have “enough points” brought his synesthesia to my attention. Seven years after that eventful dinner, MW and I happened to be again dining on roast chicken. I pointed out the coincidence and misquoted his initial description by saying that there were too many corners. MW corrected me, claiming to remember the original stimulus.

I corrected you by saying “it was too round, it needs more points” because that’s what it was, uniformly round and it needed more points. I remember the shape, not the anecdote. I remember being disappointed with the chicken because it was too round. I tasted it and I couldn’t serve it. I had to fix it. I had to give it points.

It is not the anecdote or a verbal description that MW remembers, “it’s the taste, particularly the shape.”

4.4 RELEASE HALLUCINATIONS

Release hallucinations are perceptions in any modality that occur in a deafferented field. Visual and auditory ones are most common. In vision, for example, individuals see elementary or categorical objects in a scotoma or hemianopic field (figure 4.2). Lance explains the term categorical and expresses the opinion that release hallucinations arise from association cortex. “The hallucinations are not of great complexity, suggesting that the function of the association cortex is to group images into categories of person, animal or thing, leaving the final identification to a further stage involving links with the temporal lobe and limbic system to incorporate knowledge from memory stores” (Lance & McLeod 1981, p. 327; Lance 1986). Visual release hallucinations can wander out into the nonscrotomatous field. They are experienced
in extrapersonal space, and patients always appreciate their unreal nature.

Primary idiothetic cortex has no direct links with other cortical areas except through obligate relays via unimodal association cortex that lies adjacent to it. Stimulation of association areas or their temporal-limbic projections gives rise to formed hallucinations that are “seen,” “heard,” or otherwise sensed in the external receptive field that is impaired by damage to the upstream sensory neocortex, as though the association area were released from its normal afferent input from primary idiothetic cortex (Brust & Behrens 1977; Cogan 1973; L. Jacobs et al. 1981; Lance 1976; T. C. Miller & Crosby 1979).

The performance of synesthetic subjects may be seen as involving a suppression of a rich corticocortical association, which leaves the more unelaborated sensory percept (such as synesthesia, an eidetic image, or

**Figure 4.2** Categorical release hallucinations. This patient’s category of hallucination was animals, which appeared one at a time in the “blind” area of his visual field. *Elementary* release hallucinations, looking similar to synesthetic percepts, also appear in deafferented fields. (From Lance & McLeod [1981] with permission.)
a hallucination) to be directly associated at some lower level. Having considered these theoretical issues and some perceptual experiences similar to synesthesia, let us turn now to clinical examples.

### 4.4.1 Clinical Examples

Brust & Behrens (1977) reported in detail two patients with release hallucinations in their paracentral scotoma. The first patient’s hallucinations persisted for just 2 weeks during the 18 months she was followed. Her visual field defect remained stable during that time. (Generations ago hemianopias were examined more frequently and more attentively than they are today; the appearance of a hallucination in or encroaching on the blind field was a strong characteristic distinguishing organic hallucinations from psychiatric ones.) During these 2 weeks, the stimuli that precipitated the patient’s hallucinations were quite restricted: watching television or reading a book. The apparitions would abruptly disappear whenever she ceased these activities, only to reappear promptly when she resumed. She saw “four or five men, variably dressed (two or three in business suits, one in a cowboy’s suit and hat, one in a plaid shirt) moving about, not speaking and not relating to one another.” She could not make out their faces: “It was as if they were in shadows.” The hallucinations were not frightening.

Brust & Behrens’s second patient, who had a large fixed left homonymous paracentral scotoma, experienced hallucinations for a year and a half. Computed tomography showed a right posterior temporal lucency. The hallucinations were of three kinds: (1) simple synesthesias of perpendicular red-and-green lines, red-and-blue spots, and black-and-white pulsations, (2) metamorphopsia, with the lines and spots appearing to move toward him, and only the right half of faces appearing to melt and display a yellow or violet tint, and (3) palinopsia, such as people walking across his scotoma. A palinopsia is a visual perseveration (Bender, Feldman, & Sobin 1968). Teuber (1961) described palinopsia in which the image multiplied, and also noted it after LSD or mescaline ingestion. Kinsbourne & Warrington (1963) give other examples of this phenomenon.

A somatic hallucination that mistakenly bears some resemblance to release hallucinations is the phenomenon of alloesthesia, a condition in which a noxious sensory stimulus given on one side of the body (where there is a sensory deficit) is perceived at the corresponding site on the other side. This has been shown in patients with putaminal lesions as well as anterolateral lesions of the spinal cord. It represents an elementary disturbance of sensory pathways and not a higher cortical dysfunction (Kawamura et al. 1987).
4.5 SIMPLE SYNESTHESIA AND DEAFFERENTATION

Experiments with sensory deprivation show that loss of afferent input leads to psychotic thinking (Gordon 1994), perceptual distortion, and hallucination. Milder degrees of deafferentation (cataracts, peripheral neuropathy, or hearing loss) lead to less florid results (Patel, Keshavan, & Martin 1987). Even simple boredom can produce hallucinations (Heron 1957). Normally, the brain is constantly being bombarded with sensory input, some of which is relevant but most of which is filtered out via “selective attention.” The brain is not a sessile blob, some passive observer sitting there waiting for sensory data to strike, but an active party in seeking out the stimuli that it wants. At multiple levels throughout the integrated nervous system, recurrent collaterals effect inhibition of competing synapses. This negative feedback is equivalent to raising the signal-to-noise ratio, which sharpens discrimination. What few physiologic studies exist suggest an association between hallucination and EEG activation (Hayashi, Morikawa, & Hori 1992).

Studies of sensory deprivation (Beaton, Heron, & Scott 1954; Heron, Doane, & Scott 1956; Siegel 1984) in normal subjects reveal a progression from mild to severe hallucinations. Visual hallucinations at first are simple and consistent with Klüver’s form constants (geometric patterns, mosaics, lines, and rows of dots as described below in §4.11), later becoming more complex and dreamlike, involving bizarre juxtapositions of people and objects. On emerging to a normal environment the subjects continue to experience metamorphopsia and perceive an “unnatural brightness of colors.” Siegel and West suggested that “new information inhibits the emergence and awareness of previously processed information. If the new input is decreased or impaired while awareness remains, stored images may be released and experienced as hallucinations or dreams” (Siegel & West 1975, pp 287–311).

EEG alpha rhythm activates before and during hallucinations evoked by sensory deprivation (Hayashi et al. 1992).

The sensory-deprived brain starts perceiving things that are not there. Lacking input, the brain starts projecting an external reality of its own. Evarts (1957) was one of the first to note a possible relationship between disruption of input and the very occurrence of disinhibition of the special senses (particularly vision). This situation is not as rare as it might at first seem. A common experience occurs in the shower. When the auditory system is deafferented, sensorily deprived by the white noise of the shower, how often have you hallucinated that the phone was ringing or that someone was calling your name?

L. Jacobs & colleagues (1981) studied nine patients who had anterior visual loss due to optic nerve or chiasm disorders. All patients had photisms induced by sounds that often startled them. These were usually sounds of daily life and appeared to come from the ear ipsilateral
to the eye in which the photisms seemed to be seen. Sounds included clanking of the radiator, crackling of the wall as it cooled at night, the whoosh of a furnace ignition, a dog’s bark, and slamming doors (see table 4.1 and figures 4.3 and 4.4).

The photisms ranged from simple flashes of white light to colored forms that looked like a flame, amebas, oscillating flower petals, a spray of bright dots, or kaleidoscopic effects. All patients’ photisms lasted only “a split second, an instant.” Some patients had a single stereotyped photism while others experienced multiple photisms.

It is of some interest that the photisms were perceived to arise in one eye and to be induced by sounds that were heard only with the ipsilateral ear. This, of course, is contrary to our usual understanding of physioanatomy in vision and hearing. We are unable to tell which eye is seeing an object unless we cover first one and then the other to determine that only one eye, in fact, can see a certain object (such as when the nose is in the way or when objects appear in the nonoverlapping temporal field). Acoustic localization of objects depends on differences in the sound reaching both ears. Yet

the click of an electric blanket thermostat induced a flashbulb photism in the right eye of patient 6 only when the thermostat located to her right clicked; the same clicking from her husband’s thermostat located to the left never induced

---

**Table 4.1  Characteristics of sound-induced photisms**

<table>
<thead>
<tr>
<th>No.</th>
<th>Photism appearance</th>
<th>Color</th>
<th>Location</th>
<th>Sounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flame, flashbulb</td>
<td>Red-orange, white</td>
<td>In scotoma</td>
<td>Not sure (sharp)</td>
</tr>
<tr>
<td>2</td>
<td>Spray, pollywogs, kaleidoscope</td>
<td>White, pink, red, black, green</td>
<td>In and out of scotoma</td>
<td>Clap, CT gantry</td>
</tr>
<tr>
<td>3</td>
<td>Flash</td>
<td>White-yellow</td>
<td>In scotoma</td>
<td>Walls crackling, digital clock, TV crackling</td>
</tr>
<tr>
<td>4</td>
<td>Lightbulb</td>
<td>White-blue</td>
<td>In scotoma</td>
<td>Not sure (soft)</td>
</tr>
<tr>
<td>5</td>
<td>Flash</td>
<td>White</td>
<td>In and out of scotoma</td>
<td>Engines, loud sounds</td>
</tr>
<tr>
<td>6</td>
<td>Flashbulb</td>
<td>White</td>
<td>In scotoma</td>
<td>Electric blanket, digital clock</td>
</tr>
<tr>
<td>7</td>
<td>Petal, ameba, goldfish</td>
<td>Pink, white, yellow</td>
<td>In and out of scotoma</td>
<td>Furnace, dog, voices, clatter</td>
</tr>
<tr>
<td>8</td>
<td>Plaid</td>
<td>Green</td>
<td>In scotoma</td>
<td>Book or fist on desk, loud</td>
</tr>
<tr>
<td>9</td>
<td>Flashbulb</td>
<td>Pink</td>
<td>In and out of scotoma</td>
<td>Furnace, door slam, TV, radio</td>
</tr>
</tbody>
</table>

From L. Jacobs et al. (1981), with permission.
the phenomenon. A petal photism was perceived coming from the right eye of patient 7 when a nurse spoke into his right ear. The photism never occurred when the nurse spoke into his left ear. (Jacobs et al. 1981)

The monocular visual evoked response from the scotomatous eyes showed conduction delays and reduced amplitudes. Spontaneous visual phenomena (SVPs) are common, occurring in nearly 60% of individuals whose visual loss is pregeniculate; 35% of individuals with postgeniculate lesions (as in synesthesia) had elementary SVPs (Lepore 1990). Yet positive symptoms must be specifically sought, because patients are reluctant to reveal “crazy” symptoms. SVPs can occur when visual loss is trivial (as in Lepore’s three pseudotumor cerebri patients whose acuity remained 20/20), though their frequency rapidly increase as acuity

Figure 4.3 Visual fields, with scotomata indicated in black. (Top) Nasal defect of left eye visual field. (Bottom) A flame photism was induced by “sharp” sounds. (From Jacobs et al. [1981] with permission.)
worsens past 20/50. Elementary visual experiences are more common than complex ones (table 4.2).

The present task is to investigate and, hopefully, explain the idiopathic synesthesia that spontaneously occurs in individuals without discernable CNS lesions. What the examples of release hallucinations and simple synesthesia in the setting of deafferentation can provide is help in suggesting a level of the neuraxis at which idiopathic synesthesia may operate.

The facts regarding these patients with sound-induced photisms are that (1) they have lesions of the retinal ganglion cells (third-order neurons) resulting in (2) supersensitivity of the lateral geniculate neurons, which are retinotopic. The superior colliculus is a fourth-order visual neuron and also retinotopic and could well become supersensitive too. Supersensitivity would be greatest in those geniculate cells that are partially deafferented, explaining the occurrence of the photism in the scotoma. The anatomical basis for supersensitivity seems to be axon sprouting, a well-known feature of partially deafferented postsynaptic fields (Cunningham 1972; Echlin & McDonald 1954; Goodman & Horel 1966; Merril & Wall 1978; Sharpless 1969).

The lateral geniculate normally responds to sound as well as to light, a fact not widely appreciated (Arden & Soderberg 1959; Stein & Arigbede 1972). Paul MacLean (1970, 1975, personal communication, 1981) similarly found via microelectrode recording that what we normally consider a “visual” neuron will in fact respond to stimulation from another mode, such as a sound or touch (Buser & Imbert 1961; Horn 1965; Murata, Cramer, & Bach-y-Rita 1965). Multimodal cells also exist in subcortical entities such as the caudate and red nucleus (Fessard 1961), the cuneate nucleus (Atweh et al. 1974), and the trigeminal nucleus (Dubner 1967). Afferent impulses also converge on single cells in the

Figure 4.4 (Left) Entire left field is variably defective with anopsia, achromatopsia, and dyschromatopsia. (Center) “Petal” photism. (Right) “Ameba” photism. (From Jacobs et al. [1981] with permission.)

4.5. Simple Synesthesia and Deafferentation
reticular formation (Scheibel et al. 1955). Dräger & Hubel (1975) reviewed the visual, auditory, and somatosensory inputs to the superior colliculus in animals. The convergence of multiple senses makes it evident that one important function of the superior colliculus is concerned with shifting attention and with orienting the head, ears, and eyes toward a stimulus. Both bimodal and trimodal cells exist in deeper layers, arranged in clusters rather than segregated into sublayers. They exhibit little habituation to repeated stimulation.

Cellular response to a so-called alien modality is not all-or-nothing but a question of the degree to which a cell responds robustly to a specific modality and not very much to other kinds of stimulation. That supposedly modality-specific cells respond to other modalities would seem to be the essence of synesthesia. That single cells respond to multiple kinds of stimulation is not a sufficient fact to explain synesthesia.

<table>
<thead>
<tr>
<th>Table 4.2</th>
<th>Spontaneous visual phenomena (SVPs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Content and frequency of SVPs in individuals with visual loss</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Lesion site</strong></td>
<td><strong>No. SVPs</strong></td>
</tr>
<tr>
<td>Retina</td>
<td>4</td>
</tr>
<tr>
<td>Optic nerve</td>
<td>29</td>
</tr>
<tr>
<td>Chiasm or tract</td>
<td>1</td>
</tr>
<tr>
<td>Postgeniculate</td>
<td>11</td>
</tr>
<tr>
<td><strong>SVP content</strong></td>
<td><strong>No. of patients</strong></td>
</tr>
<tr>
<td>Elementary</td>
<td></td>
</tr>
<tr>
<td>Mobile photopsias</td>
<td></td>
</tr>
<tr>
<td>Achromatic</td>
<td>23</td>
</tr>
<tr>
<td>Chromatic</td>
<td>7</td>
</tr>
<tr>
<td>Stationary photopsias</td>
<td></td>
</tr>
<tr>
<td>Achromatic</td>
<td>13</td>
</tr>
<tr>
<td>Chromatic</td>
<td>5</td>
</tr>
<tr>
<td>Diffuse color or glow</td>
<td>4</td>
</tr>
<tr>
<td>Geometric forms (lines, waves, ring, spots, smoke, snowflakes, egg crate, rolling bar)</td>
<td>13</td>
</tr>
<tr>
<td>Multiple types of elementary SVPs</td>
<td>9</td>
</tr>
<tr>
<td>Complex</td>
<td></td>
</tr>
<tr>
<td>People</td>
<td>13</td>
</tr>
<tr>
<td>Faces or body parts</td>
<td>7</td>
</tr>
<tr>
<td>Animals or insects</td>
<td>5</td>
</tr>
<tr>
<td>TV or movies</td>
<td>3</td>
</tr>
<tr>
<td>Vehicles</td>
<td>2</td>
</tr>
<tr>
<td>Clothing</td>
<td>2</td>
</tr>
<tr>
<td>Palinopsia or polyopia</td>
<td>2</td>
</tr>
<tr>
<td>Miscellaneous objects (jars, numbers, lamp, steps)</td>
<td>5</td>
</tr>
<tr>
<td>Multiple types of complex SVPs</td>
<td>12</td>
</tr>
</tbody>
</table>

From Lepore (1990), with permission.
Stein & Meredith (1993), for example, summarized much research regarding a “merging of the senses” in the connotation of such multisensory cells. Sensory convergence at the single-cell level is a topic qualitatively different from synesthesia. Still, their book is a useful summary of sensory convergence at the cellular and nuclear levels.

Intriguingly, all nine of the patients of Jacobs et al. startled at the photisms’ appearance. It is well-known that startle responses produce ponto-geniculo-occipital (PGO) spikes, that is, brief discharges in the geniculate as well as other portions of the visual system (Bowker & Morrison 1976; Groves, Wilson, & Boyle 1974).

What these cases suggest, therefore, concerning a hoped-for explanation of idiopathic synesthesia, is a functional level above third-order neurons (geniculate) but below unimodal (e.g., calcarine) cortex. The present level centers on the brainstem, an intermediate level in accordance with earlier theoretical predictions.

Miller & Crosby (1979) reported on musical and verbal hallucinations in a woman with progressive hearing loss. She had no mental disturbance. The hallucinations were disturbing only in their monotony and persistence. The opinion that such hallucinations result from deafferentation has not changed in over 100 years (Coleman 1894; Ross et al. 1975). Patel et al. (1987) described vivid visual and musical hallucinations in an elderly woman with visual impairment.

Finally, in this group of phenomena I must mention the Charles Bonnet syndrome of visual hallucinations in persons with visual loss (Berrios & Brooke 1982; Rolak & Baram 1987; Rosenbaum et al. 1987; Teunisse, Zitman, & Raes 1994; Teunisse et al. 1995, 1996). Affected individuals are otherwise normal and not in a setting of sensory deprivation, except inasmuch as low vision itself can be an instance of sensory deprivation. The syndrome is characterized by hallucinations that are exclusively visual and highly detailed, such as people and scenes. Patients are not psychotic and remain quite aware that they are hallucinating. The hallucinations are unemotional and nonthreatening, disappear on eye closure, and are brief. They occur in a setting of visual loss: macular degeneration, cataracts, glaucoma, or other acquired causes of reduced acuity.

Although usually affecting elderly persons, the syndrome can occur at any age; indeed, Schwartz & Vahgei (1998) described it in children who underwent rapid visual deterioration between ages 6 and 8 years. Formed visual phantasms included geometric shapes, people, and buildings; the images were both stationary and in motion.

Concerning the issue of sensory deprivation in the Charles Bonnet syndrome, a number of factors seem able to stop the hallucinations—most of which have to do with general arousal (Schultz & Melzack 1991). Historically, the syndrome has been notorious for its lack of response to various medications, especially antipsychotics. Recently,
however, antiserotonergic agents such as cisapride, carbamazepine, and butyrophenone have been successful (Batra, Bartels, & Wormstall 1997; Ranen, Pasternak, & Rovner 1999; Gorgens & Liedtke 1990).

The detail of these hallucinations bears no relationship to the categorical features of synesthesia or release hallucinations by virtue of their complexity. I mention them here only because they are sometimes confused with synesthesia, but the Charles Bonnet syndrome remains a distinct clinical syndrome related to ocular disease.

4.5.1 Simple Synesthesias With Gross Brainstem Lesions

Vike, Jabbari, & Maitland (1984) reported a patient who acquired auditory-visual synesthesia ipsilateral to a large cystic tumor of the left medial temporal lobe and adjacent midbrain. The patient had normal vision, and the synesthesia resolved after removal of the mass. This patient is of extreme interest because (1) he had normal vision (acuity, pupillary response, color plate and Farnsworth–Munsell 100 hue discrimination, direct ophthalmoscopy, tangent screen and Goldmann perimetric fields, visual evoked response, and slit-lamp examination with Hruby lens); (2) his synesthesia was stimulus-dependent and could be manipulated (increasing click rate at a constant 65 dB altered the intensity and movement illusion of his photisms); (3) his hearing was normal (audiometry and brainstem auditory evoked response); (4) he believed the photism came only from the left eye and only when clicks were presented to the left ear; (5) he had a postchiasmal cystic tumor of the left medial temporal lobe extending to the midbrain; and (6) his synesthesia could not be induced following removal of the tumor.

Cascino & Adams (1986) presented three patients with brainstem auditory hallucinosis who had intact cochleae, cochlear nuclei, and auditory nerves similar to the patient above. These patients had lesions at the level of the pontine tegmentum. Although Cascino & Adams drew an analogy with the brainstem peduncular hallucinosis of Lhermitte (Dunn, Weisberg, & Nadell 1983), the dreamlike quality seen in peduncular hallucinosis was not evident in their patients. In his characteristically terse style, Raymond Adams summed up an attempt to give a clinicoanatomical explanation of this disorder: “knowledge of the physiology of ascending and descending auditory centers is too meager . . .” (Cascino & Adams 1986).

Nashold (1970) reported the elicitation of phosphenes on stimulating the human superior colliculus. The flashing lights were “white or cold,” and arranged in straight or wavy lines, off-center, in the contralateral field from stimulation, and superimposed on the visual scene. Adams & Rutkin (1970) achieved similar results with direct stimulation of subcortical limbic structures.
4.5.2 Synesthesia During Meditative States

Formal meditative states such as in Zen or Yoga are states of reduced afference, and thus qualitatively akin to states of sensory deprivation. In asking whether synesthesia can be cultivated, Walsh (submitted manuscript) turns to three groups of Buddhist meditators with different lengths of meditative practice: (1) Tibetan retreat participants, (2) physicians in a Vipassana cohort, and (3) teachers from three Buddhist schools (Theravadin, Tibetan, and Zen).

Synesthesia was experienced by 35%, 63%, and 86% of meditators in each respective group. Length of meditative experience correlated with an increase in synesthetic perception. For example, as a group, retreat participants were most naïve; yet within the group, those who did experience synesthesia had nearly twice as much meditation experience as nonsynesthetes, a difference significant for years of practice ($p < .05$) but not for time spent in retreat ($p > .1$). Neither was the disparity due to differences in age. Compared to a possible incidence of 0.4% as determined by the population studies discussed in §2.8.2, the incidences reported above by meditators is two orders of magnitude greater. Within the most experienced group of teachers, 57% experienced polymodal synesthesia.

Walsh argues a commonly held opinion that meditation training induces perceptual change inasmuch as meditation has been experimentally demonstrated to enhance perceptual sensitivity, and given that “refinement of awareness” is a central goal of established meditative tradition (Walsh 1999, 1977; West 1987; Brown & Engler 1986; Brown, Forte, & Dysart 1984; Shapiro & Walsh 1984). In my popular book on synesthesia, The Man Who Tasted Shapes, I argued that, “synesthesia is actually a normal brain function in every one of us, but that its workings reach conscious awareness in only a handful” (Cytowic 1993, p 166). Based on empirical observation, Walsh contends that awareness-enhancing techniques such as meditation may unmask an ever-present synesthesia to consciousness.

Walsh’s most intriguing observation is that the most experienced meditators reported concept-based or categorical-sensory amalgamations. That is, cognitive phenomenon such as “emotions, thoughts, and images” were experienced in sensory terms such as sound, taste, or touch. For example, emotions were experienced most often as touch, less so as taste or sound. One participant “tasted thoughts” whereas another experienced them as quivering “vibrations.” For yet another, “the thought of a friend can have the scent of frangipani.”

I related some of my own Sōtō Zen experience in The Man Who Tasted Shapes (Cytowic 1993, pp 172–182). Having read Walsh’s paper, I must concur with his observation regarding thought or emotion being experienced as physical touch. After a period of dedicated practice,
individuals learning meditation may find that physical sensations such as coldness, tingling, or distortion of a body part manifest suddenly and then subside. Standard teaching is that such phenomena are of no importance and can become distractions or impediments (makyō) if attended to. Above all, the student should not interpret them as indicating spiritual advancement or think them a sign of enlightenment known as a kenshō (satori) (Jiyu-Kennett 1976). I therefore paid no attention to such experiences wherein an arising thought or feeling was paired with a sense that my extremity was suddenly cold or numb, or a feeling that I was leaning over despite knowing that I was sitting up straight.

The apparent incongruity of calling the union of mental states with sensory ones “synesthesia” was addressed in chapter 2 regarding the attachment of color to categories. I revisit this issue in chapter 7. Several Eastern philosophies regard mental objects as sensory ones and vice versa, and have recognized polymodal synesthesia for over two thousand years. In Indian philosophy, for example, not only are the senses interrelated, but also combined with color, gender, and the devnagari alphabet. Accordingly, the alphabet is termed “varnamala” (varna = color, mala = garland) N. Y. Joshi, personal communication, 1989).

In the liturgy of Sōtō Zen, the sandōkai states, “Each sense gate and its object all together enter thus into mutual relations,” whereas the scripture of great wisdom (prajnaparamita) asserts:

O Shariputra, form is only pure,
Pure is all form; there is, then, nothing more than this,
For what is form is pure—and what is pure is form;
The same is also true of all sensation—thought, activity, and consciousness …
O Shariputra—in this pure there is no form, sensation, thought, activity or consciousness;
No eye, ear, nose, tongue, body, mind; no form, no tastes, sound, color, touch or objects … (Jiyu-Kennett 1990)

As Walsh comments, “To what extent these ancient claims represent accurate descriptions of very advanced meditation experiences, and to what extent they represent idealized extrapolations is unknown.” His observations, however, point out that meditators may be an untapped subject pool for studying synesthesia and cross-modal metaphors.

4.6 TEMPORAL LOBE EPILEPSY

Mention was made in the previous chapter of diagnosing medical conditions that are entirely experiential. The peculiar subjective experiences and perceptual distortions caused by temporal lobe epilepsy (TLE) were given as an example. It is important to remember that ictal
discharges of TLE can combine elements of smell, taste, vision, hearing, memory, and emotion (MacLean 1949; Penfield 1958).

The phenomena of TLE are well-known. The behavioral aspects of it were more a focus of attention in the 1940s and 1950s, particularly as the understanding of the limbic system and theories of emotion were developing. The papers of Papez (1937), Yakovlev (1948, 1970), and MacLean (1949) are of interest in this regard. Readers are assumed to be familiar with the current kinds of behavioral manifestations witnessed in TLE, including the so-called temporal lobe personality and multiple personalities (Bear 1983; Bear & Fedio 1977; Spiers et al. 1985). Readers not familiar with these manifestations can see Cytowic (1996, pp 231–239).

Little more remains to say than that synesthesia can be a rare manifestation of TLE. Since all association areas project to the temporal lobe, it is believed that this area integrates complex hallucinations with affect. I will say more regarding the temporal lobe and limbic anatomy in chapter 6 in discussing the evolution of these brain structures, their phylogeny, and their anatomy.

### 4.6.1 Clinical Examples

Jacome & Gumnit (1979) described an epileptic trimodal synesthesia involving vision, audition, and pain in a trigeminal distribution. The patient would hear the word “five” binaurally and then see the numeral 5 on a gray background projected in front of him; or he would hear the word “first” and then see it spelled in front of him. These phenomena were associated with a shooting pain in all three divisions of the trigeminal nerve on the right. His EEG showed slow-wave reversals at F3 and F7 (i.e., left temporal) and anterior temporal (T1) spikes on the left.

Jacome (1999) described another patient with epileptic synesthesia whose visual hallucinations were always stationary and confined to the upper temporal quadrant of her left eye. Furthermore, her hallucinations were miniature (“Lilliputian”). In this regard, her experiences are remarkably similar to the categorical release hallucinations depicted in figure 4.2. Dysmetropsia is the general term for the aberration of visual perception characterized by a modification in size of perceived objects. That is, objects appear either enlarged (macropsia) or shrunken (micropsia). Lilliputian, or smaller-than-life visual hallucinations, in color, and in the face of a clear sensorium, are typical of peduncular hallucinosis and therefore imply a lesion in the mesencephalon (Lhermitte 1922a, 1922b).

Ictal pain is exceedingly rare. Pain is sometimes a feature of synesthesia. Dudycha & Dudycha (1935) reported just such a patient with
“visual pain and visual audition.” Among the current patients, VE feels a sharp stabbing pain in her forehead on hearing high-pitched or shrill noises; DS sees a thin metallic line and gets a splitting headache when her children shout (recall the geometric pain of RB; see chapter 2, figure 2.4). In a series of 205 outpatients with closed head injury (Cytowic, Stump, & Larned 1987), three patients (1.4%) had photoalgesic or audioalgesic synesthesia or both. That is, they would experience hemi-cranial pain on seeing bright light or hearing a crashing sound “like gears grinding” or “banging on a pot.” Sometimes the pain would radiate into an arm or the trunk, but it always remained unilateral and was never segmental. Never was the head pain in a discrete distribution of the trigeminal or occipital nerves, even though traumatic occipital neuritis is extremely common in these patients (Cytowic 1990). Needless to say, we studied these patients in detail and found them normal in the conventional sense. Electrophysiologic studies were unrevealing. The only perceptual disturbance was found on Goldmann perimetry, in which they had some mild concentric narrowing and a slight nasal step defect.

I am unable to offer any mechanism for this phenomenon in the setting of closed head injury other than to say that it appears benign and in these three patients resolved within 6 to 9 months (Cytowic et al. 1987). Of course the biomechanical action of consequence in closed head trauma is a shaking injury of the brain wherein the maximal shearing force occurs at the brainstem-diencephalic junction—that is, at precisely the brainstem–temporal limbic level of which we have been speaking. Anatomically, the temporal lobes sit in the bony temporal fossae and nestle against the sharp edges of the dura, which explains their proneness to both surface contusions as well as tearing of long fiber tracts from rotational Strich shear-strain injuries (Strich 1956, 1961, 1970). Therefore, based on known pathophysiologic mechanisms of closed head injury, we can speculate that brainstem damage may be a mechanism of temporarily acquired synesthesia following such head injury (Parker 1990; Long & Williams 1988; Ommaya 1981; Cytowic et al. 1987).

Various synesthesias occur in temporal lobe seizures, such as the cases of Gowers (1901), whose patients had elaborate visual and auditory auras. One patient saw “beautiful places, large rooms” and heard at the same time “beautiful music.”

Olfactory hallucinations are supposed to be especially suggestive of TLE. Other than Luria’s subject, S, who sometimes had all five senses synesthetically engaged, and VE, in whom color induced smell, I personally know of no instances in which smell is the parallel synesthetic sense. In MW, olfaction can be the trigger for synesthesia and, as we have seen, some of the current patients (MW, above; SdeM in §§2.7.2 and 5.6.2.2) can remember specific smells, and ability that certainly
does not reflect common experience. For want of a better place I will mention here that high levels of carbon dioxide produce a pungent olfactory sensation reminiscent of gunpowder or rotten eggs. The phenomenon is termed “olfactory hallucination” but may affect senses other than smell (White et al. 1952). Such a phenomenon was seen in the degassing of Lake Nyos in Cameroon, a natural disaster that occurred in 1986. Survivors also reported feeling a sensation of warmth (Kling et al. 1987), which the authors considered hallucinatory. Gustatory and olfactory epileptic manifestations are usually categorized together and their rarity makes them difficult to study. Hausser-Hauw & Bancaud (1987) found gustatory hallucinations in 4% of 718 patients with seizures. In their series, there was a clear perisylvian distribution of the epileptic activity and frequent involvement of the amygdala and hippocampus. Tastes are usually not described in detail but in more general terms, such as “bitter,” “unpleasant,” or simply “a taste,” unless seizures involved the temporal lobe and suprasylvian regions at the same time. Then, the taste was often more specific (“rusty iron,” “oysters,” “artichoke”).

The role of the temporal lobe in the genesis of a gustatory sensation seems difficult to explain from an anatomical standpoint unless we allow that all five senses are represented in the hippocampus and insula. First-order taste neurons from the taste buds travel in the chorda tympani (a branch of the facial nerve) for the anterior two-thirds of the tongue; the lingual branch of the glossopharyngeal nerve serves the posterior third of the tongue; the greater superficial petrosal nerve, the palatal taste buds; and the superior laryngeal nerve (a branch of the vagus), the taste buds on the pharynx, larynx, and epiglottis. They synapse in the nucleus of the solitary tract in the medulla and ascend to the medial parvocellular part of the posteromedial ventral nucleus of the thalamus. Other projections are to the pontine parabrachial nuclei, lateral hypothalamus, central nucleus of the amygdala, and bed nucleus of the stria terminalis. The parvocellular part of the ventral posteromedial nucleus of the thalamus is the synaptic relay of the ascending pathways to the cortical taste area (CTA). Most species have two CTAs as determined by the evoked potential method (Yamamoto 1984). One is near the somatosensory tongue projection in the parietal operculum and the other is in the frontal operculum or limen insulae. In humans, the CTA appears to be in the fronto-insular junction (Brodmann area 43). Once considered possibilities, the temporal and parietal cortices are no longer considered by anatomists as locations of the CTA (Mesulam 1998). Responses of single cortical taste neurons show that more than half the neurons respond to tactile and thermal stimuli as well as taste (Cohen et al. 1957; Landgren 1957). Numerous anatomical examinations show corticofugal connections, yet few electrophysiologic studies have been done and little is known of the functional cortico-
fugal pathways. They do feed back to somatosensory, visual, and auditory systems and may be important for taste discrimination (Monnier 1975; Towe 1973; Wisendanger 1969). Further evidence contributing to the paradox of the temporal lobe in the genesis of gustatory sensations is the fact that only extensive removal of the entire anterior sylvian cortex (including the parietal operculum) produces marked and prolonged ageusia (Bagshaw & Pribram 1953; Hausser-Hauw & Bancaud 1987).

After careful analysis of spontaneous and electrically induced seizures, Hausser-Hauw & Brancaud found that isolated gustatory hallucinations in humans are related to the disorganization of the rolandic or parietal opercula or both. Seizures originating from the temporal lobe, they found, were intermixed with many other subjective symptoms, a finding that again implicates the anterior temporal cortex and underlying limbic structures in heterogeneous synesthetic experiences. Following are some examples of epileptic synesthesia involving gustation.

Anderson (1886) cited a 23-year-old man who had a “sensation in his mouth, a rough, bitter sensation” combined with a “peculiar sensation passing down the right arm into the hand, then up the spine from the level of the shoulders to the head, finally spreading over the back of the skull as a cold sensation.” He would often shiver during the seizure, and see the same scene from his childhood. He was found to have a large pituitary tumor that undermined the posterior three-fourths of the temporal lobe.

The following epileptic synesthesias are from Hausser–Hauw & Bancaud’s (1987) cases:

Case 21. A taste of bile, dysesthesia of the left wrist, abduction of the left corner of the mouth, and clonic contractions of the left side of the body
Case 24. Epigastric pain, shivers, a bitter taste, nausea
Case 25. A lump in the throat, oral movements, phosphenes in the right upper fields, a bitter taste
Case 28. An intense heat that ascends from the stomach to the mouth accompanied by a disagreeable taste
Case 30. Bitter taste, hypersalivation, swallowing, spitting (sometimes vomiting), angry outbursts accompanied by shouting

These are, I think, remarkable examples. One of their patients experienced gustatory hallucinations, similar to his spontaneous ones, 30 to 50 seconds after ingesting food or water. This is, of course, what is known as reflex or sensory epilepsy (Bencze, Trupin, & Prockop 1988; Forster 1977; Herskowitz, Rosman, & Geschwind 1984; Micheloyannakis & Ionnidou 1986; Reder & Wright 1982; Wishaw 1987). For a long time it has been known that seizures could be evoked in certain epileptic
individuals by a physiologic or psychological stimulus of one of five
types: visual (flashing light), auditory (unexpected noise, specific mu-
sical themes or voices), tactile, reading, and eating.

Because the association of TLE and psychosis is strong, it is not
surprising to observe synesthesia in the context of psychosis. McKane
& Hughes (1988) described gustatory, olfactory, tactile, and auditory
synesthesias in two cases of psychotic depression. The pairings were
taste-smell, taste-hearing, and taste-pain—quite different from what is
usually observed in idiopathic synesthesia.

4.7 ELECTRICAL STIMULATION OF THE BRAIN

The work of Penfield and Jasper (1954) is well-known and has achieved
the status of medical fact, certainly among laypersons. I cite weak-
nesses of Penfield’s method in §4.7.3. Experiential responses occurred
only when Penfield stimulated the temporal lobe. Most responses came
from stimulating the lateral and superior surfaces of the first temporal
convolution. None were obtained from Heschl’s gyrus. Like synes-
thesites, those patients who have their cortex stimulated are able to
appreciate “both worlds.” These patients have a strong conviction that
the experience they are reliving is real, without losing sight of the fact
that they are on an operating table in Montreal. Like synesthesia, the
elementary percepts—the components of their experience—combine
without losing their own identity. As their patient GLe put it, “I see the
people in this world and in that world too, at the same time” (Penfield
& Perot 1963, p 635).

Penfield showed that electrical stimulation could make patients
relive the past as though it were the present. This was Proust on the
operating table, an electrical recherche aux temps perdu, yet obviously
not perdu. Patients were startled to relive an experience.

The recollection produced when the electrode is applied to cortex is
not static. It proceeds in a normal time frame. It changes as it did when
it was originally seen, according to the patient’s point of view, altering
when he had perhaps changed his gaze or as a conversation unfolded.
“The recollection of a song produced by cortical stimulation progresses
slowly from one phrase to another and from verse to chorus. The
thread of continuity in evoked recollections seems to be time” (Penfield
& Perot 1963).

The evoked memory is more than an ordinary memory, appearing
to be a full somatic participation of the original experience. There are
distinctive differences between the characteristics of evoked memory
and those mediated by verbal symbols of generalizations. Kubie (1943),
in particular, thought electrical stimulation of the brain (ESB) was a
shortcut to psychoanalytic technique in that it recaptured “unconscious
memories in the pursuit of insight.” But to explore this would take
us too far afield. Later work on ESB has tended to focus on language. We can glean some useful facts in these efforts that are related to synesthesia.

### 4.7.1 ESB Mapping

Beginning in the late 1970s, electrical stimulation studies directed by the American neurosurgeon George Ojemann gradually disclosed the need to revise the classic model of language organization based strictly on neuroanatomy. (Others have reached the same conclusion, but I focus on Ojemann to keep us from going too far afield in this broad body of literature.) His studies confirmed that language was indeed discretely localized in any given individual, but that its exact location varied widely among individuals. This makes us wonder if synesthesia will be “discretely” organized across any given group of individuals or whether we will see broad intersubject variability in objective measurements, just as we do behaviorally. This thought should give us pause before we blithely lump subjects together or average electrophysiologic or functional imaging studies.

Ojemann’s results are important not only for patients undergoing cortical resection in the language hemisphere but also because they show how language cannot, in fact, be reliably localized solely on anatomical grounds using such tools as scans or angiograms. The theoretical implications are broad: the variability of any given individual’s functional language map really forces us to treat Broca’s and Wernicke’s areas less as concrete entities whose boundaries are sacrosanct and more as *conceptual entities* whose physical bases we are only now beginning to understand. Try drawing Wernicke’s area and you find that you can’t (Bogen & Bogen 1975). We have not been able to show that a conceptual cortical language area corresponds firmly to any specific cytoarchitecture. However, individual variability in cytoarchitecture in general has hardly been explored in either humans (Galaburda, Sanides, & Geschwind 1978) or animals (Merzenich et al. 1987). Thus, the typographic extent of language is likely to be wider than that indicated by classic maps. Within this zone, language is discretely localized, with different sites variably committed as measured by naming (Ojemann & Whitaker 1978; Whitaker 1979).

This type of mapping study shows that neither the location nor the absence of a language function at a given cortical site can be reliably predicted by conventional anatomy. Because the study population is abnormal by virtue of the patients’ need for craniotomies, it is reasonable to ask whether their cortex might not have reorganized relative to their lesions, especially those lesions acquired early in life. The results are the same, however, whether individuals damaged their brains as
children or as adults. Neither is linguistic experience a variable, as similar results are obtained in those with the least language experience (a 4-year-old boy) and those with the most (80-year-olds).

A high degree of variability in localization between subjects is apparent and may be a consequence of considerable variability in the detailed anatomy of the cortex. This suggestion is bolstered by studies of striate cortex that were undertaken as part of the visual prosthesis project in which implanted electrode arrays produce phosphenes that blind subjects could “see” (Brindley & Lewin 1968; Dobelle & Mladjeovsky 1974). Contacts that are adjacent to each other may or may not produce phosphenes that are adjacent in the perceived visual field. Nonetheless, the phosphenes that are produced remains stable in each patient even though such maps differ between patients. This suggests a high degree of variation in striate cortex to stimuli between patients but considerable reproducibility of responses in any given patient. If such a degree of individual variation exists in the visual system, generally agreed to be one of the most “hard-wired,” then anatomical and functional variability seem certain in other systems.

Studies of morphological asymmetries seem to point to the same conclusion. As Ojemann & Whitaker (1978) suggested, “the detailed functional anatomy of our brains may be as individualized as the detailed anatomy of our faces.”

4.7.1.1 ESB and Memory, Revisited Working with ESB, Penfield was the first to suggest that memory was stored in different ways, although he did not fully recognize this. First, memory is stored in patterns of verbal representation as nonspecific generalizations from discrete experiences that are predominantly intellectual and unemotional in content. At the same time, it seems possible to reproduce the original episode with all of its vivid sensory and emotional connotations.

This is so because memory is not simply a fixed lookup table, but a creative process during which the state of the brain’s electrical fields change (Freeman 1995). The sensory cortices generate a distinct pattern for each act of recognition and recall, with no two ever exactly the same. They are close enough to cause the illusion that we recognize and have seen some event before, although this is never quite true. Each time we recall something it comes tainted with the circumstances of the recall. When it is recalled again, it carries with it a new kind of baggage, and so on. There is no such thing as an entirely new experience or memory. So each act of recognition and recall is a fresh, creative process and not merely a retrieval of some fixed item from storage.

This naturally suggests how easy it might be to combine sensory qualities with an emotional conviction—thus producing synesthesia.
That is, persons, objects, and events are not perceived in their entirety but only by those aspects which are, have been, or can be experienced and acted upon by an observer. An example of this fragmentary nature of perception is in any mundane object such as a disposable plastic cup. Everyone knows that you drink from it. But we can comment on little else—for example, its tensile strength, translucency, thermal coefficient, chemical composition, or what is stamped on its bottom. A physical universe is contained in that cup by such an analysis. Yet all we really know about it is *what you do with it*. This limited aspect of knowing is peculiar to humans, the observers and manipulators. All that we can know about anything outside ourselves is what the brain creates from raw sensory fragments, which were actively sought by the limbic brain in the first place as salient chunks of information (Nauta & Feirtag 1986; Freeman 1995).

Brains move their bodies through the world. Knowledge of space and time is constructed by combining the messages sent to the muscles with subsequent changes in receptor activity. This is the basis for brains knowing when things happen inside and when things happen outside, including their bodies, which are outside of brains. We have forgotten the time when our brain constructed space and time, because it did so when our brain functioned intentionally at the level of the salamander.

The anatomist Walle Nauta, in commenting on the "omnisensory amygdala's modulation of the neocortex," reverses the direction of flow in the standard model to postulate sensation as projecting inward, the reciprocal connections thus projecting outward to those parts of the neocortex that receive the final cascade of sensory data en route to the limbic system. What projects to the neocortex is "the repeatedly pre-processed multisensory appreciation of the organism's environment."

A more familiar way of putting this is to note that people often call contemporary artists weird because the artists do not seem to be seeing the same things that the majority see. It is critical to realize that the sensory gateways that feed into the brain establish their own conditions for the creation of images and knowledge. Artistic giants know full well that their visions are not shared by most people. Even when persecuted or abandoned because of their vision, artists persist. This is all that they can do because their visions are their reality, and for many of us they subsequently become our reality when we later experience their art.

### 4.7.2 Olfaction and Evoked Memories

The experience of the gustatory synesthete MW makes us particularly interested in taste and smell. (CSc, MG, MN, RP, TP, and VE also have taste and smell among their synesthesias.) It is curious, given the inti-
mate relation between olfaction and gustation, that tastes and smells
did not figure prominently in the evoked experience during ESB. Stim-
ulation of the olfactory cortex results in simple perceptions just as in
the case of somesthetic, motor, or primary isomodal cortex stimulation
(e.g., agreeable or disagreeable odors, metallic tastes).

Penfield did stimulate the uncus and hippocampus almost as fre-
quently as the convexity of the temporal lobe, because epileptogenic
foci often arise in the uncus and run back to the temporal incisura. Yet
he found no patient whose stimulation caused him to remember a
smell. Common experience tells us that a familiar odor can bring back a
memory quite vividly, although not as vividly as the recollections dis-
cussed in synesthesia, eidetic memory, or ESB. A change in memory in
SdeM following postoperative loss of olfaction is discussed in §5.6.2.2.
In real life, an odor may indeed bring back an elaborate memory, but
the memory of an odor is rarely, if ever, revived.

4.7.3 Weaknesses of Penfield’s Method

1. All patients were being operated on for epilepsy and usually
had abnormal seizure foci in the temporal lobe. This is a funda-
mental difficulty of all ESB work. Even later work by Ojemann and
others used epileptic patients. It had always been thought that the
ethical constraints of stimulating a “normal” brain could never be sur-
mounted, though perhaps transcranial stimulation with superconduct-
ing quantum magnetic devices and similar approaches may resolve
this.

2. Inasmuch as the extraction of an evoked memory stimulated such
interest among psychoanalysts, a preoperative psychoanalytic analysis
would have been helpful to compare to a content analysis of the utter-
ances during operation. So would comparison of operative utterances
to what we call conventional memory or those produced by other
techniques.

3. Psychological testing was not undertaken in Penfield’s patients. This
probably reflects the climate of neuropsychology rather than poor
methodology.

4. It is wrong and simplistic to say that memory resides at the point of
stimulation. A possible spread of electrical activity is possible, perhaps,
by callosal pathways. Although Penfield and later investigators rea-
sonably convinced themselves, and others, that the electrical spread
was physically not wide, some still question if the memory resides
under the locus of stimulation. Increasing the strength of stimulation
would produce a seizure, but could never force out a memory if the
cortex was “not ready to give it.” Excision of the epileptic focus did
not destroy the postoperative memory that could be elicited from the excised area (Penfield & Perot 1963, pp 620, 677, 689). This is consonant with my earlier comments about two different kinds of memory: verbal generalizations as opposed to discrete episodes.

Over the past 20 years, Joachim Fuster (1995) has demonstrated the ubiquity of memory functions in a variety of networks throughout the cerebral cortex. That is, distributed systems (see chapter 6) involving sensory, associative, prefrontal, cerebellar, and motor cortices are the neural basis of conscious memories. Even though dichotomies in memory prevail in the field, Fuster does much to free us from the either-or forced choice between cortical and limbic entities.

5. The idea that memory is located in the hippocampus or the nearby temporal pole stems largely from Penfield’s work in surgical patients. Penfield reported evoked memories in 40 of 1132 patients so stimulated. Thus, the detailed explications were obtained from just 3.5% of patients, and these results were never replicated by other surgeons. In recent times, no one has tried.

4.8 SUMMARY

What all these phenomena that we have studied above have in common is a disruption, inhibition, or suppression of higher cognition, with a diminution or occlusion of primary afferents or the primary receptive field (sensory deprivation, simple synesthesia, release hallucination), or sensory cortex itself (TLE, electrical stimulation of the brain), or both (LSD-induced synesthesia). The electrophysiologic data that are available from animal and human experimentation show desynchronization of cortex and inhibition of neocortical axodendritic potentials with paroxysmal limbic and sublimbic spikes and slow waves.

The range of anatomical levels suggested by these phenomena is between brainstem and association cortex (either isomodal or heteromodal at this point). The heightened emotional and mnestic qualities, as well as the remarkable case of Vike et al. (1984), discussed in the section on simple synesthesia (§4.5), point strongly to temporal-limbic structures as a possible functional locus of synesthesia.

These cases also reveal a range of synesthetic performance. As a clarification of nomenclature I will call photisms simple synesthesias if they arise spontaneously; those that are stimulus-induced after patients acquire CNS lesions (such as a clanking radiator causing a flame photism in a scotoma) will be called induced synesthesias. This term can also apply to the synesthesia arising from LSD, which I call drug-induced. Spontaneous synesthesia occurring as a lifelong characteristic in patients without demonstrable CNS pathologic findings is what I refer to as idiopathic synesthesia throughout this book.
4.9 SUPPORTING EVIDENCE FOR ANATOMICAL LOCALIZATION

Keep in mind that the patient of Vike et al. had a cystic tumor in the left medial temporal lobe. Unfortunately, neuropsychological assessment was not performed to see whether he had any higher cortical deficits attributable to dysfunction of the left hemisphere. Jacome & Gummit’s (1979) patient with trimodal epileptic synesthesia had a left temporal EEG focus. He showed poor performance on Porteus mazes but no other disturbance on neuropsychological assessment. I have not considered until now that synesthesia could be asymmetrically represented in the brain. I examine data below that show that this may be so.

Concerning the what and the where of synesthesia, my hypothesis is that the \textit{what}, that is, the link, should be below the neocortical level of unimodal cortex and the \textit{where} is the limbic system–temporal lobe. It proposes that synesthesia does not involve activation of the most differentiated neocortical areas with a relative enhancement of limbic projections.

Unless otherwise stated, the studies reported below relate to the gustatory synesthete with geometric taste, MW, in whom both taste and smell induce tactile perceptions of shape, texture, temperature, weight, and movement.

4.9.1 Drug Studies in MW

The fact that the mapping experiments showed some regularity to synesthetic perception led naturally to pharmacology and the question of whether any drugs could modulate synesthetic performance. There would be too many variables in repeating mapping experiments under a drug’s influence. Rather, the strategy was to find substances that altered the \textit{experiential response}, that is, substances that would augment or broaden the synesthetic perceptions and those that might abolish it.

Questioning MW about the various settings in which he experienced synesthesia first suggested a diurnal response that, on closer examination, was perhaps related to his caffeine and ethanol ingestion. He thought that he had fewer synesthesias in the morning compared to later in the day and especially in the evening, when they seemed more intense and vivid. He supposed this might be due to being “more relaxed” in the evening and better able to appreciate his synesthesia without the distractions of work competing for his attention.

This turned out not to be the explanation, however. His apparent “relaxation” was induced by fairly large quantities of ethanol, as I shall discuss below, and a diary I instructed him to keep showed that he was in fact experiencing synesthesias in the morning and throughout the day. It turned out that the synesthesias in the morning and throughout
the early afternoon were merely attenuated in their expression. “It’s not as intense.” “I just get brief flashes.” “There are little things at my fingertips and I don’t grab onto them.” “The shapes are smaller and further away from me. I have to reach into the distance.”

MW’s standard breakfast was cigarettes and coffee (five mugs by noon), and he drank ethanol regularly in the evening. This suggested that conventional stimulants might attenuate synesthesia while depressants could enhance it, an idea that I tested. A third substance, amyl nitrite, markedly enhanced the synesthetic percept and is discussed below in the section on regional cerebral blood flow where it is shown to decrease cortical flow.

Table 4.3 gives a summary of drug effects on synesthesia.

### 4.9.1.1 Dextroamphetamine

MW was not naive to dextroamphetamine but had not ingested any in at least 4 years preceding this experiment. Originally blinded, he deduced the drug’s identity during the experiment. The stimulus was an inhalation of spearmint essence that was previously shown on multiple occasions to produce a stable synesthesia that did not fatigue. The characteristic perception of spearmint was of smooth, cold, glass columns that MW could palpate. He could run his hand along the back curvature and up and down the cylinder’s length. This synesthesia was reasonably constant and MW was instructed to report any differences in the tactile qualities that he felt. Strawberry essence, as a backup, produced a sensation of round, warm spheres.

Table 4.4 tabulates MW’s pulse and blood pressure during the experiment, which were measured to ensure that the amphetamine caused a physiologic response. The following comments correspond to the data in the table.

1. **Time 0:0.** Baseline pulse and blood pressure obtained. Five milligrams of dextroamphetamine ingested.

2. **Time 0:01.** No change in vital signs. Amyl nitrite was used as an adjuvant. The “standard method” was to inhale a volatile essence followed by a 2-second inhalation of amyl nitrite. During the synesthesia, in which there was a replication of the columns that was intensified to the point that he was “in among the columns, touching and feeling
their surfaces," there was a marked rise in pulse and blood pressure due to the amyl nitrite alone.

3. Time 0:10. Recovery from the amyl nitrite.

4. Time 1:10. Physiologic response. MW acknowledged that he was "speeding." Inhalation of the mint gave an attenuated synesthesia. He described a "small field of perception" with one or perhaps two columns far in the distance, very difficult to touch. "This is quite different. The feeling comes faster than before but they are much smaller. They are still as vivid as a miniature would be compared to a large oil painting. The emotion is less intense but it is still pleasurable. The whole thing is just more distant." He explicated further: "I'm not sure how I can explain it. It's like slipping out of my hands." Inhalation of strawberry essence caused him to feel round spheres but on a smaller scale than that to which he was accustomed.

5. Time 1:15. Positive physiologic response from amphetamine continues. Inhalation of mint followed by amyl nitrite adjuvant. Compared to the intensification that MW experienced with amyl nitrite on previous occasions and again in this experiment at time 0:01, the adjuvant effect while stimulated with amphetamine was diminished. "This is not as visceral as an hour ago. Instead of feeling it intensely in my hands, my back, neck and arms, it is more centered on the fingertips and my face. Instead of having a shape which is there all the time on which I can concentrate, it has become a series of small flashes of sensory things, only at the fingertips. I can’t feel the quality of the column, the tactile quality is smaller. It is like a scale model, somehow, or a miniature. The whole thing is just incredibly different. What have you done to me?"

6. Time 2:30. Recovery of pulse rate, but still physiologic response from dextroamphetamine. Subjectively "still speeding, and pleasurably so." Inhalation of spearmint and strawberry were "pleasurable" but there was no bona fide synesthesia. Additional trials of almond,
banana, methyl salicylate, and camphor also could not induce synesthesia. At the most, MW felt lines, dots, and non-geometric shapes (quite unusual for him) and most of these were “always receding from my grasp.” (Various foods consumed after this experiment were also unsuccessful in producing synesthesia.)

An attempt was made to induce synesthesia with the amyl nitrite adjuvant. Despite a subjective and physiologic response to the amyl nitrite, it was not successful. “This is not sustained. It’s pulses of a sensation, a sort of cinematic frame-by-frame sensation rather than being a one long shape that I can concentrate on. The poppers [amyl nitrite] somehow make the feeling more intense but the small scale and the distance is still the same. With the speed I stay outside of the columns and can’t get in, even with the poppers.”

4.9.1.2 Ethanol A similar experiment was performed with 1.5 ounces of absolute ethanol. This produced a standard physiologic response of tachycardia and peripheral vasodilation. The details need not be given, but the magnitude and intensity of MW’s synesthesia was increased by the ethanol compared to the synesthesia he experienced at midday (during which time he had not been permitted to consume caffeine) and 5 hours later before the ingestion of any ethanol.

A “natural experiment” then occurred. When I first discovered MW’s synesthesia (in 1979) his average ethanol consumption was 8 ounces daily. His ethanol consumption began to escalate in 1983 until, when he stopped drinking on April 7, 1985, he consumed almost a fifth of liquor daily. For 2 to 3 months after total cessation his synesthesia was attenuated, presumably as a result of supersensitivity and rebound following removal of this classic cortical suppressant to which he had been chronically exposed.1 This is in keeping with the known effects of alcohol: following withdrawal, there is an enhancement of cortical activity, sometimes manifested by seizures, and an increased autonomic activity, insomnia, rebound REM sleep, and motor hyperactivity.

He was horrified and distraught that his synesthesia was leaving him. Life was just not the same. Of course, he made no association between the “fading away” of his synesthesia and his cessation of alcohol. Predictably, it returned. At 20 months sober (in December 1986) his synesthesia has resumed its previous intensity and proportion with the noticeable exception of diminution in the morning, congruent with his usual breakfast of caffeine and nicotine, both cortical stimulants.

1 Those unfamiliar with alcoholism might think that 3 months is far too long for a rebound stimulant effort to endure, assuming that all physiological and behavioral effects should be nil following metabolism of the last ethanol dose by alcohol dehydrogenase, which is on the order of hours. However, what are termed post-acute withdrawal symptoms persist for months following cessation of drinking.
Coffee consumption, previously at 10 cups per day, is now at three cups daily.

4.9.1.3 **Amyl Nitrite**  Observations indicated that amyl nitrite could intensify the synesthetic experience. Some of its results are noted above. It is important to realize that amyl nitrite in itself does not induce synesthesia. MW’s experience with the drug is quite consonant with the wider social use of the substance as a recreational drug.

This drug, which peaked in popularity in 1975–1980, was commonly used at discos and during sex. It relaxes smooth muscle throughout the body and because of this its major effect is vasodilation. Its original use for angina pectoris has been supplanted by nitroglycerin. Its effects include a withdrawal into the self, slowing of time sense such that music may seem more distant or slower, metamorphopsia, disinhibition, and heightening of emotions so that one appreciates the tribal aspects of the rhythmic throng while dancing. Physiologic correlates are a rushing sensation to the head, flushing in the face and chest, and reflex tachycardia secondary to the vasodilation. During sex there is a sense of heightened and prolonged orgasm, an oceanic state of oneness with the sexual partner, a sense of rhythmicity and mouthing, and an abandonment of judgment. It is common for users to acknowledge sexual acts performed under the influence of amyl nitrite that they otherwise would be unable or unwilling to do. The whole physiologic effect is brief, lasting minutes.

The drug has the properties of a cortical solvent and that this is so is apparent on examination of the blood flow data. “Solvent” in this context refers to the hierarchical dissolution of higher cortical functions, such as judgment, social inhibition, and reasoning. Ethanol, too, is a well-known cortical solvent that depresses inhibitions and makes one loquacious. Used in increasing amounts one starts to associate with all types of people and exercise poor judgment.

4.9.2 **Cerebral Metabolism**

If one were to judge by the books, audiotapes, and public television series devoted to the so-called wonders of the brain—often couched in terms of “mystery”—one can’t help but notice how often the focus is entirely on the cerebral neocortex, which is hardly the whole brain. This is synecdoche in action, reminiscent of a gorgeous wedding cake that might be on display as a tribute to the confectioner’s art. We marvel over the rosettes, garlands, and the anaglyphs in sugar. But there is a catch: there is no cake. Underneath the icing is only cardboard and aluminum foil, nothing to sink one’s teeth into.

The human brain is not like this. The brain is not just neocortex held up by inert filler. To pursue the saccharine metaphor, the gray matter...
“icing” varies in breadth from one cortical area to another, but is only 2 mm thick on average, a mere fraction of the average total cerebral volume of 1350 mL. There is, however, plenty of cake underneath. Subcortical aggregates of nervous tissue do much biochemical work. They are not there just to hold the surface up. One can observe extensive behavior in animals that do not have any cortex to speak of, such as birds (Cobb 1960, 1969). Suction removal of large expanses of cortex from monkeys results in animals not so terribly different from their cage mates, suggesting that the cortex only provides a finer grain of discrimination, better calculation to inform the limbic brain, which is the final arbiter of whether to act or not.

Instead of assuming that synesthesia would be “localized” to some cortical area—such as a tertiary association or heteromodal area of neocortex, which would be the most logical choice according to the hierarchical model of brain organization—one could try to prove the opposite: that the highest, most differentiated areas of cortex were not “working” during synesthesia.

It is well-known physiologically that in all biological tissues doing work, more energy metabolism takes place than in those tissues that are not working. Skeletal muscle performs physical work against gravity, and its metabolism correlates with the amount of work done. The heart does work by pumping blood out against a pressure head. The same applies to the kidney as it does chemical-osmotic work in concentrating substances against a gradient. In all cases, the amount of work done correlates well with the degree of oxidative metabolism in the tissue concerned. Although it is not always clear what the nature of the physical work is that is going on in nervous tissue, the measurement of energy metabolism does serve as a marker for how much a given part of the nervous system is doing in any functional state. The important thing is to localize such measurement to specific regions of the nervous system, preferably by a method that can look at all regions simultaneously but independently.

The measurement of regional cerebral blood flow (rCBF) does nicely because rCBF and cerebral metabolism (as measured by glucose utilization) correlate well (Sokoloff 1981).

4.9.2.1 Reduced Cortical Blood Flow During Geometrically Shaped Taste Synesthesia Although the xenon-133 technique for measuring rCBF has been supplanted by later methods of functional imaging, I present it here unchanged from the first edition. Despite the recent synesthesia renaissance, we still have relatively little hard experimental data, and at the time of the first edition (1989) the following study was the only physiological data in existence. The xenon method’s advantage was brevity—a behavioral state needed to be sustained for only 5 to 10 minutes compared to nearly 2 hours with the then-nascent PET tech-
nique. MRI was also in its infancy; the term “functional imaging” had not yet been coined.

Xenon\textsuperscript{133} inhalation rCBF measurements were made for MW in baseline, synesthetic, and adjuvant-intensified states (Cytowic & Stump 1985). Those not familiar with this technology can consult the review by Stump and Williams (1980). This method measures a fast component flow for gray matter and a slower component representing white matter flow in milliliters per 100 grams of tissue per minute. The general procedure is for the subject to lie on a couch, head in a helmet in which radiation detectors are mounted to measure clearance of the tracer. Probes number 8 to 256 per hemisphere and are collimated.

Mathematical analysis of the desaturation clearance compared to carbon dioxide, oxygen, and xenon tracer in expired air permits following of the cerebral blood flow at each region of interest simultaneously from moment to moment to see which regions change the most during the behavior under study. The pattern of flow, called a landscape, is obtained during a resting baseline state as well as one or more states of activation, and these different states are compared. You generally expect at least a 10% increase in those brain regions that participate in the activation task. For example, Ginsburg et al (1988) simultaneously measured regional cerebral glucose utilization as well as rCBF in 10 normal subjects performing a somatosensory-motor task: blind palpation and sorting of mah-jongg tiles by their engraved design. As expected, this somatosensory stimulus elevated the regional cerebral glucose utilization by 16.9% ± 3.5% and the rCBF by 26.5% ± 5.1% in the contralateral sensorimotor cortical region.

**Method** In the gas delivery system for the inhalation method of measuring rCBF, the subject is attached to the system via a tight-fitting face mask and short hose. A valve is in line to switch from breathing ambient room air to breathing the xenon mixture. It is easier to introduce volatile odorants at the room air intake than to use liquid flavorants sucked through flexible straw tubing passing under the face mask. The latter technique is prone to air leaks around the mask and was subsequently discarded in favor of the inhalation of odorants. From experience, both tastes and smells were sufficient to induce stable, non-fatiguing synesthesias as outlined in the section on drug studies above.

MW breathed a xenon mixture of 7 \textmu Ci/L of air for 1 minute and then was switched to room air. Desaturation was measured for the next 10 minutes of clearance. During this time either the stimulus odorant or an odorant followed by amyl nitrite adjuvant was introduced into the face mask and inhaled by the subject. This produced a synesthesia of up to 1 minute in duration. MW was instructed to maintain as near constant state of synesthesia as possible and to signal for additional stimulation by moving only his left index finger. Eyes were closed, the
room darkened, and the ambient environment filled with a steady white noise.

**Probe Locations** Scintillation detector probes are placed radially in a helmet with neuroanatomical references based on a modified 10–20 electrode placement system. Using bony landmarks, probe sites are marked on a cadaver head and holes are drilled into the brain. By this method site verification is within 5 mm of any desired cortical region. In the left hemisphere probe F3 is in the frontal eye fields of Forester; F2, inferior frontal gyrus (Broca’s area); F4, hand region of the precentral gyrus; P1, hand area of the postcentral gyrus; T2, lateral convexity of Heschl’s gyrus; P2, inferior parietal lobule, primarily the angular and supramarginal gyri; T0, the anastomotic area between the middle cerebral artery (MCA) and the posterior communicating artery (PCA) circulation; and O1, occipital pole (figure 4.5, *top*). Probes are similarly placed over the right hemisphere.

![Figure 4.5](image)

**Figure 4.5** (*Top*) Scintillation detector probe placements for rCBF study. Percentage change from baseline to synesthesia is represented by black areas on clocks (those moving clockwise, percentage increase; those moving counterclockwise, percentage decrease). (*Bottom*) Absolute blood value flows (in mL/100 g/min) for MW for baseline (x) and synesthesia (o) studies for the probe location shown at top. (Data Display Program by permission, D. A. Stump & L. Hinschelwood, Bowman Gray School of Medicine, Winston-Salem, N.C.)
**Baseline rCBF**  Mean flow gray (Fg) levels in the left hemisphere are reduced for a person of MW’s age (56.3 mL/100 g/min), and his resting hemispheric landscape is unusually variable (SD = 12.0) (figure 4.5, bottom). The average person in our laboratory has a mean flow of $65 \pm 4$. Inferior temporal and occipital flows (probes T0 and O1) are pathologically low and approaching the floor limits of the apparatus to detect any flow at all. The right hemisphere shows near-ischemic flows in the right inferior frontal and occipital areas (probes F2 and O1), and also has high variability (SD = 13).

The remarkable feature of MW’s resting blood flow is its inhomogeneity and areas of frank ischemia. However, his neurological examination shows no focal deficits nor has he ever had any history of transient ischemic attack or stroke.

**During Synesthesia**  The average left hemispheric flow drops to 43.3 mL/100 g/min, which is close to 3 SD below acceptable limits—a level of flow at which we have never seen a patient in our laboratory who was not symptomatic at the time of study (see figure 4.5, bottom). The central MCA territory drops to flow levels in the 30s, which is usually consistent with chronic ischemia or passive flow secondary to stroke (probes F4, P1, P2, and T2).

MW’s mean left hemispheric flow drops 18% during synesthesia, an occurrence rarely—if ever—seen in a normal study. Even with the administration of 100% oxygen inhalation or aminophylline, which acts as a potent vasoconstrictor, one sees only a 10% to 15% decrease. The observed reduction in blood flow seen during the synesthetic experience would be difficult to obtain with a drug in a normal person.

The 11% decrease in the right hemisphere is largely a reflection of the high precentral flow (probe F4) during baseline, possibly due to index finger movement during signaling. Prorating probe F4, the mean decrease in right hemispheric flow during synesthesia would be 5%, which is within the normal variability.

**Hemispheric Symmetry**  Hemispheric symmetry (comparing left to right hemisphere) is quite poor for both baseline and synesthesia. Normally, the correlation ($r$) is $0.5$ to $0.9$ for a younger normal person. The synesthete has asymmetrical hemispheric flow to begin with in the baseline ($r = 0.164$), which becomes worse during synesthesia ($r = -0.05$) (figure 4.6). Looking only at the MCA territory (probes F2 to T2), one sees a good correlation except that the left hemisphere is about 10% lower than the right, which is inconsistent and opposite to what is normally seen. The left anterior temporal and parietal areas are significantly lower than the homologous right hemispheric areas and below the lower limits of normal.
Therefore, there is an unusual dissociation between anterior and posterior circulations during MW’s synesthetic experience.

**rCBF During Amyl Nitrite Activation** No data exist regarding the effect of amyl nitrite on rCBF in normal brains. It is known to increase intracranial pressure in animals (Malkinson, Cooper, & Veale 1985). Some argue that rCBF increases because of increased cardiac output while others argue that it decreases because of vasodilation. Goodman and Gillman (1975, pp. 727–735) suggested that the adverse effects of lightheadedness, dizziness, and telecussis are in fact due to cerebral ischemia and the data here support that idea. Figures 4.7 and 4.8 compare flow during synesthesia with flow during adjuvant. Inhalation of amyl nitrite, which intensifies synesthetic perception (see above), causes a massive redistribution of flow, particularly in the left hemisphere. Areas of the MCA territory dip below the lower acceptable limits of normal while the previously ischemic areas in the posterior circulation now elevate to the normal range. There is an interesting dissociation between flow in the MCA and PCA territories (probes T2, T0, and O1) on the left side. The major difference between plain synesthesia and synesthesia with adjuvant administration is a higher flow over the angular and supramarginal gyri of the posterior parietal cortex (probe P2) and the motor hand region (probe F4).

Even though mean hemispheric flows with amyl nitrite are higher than the mean flows during plain synesthesia, the adjuvant flows are still below the baseline (−8.0% left, −9.8% right)—well within the range one expects to see with bona fide activation. What is extremely unusual, however, is that MW’s flows decrease rather than increase with an activation procedure. Normally, with any activation, whether it be hand movement, a cognitive task, or drug administration, one anticipates a 5% to 10% increase in rCBF.
The major effect during this episode of synesthesia is almost exclusively in the MCA territory of the left hemisphere, with a "flip-flop" between the MCA and PCA territories. Baseline posterior flow is low, whereas the flow during synesthesia decreases dramatically in the MCA of the left hemisphere as if there were a steal in the posterior circulation. MW's rCBF looks, in fact, like those of patients with arteriovenous malformations or subclavian steal, or transient global amnesia patients who also have migraine headaches (Crowell et al. 1984).

For those not familiar with rCBF measurement, I should emphasize that the data analysis of the inhalation procedure is mathematically complex. In a system with 16 probes, the use of the 12 most common parameters yields 192 separate calculated values. This is a rather large data set. Because of the highly unusual patterns both in baseline and during synesthesia and adjuvant activation in MW, both an actuarial approach—that is, a pattern analysis, manipulation of parameters, and the use of indices that separate particular patient populations—and the basic science approach involving analysis of the clearance curve, the ultimate and primary source of information in this technique, were
used. Every effort was made to identify possible sources of artifact. Raw, fitted, and derived curves, as well as Z scores for nine different parameters, were analyzed. The data are an accurate reflection of actual cerebral blood flow.

These rCBF results support the theoretical hypothesis and are compatible with the experimental data that synesthesia is not a semantically mediated cross-modal association, but a physically based phenomenon that involves a relative suppression of cortical activity.

4.9.3 Cerebral Angiography

Because of the striking abnormality found on rCBF it was medically necessary to investigate MW for a vascular lesion in the left hemisphere. A left carotid and vertebral angiogram showed absence of the left PCA at the circle of Willis. There was no disease of the carotid bifurcation and there was excellent supratentorial filling. The vessels reached the inner table uniformly without displacement. There were no occluded vessels, aneurysms, or early-draining veins. The left vertebral injection showed normal visualization of the posterior cerebral vasculature.
Thus, without an anatomical vascular lesion, the blood flow abnormalities both in baseline and during synesthesia become all the more intriguing. The absence of the PCA on the left could explain the flip-flop seen between the MCA and PCA territories but cannot explain the unusual ischemia at probe T0, which lies over the anastomotic areas between the MCA and PCA territories. Why flow should increase in this cortical region during synesthesia, however, is not clear, although posterior activation was also seen in the study of spohem word-color synesthesia by Paulesu et al. (1995; see §4.9.9). Nor is baseline ischemic flow in both occipital lobes easily explained. The selective vertebral injections showed excellent filling of these vessels. Although his absent PCA may explain some of the rCBF results, it is not sufficient to explain the peculiar landscape of regional flow and its reactivity to ordinary stimuli.

The result surprised us and we were further surprised by what happened during the injection of contrast material itself. Normal patients experience a feeling of heat for the few seconds that contrast fluid replaces blood in their cerebral arteries. Other than this they manifest no symptoms while the vascular lumen contains this nonoxygenating fluid. In marked distinction to the usual reaction, MW experienced visual, auditory, and tactile sensations during the time his blood was replaced by nonoxygenating contrast. Perhaps areas of his cortex are peculiarly balanced in their energy metabolism and become pathologically ischemic during the psychophysical state of synesthesia.

4.9.3.1 Left Carotid Injection During the left carotid injection MW experienced visual perceptions with eyes closed (i.e., no striate afference) that attenuated almost completely with eyes open. “I sense it on the left side. An intense pink and the blackest black I’ve ever seen. It flashes like lightning and grows in intensity. The pink is mainly on the left side. Everything else is pitch black.” He saw this inside his head and not projected externally.

What could account for his visual perception? One hardly expects a carotid injection to affect striate cortex and in fact this injection could not because his PCA is missing. Besides, it would have to be his right striate cortex that was active inasmuch as MW is adamant that he perceives the pink “on the left.” Because his left hemispheric MCA territory flows are already low, his visual perception may be due to (1) further ischemia in the inferior parietal lobule (probe P2) or temporal cortex (because the peripheral retina is represented in the lingula of the temporal lobe); or (2) a temporary disconnection of callosal projections to the right hemisphere. If such a disconnection involved the speech regions, the right hemisphere might “confabulate” in the left visual hemifield.
4.9.3.2 Vertebral Injection Several sensations occurred during the vertebral injection. MW heard a ringing in the left ear, a “high-pitched whine, higher than a siren. Very, very high beyond 20 kHz.”

MW felt excruciating pain “bone pain, like a toothache” in his neck, occiput, and at the vertex. Patients sometimes experience neck pain if anastomoses exist between the skeletal muscle arteries and intracranial arteries of the vertebral circulation; however, no such anastomoses were present in MW. The angiographer had not witnessed such an intensely painful reaction during more than 20 years’ experience. An anatomical mechanism is difficult to propose, but involves the segmental levels C2–C4 or the spinal nucleus of the trigeminal nerve. Spinothalamic tract disruption is difficult to conceive of without the patient experiencing hemisensory loss.

When the small test dose of contrast was injected to localize the catheter tip in the ostium of the vertebral artery, MW saw an intense red spot centrally, “like the fixation point on the perimeter.” It obscured real objects in his field. This persisted for 40 seconds. One might assume this to be an ischemic symptom of the occipital pole, which subserves macular vision. Probe O1 was ischemic during baseline rCBF. (Replacement of real object space by hallucinated objects is discussed in §9.5.)

Visual images consisted of overlapping geometric squares like Art Deco tiles that rapidly alternated in a black-and-white pattern shift. This attenuated when MW opened his eyes but continued to block part of his normal field of vision. He received photic stimulation later during an EEG. As the strobe flash got faster the shapes of black-and-white patterns became more complex, “growing like crystals.” They started like squares, became hexagons, then developed into overlapping shapes similar to those seen during vertebral angiography, “if not the same.”

Cerebral hypoxia has been proposed to play a role in hallucinogenic images (Corales, Maull, & Becker 1980; Stimmel 1979); phencyclidine, LSD, and mescaline produce in vitro cerebral artery spasms via specific receptors in the cerebral arteries (Altura & Altura 1981).

4.9.4 Electroencephalography

The visual shapes seen during photic stimulation are unusual both in the rarity of their occurrence in this setting (Freedman & Marks 1965; Smythies 1960) and in their similarity to the images MW saw during vertebral angiography. The EEG was performed within an hour of the angiogram. I have not subjected MW to photic stimulation at a separate time. He showed blocking of alpha rhythm only on the left side during inhalation of volatile odorants. T1, T2, and nasopharyn-
geal electrodes were used. No paroxysmal or focal disturbances were observed.

4.9.5 Magnetic Resonance Imaging

By all accounts MW had a normal brain that was behaving quite abnormally. Perhaps magnetic resonance imaging (MRI) could disclose some aberrant signals in this unusual subject. Geschwind and Levitsky (1968) had shattered the dogma that the hemispheres are exactly symmetrical and this new (in 1984) high-resolution anatomical tool could help with that question. Geschwind had proposed on theoretical grounds alone that asymmetry should exist in the brain. He then showed that such asymmetry was not necessarily “subtle,” as was widely conceded at the time, or in need of microscopes to detect, but could be measured readily with rulers.

MW’s MRI (at 1.5 tesla) showed no abnormal signals in the gray or white matter of the cerebrum or brainstem. In symmetrical cuts in which there is no more than 1.0 mm of tilt in the horizontal axis there was a simpler lobulation of the cortical ribbon and fingers of white matter on the left anterior temporal lobe compared to the right. On the lateral basal aspect of the temporal lobe there was a single broad gyrus compared to three on the right. Corresponding coronal views showed this flat broad surface compared to the more configured gyration on the right side. This asymmetry in the gross architecture is tantalizing but highly speculative. MRI was too new at the time and this asymmetry may have no functional significance. Functional MRI (fMRI) did not yet exist and MW died before its advent. There are no normative data regarding symmetry of lobulation and similarity of gyration in homologous brain regions, though suitable material exists in the Yakovlev Collection, for example, to address the issue.

4.9.6 Neuropsychological Assessment in MW

Tests Administered

Weschsler Adult Intelligence Test (Revised)
Weschsler Memory Scale (Form I)
Halstead-Reitan Aphasia Screening Test
Drawings on Command
Tapping Test and Grip Dynamometry
Form Board
Reitan-Kløve Sensory Perceptual Examination
Trail Making A and B
Whittaker Acalculia Battery
Minnesota Multiphasic Personality Inventory
Fargo Map Test and New Map Learning
The results of these tests are summarized in table 4.5.

**Background Information**  This 40-year-old right-hander with a BA degree in botany was evaluated for synesthesia. He has no family history of left-handedness or personal history suggesting mixed dominance. Historically, he has difficulty with mathematics and must do calculations on paper, even those pertaining to activities that have great relevance to him in his work as a theater lighting designer (e.g., beam angles involving trigonometry, simple summation of wattages, and calculation of electric loads).

MW has a history of right-left confusion since childhood. He finds it easier to remember “windows” and “bulletin board” instead of “left” and “right,” a mnemonic device stemming from the arrangement of his elementary schoolroom.

**Behavioral Observations**  No behavior is remarkable except for his surprise on encountering difficulty with finger gnosis and fingertip graphesthesia.

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**Table 4.5  Summary of neuropsychological testing of MW**

<table>
<thead>
<tr>
<th>VIQ</th>
<th>128</th>
<th>PIQ</th>
<th>119</th>
<th>MQ &gt; 143</th>
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<td>Pic composition</td>
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<td>Information</td>
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<tr>
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<td>R 60 sec</td>
<td>R 18 psi</td>
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<td>L 2'41&quot;</td>
<td>L 50 sec</td>
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<td>Extinctions: L ear</td>
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<td>B 55&quot;</td>
<td>Finger graphesthesia</td>
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<td>R 5/8 errors</td>
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<td>L Hesitant, 3/10 errors</td>
<td>L 4/8 errors</td>
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<tr>
<th>Acalculia battery</th>
<th>Fargo map: Good geography</th>
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<tbody>
<tr>
<td>Finger agraphesthesia</td>
<td>New map learning: Average</td>
</tr>
</tbody>
</table>

| Lexical misspellings | |

VIQ, verbal IQ; PIQ, performance IQ; FSIQ, full-scale IQ; MQ, memory quotient.
**Intellectual Functioning**  MW’s verbal IQ is 128, his performance IQ is 119, and his full-scale IQ is 129. He had difficulty with arithmetical competency as well as a more general use of digits. He had relative difficulty distinguishing essential from nonessential visual details.

**Memory Functioning**  MW’s memory quotient (MQ) is >143.

**Language Functioning**  MW’s drawings were performed like a draftsman; there was no constructional apraxia. Repetition was normal and there was no alexia, aphasia, or agraphia. There was some hesitancy with right-left identification on the examiner. Finger identification on the right was normal, but he had difficulty (3/10 errors) on the left. Speed of answering was much slower and he was uncertain.

**ACALCULIA BATTERY**  Three trials of numerical fingertip writing were performed on the sensory perceptual examination and five trials on the acalculia battery at separate times for a total of eight trials. He made 5/8 errors on the right and 4/8 on the left. An example of errors on the right were calling an 8 a 2 or 6; on the left he called 4 a 9, 3 an 8, and 6 either a 0 or an 8. He showed difficulty in digit-to-lexical transcoding and a spelling error in auditory-to-lexical transcoding. He used the “carry method” in addition and during the task of auditory multiplication, he had a lapse of “forgetting” the multiplication tables.

**Sensory Perceptual Functioning**  There was no deficit to unilateral stimulation in the tactile, visual, or auditory modes. MW did show auditory extinction in the left ear with simultaneous stimulation and had errors of fingertip graphesthesia as noted above. Performance on the form board showed appropriate cross-transfer learning. Manual dexterity was appropriate but grip dynamometry showed unexpected counterdominance, with the right hand being weaker than the left.

**Summary of Neuropsychological Testing**  MW shows arithmetical symbolic difficulty, including digit-to-lexical and auditory-to-lexical transcoding. There was a bilateral disturbance of numerical fingertip graphesthesia and finger agnosia on the left. The left ear extinguishes on simultaneous auditory stimulation. Form discrimination is preserved and there is motor dominance for dexterity but weakness of the “dominant” hand on dynamometry.

Results imply an abnormality in the left parietal area of the angular gyrus, possibly affecting deeper white matter.

### 4.9.7 Higher Cortical Deficits in Other Subjects

MW is not unique in having mild cognitive difficulties that are suggestive of a left hemispheric dysfunction. Thirty-three of 42 subjects claim...
to have difficulty with arithmetic, compared to 9 of 42 who felt that their skills were good or better than average.

Subject DS  
Tests Administered  
Wechsler Memory Scale  
Trail Making A and B  
Whittaker Acalculia Battery  
Reitan-Kløve Sensory Perceptual Examination  
Fargo Map Test and New Map Learning  
Halstead-Reitan Aphasia Screening Test  
Minnesota Multiphasic Personality Inventory  
The results of these tests are summarized in table 4.6.

Background Information  Subject DS has acalculia and a family history of dyslexia. Her son had failure to thrive with stunting of growth. Whether this was a pituitary abnormality was never resolved convincingly. He had trouble reading, learning the alphabet, and learning numbers. Compared to other children he has a noticeable appreciation for rhythm, and “relates to music.” He wants to be a ballet dancer despite being clumsy.

“I have severe math difficulties,” says DS. She miswrites checks and has to tear them up, adds and subtracts on her hands, and if asked to

Table 4.6  Summary of neuropsychological deficits in DS

<table>
<thead>
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<th>Memory quotient</th>
<th>101</th>
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<tbody>
<tr>
<td>Trail A</td>
<td>30”</td>
</tr>
<tr>
<td>Trail B</td>
<td>55”</td>
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<tr>
<td>Acalculia battery</td>
<td></td>
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<tr>
<td>Subtraction</td>
<td></td>
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<tr>
<td>Auditory multiplication</td>
<td></td>
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<tr>
<td>Lexical-to-digit</td>
<td></td>
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<tr>
<td>Digits to dictation</td>
<td></td>
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<tr>
<td>Stereognosis: OK</td>
<td>Finger gnosis: None</td>
</tr>
<tr>
<td>Extinctions: None</td>
<td>RH hesitant</td>
</tr>
<tr>
<td>Fingertip graphesthesia: Right-left</td>
<td></td>
</tr>
<tr>
<td>LH OK</td>
<td>Confusion</td>
</tr>
<tr>
<td>RH 3/5 errors</td>
<td></td>
</tr>
<tr>
<td>Fargo map(^a): Low-average</td>
<td></td>
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<tr>
<td>New map learning: Failed</td>
<td></td>
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</table>

\(^a\)Discussed in chapter 5.
perform a simple addition or multiplication task in her head will instead draw in the air as she visualizes the calculations. She holds an MS degree. Her most difficult course was statistics. “The concepts were not difficult—it was all those numbers.”

I didn’t want to have anything to do with numbers. I never understood them. If I couldn’t visualize a pattern or a relationship with numbers, I couldn’t do it. The difficulty started as early as I can remember in grade school. I left Florida and went back up North where I had never heard the expression “naught” for “zero.” This made things worse. I felt intimidated. (2/16/87)

ACALCULIA BATTERY DS has much difficulty doing subtraction with pencil and paper. She is slow and makes errors that are unexpected for someone with her education. Writing numbers to dictation is particularly difficult. She must vocalize during lexical-to-digit encoding, and even then still makes errors. She gives up during auditory multiplication. “I can’t do it. The numbers keep going away. I have to write it down.”

WECHSLER MEMORY Comments regarding DS’s memory have been used as examples throughout this book. Although she claims to have an excellent memory, her actual MQ is only 101. She had difficulty in the mental control task of counting by 3s and had omissions and transpositions in digits, scoring 7 forward and 5 backward. She drew in the air with her index finger to reorder the numbers in the backward recitation. Learning of paired associates was excellent, but she scored only 5 on visual reproductions. She tended to get the overall gestalt correct but made errors of detail. During story recall she remembered by “visualizing the sentences.”

SENSORY PERCEPTUAL EXAMINATION There was no loss to single or simultaneous stimulation in the visual, auditory, or tactile modes. DS demonstrated right-left confusion on both herself and the examiner, was hesitant in finger identification in the right hand, and made errors in fingertip graphesthesia on the right index finger (e.g., calling 9 a 0 and 6 either a 2 or a 3). Trails were performed within time limits and without sequence errors.

GEOGRAPHIC COMPETENCY DS’s geographic competency is discussed in chapter 7.

LANGUAGE Compared to her disregard for numbers, DS is an avid reader and learned to do so early. “I read in kindergarten [at 4 years old]. I wasn’t satisfied with the rate the teacher was going. I would get out of bed and sit in the hall by the nightlight reading. My mother yelled at me because she thought I should be asleep.”

There was no evidence of an aphasic disturbance, although this was not studied in detail with, for example, the Boston Diagnostic Aphasia
Examination. Repetition was normal, as was confrontation naming and fluency of speech. The only suggestion of a disturbance is her comment that during her several hours of daily typing “I find I must continue to look at the keyboard just to make sure I’m hitting the right letters. I often strike more than one key and I substitute locations of keys (I’ll be thinking ‘F’ and hit ‘J’ instead)” Yet she is good at anagrams and comments “I’m very quick at unscrambling words; usually I can do them in my head. The letters reorganize themselves in different configurations until they make sense. I’m also a good speller.”

She expresses a preference for written communication and a need for vocal or subvocal rehearsal.

I am poor at verbal communication and am better able to express myself in writing. I cannot concentrate, organize, or think logically in conversation; but alone, with pen and paper I am more confident. (I am sure this was evident at our meeting.)

Reading is not sufficient if I want to remember. I MUST write down what I want to retain. This is true also with taking directions. In my Taekwondo class I must translate each form [set of prearranged stances involving arm and leg movements] to a [sic] original code which I then VISUALLY memorize. I also verbally rehearse constantly when I need to remember, either vocally or subvocally. (3/1/87)

Thus, although there is no frank aphasic disturbance, there is a certain peculiarity in DS’s linguistic performance. She also has elements of Gerstmann’s syndrome. One gets the impression that there is a visuospatial problem and perhaps an attention problem in addition to the acalculia. Acalculia, of course, does not have to covary with the aphasia.

Subject TP The male patient TP is dyslexic, and still makes reversals and has difficulty spelling at age 24.

Subject DoS DoS was precocious in mathematics, learning algebra in grade school from her brother, who was 9 years older. The brother is also proficient in mathematics and particularly liked calculus. In contrast to her hypercalculia, DoS has great difficulty learning foreign languages. Attempting Spanish, French, and Hebrew led to termination of study despite her concerted effort. She spoke English early as a child and was voluble.

Subject PO This 41-year-old left-handed Canadian podiatrist has had a colored number form since childhood (see §5.4 for discussion of number forms). His mother is left-handed. “I read the article [about synesthesia] in the Toronto paper and almost cried. It struck home. I was so emotionally overwhelmed. I didn’t know there was a name for this.” He had never told anyone about his synesthesia.
PO had a ruptured right middle cerebral artery aneurysm that did not influence his synesthesia. This lack of change is supportive that synesthesia may depend more heavily on left hemispheric processes.

**Subject BB** It is rare for synesthetes to attach any meaning to their synesthesias, as BB does. BB shows frank linguistic difficulties. His writing reveals semantic-cognitive distortions and his errors in grammar and semantics make his writing appear like that of a partially recovered aphasic. The meaning that BB assigns to his colors is also reminiscent of medieval religious symbolism:

A white color, of course, it is clarity [sic] and truth. Blue is comfort with pleasure of completeness to any thoughts. Amber is a lingering beyond [sic] reality to a motion. Not a fault its self [sic] but a zone of balance. Green is caution, sensitivity, compassion, jealousy [sic], potentially tearing or conflicting [sic]. Red is also a flag of caution to which anger, strength, movement is at hand. To me both green and red require patients [sic] and effort.

In addition to BB’s frank dyslexic and syntactic errors, other subjects have shown related analytical deficits such as acalculia, right-left confusion, and impaired finger gnosis. Other spelling errors can be gleaned from the examples in chapter 2. These impairments, together with the examples given in this chapter of simple synesthesia in patients with left hemispheric brain lesions, are supportive of the notion that the neural locus for synesthesia resides in the left hemisphere.

**Summary** The higher cortical dysfunctions in these patients further supports the left hemispheric representation of synesthesia. A few patients have elements of Gerstmann’s syndrome.

**4.9.8 Evoked Potential Studies**

An evoked potential study done by the Hannover group (Schlitz et al., 1999) on seventeen synesthetes with chromatic-lexical synesthesia showed significantly higher and more positive waveforms over frontal and prefrontal regions compared to controls \((P < .0003)\). The P 300 wave had an approximate peak latency of 430 ms. Although only fourteen of their seventeen subjects (82%) reported experiencing their typical synesthesia during the experiments, the method nonetheless seems productive.

Task-related evoked responses were the same in both groups, and behavioral indices of task performance (such as mean reaction time to target stimuli) were also similar. The authors interpreted their results in terms of frontal inhibition that could either (1) “lead to increased distractibility and possibly to leakage between modalities” [in this case color and reading] or (2), given its rich multisensory neurons, the
frontal region’s inhibition “could be thought of as an effort of the nervous system to keep the synesthetic perception to a minimum, since they are interfering with normal perception and are leading to sensory conflicts.” Both of these alternatives are currently being tested.

The study’s aim was to screen for “electrophysiological differences between subjects experiencing synesthesia and matched control subjects.” The results indicating cortical inhibition are in agreement with my general line of discussion.

4.9.9 Functional Imaging Studies

Three important developments occurred since the first edition of this book: (1) the discovery of a specialized color area in the human brain, (2) the invention of functional magnetic resonance imaging fMRI and (3) the refinement of positron emission tomography (PET) as investigative tools in neuropsychology.

Much is known about the psychology of color perception and much remains to be learned, so the preponderance of color among synesthetic responses of all kinds naturally piques interest in the neurophysiology of color perception. Lueck & colleagues first demonstrated the existence of a specialized color area in the human brain in 1989. They used the PET method to measure cerebral blood flow in three male volunteers. They localized this V4 analog of the macaque to homotypic isocortex near the lingual and fusiform gyri. Later fMRI probes pinned down V4’s location on the lateral aspect of the collateral sulcus on the fusiform gyrus (McKeefry & Zeki 1997).

Of most interest, the initial proof that an assemblage of neurons devoted to color does exist in humans showed the “color module” to be asymmetrical. That is, the average increase in rCBF during color stimulation compared to that during gray stimulation was 28% in the left hemisphere and 12% in the right (standard deviations were not published). According to generally accepted principles of brain metabolism, this indicates a robust activation on the left, the lower right-hemispheric value being near the typical 10% cutoff expected for passive flow. Subsequent work has not upheld a marked lateralization of V4, however. Later work also implicates three bilateral sites in chroma operations: V1 (which is wavelength selective), anterior ventral occipitotemporal (VOT), and posterior VOT (Beauchamp et al. 2000). Further research will settle the issue of possible lateralization of color perception.

As with rCBF measured by either the xenon or PET methods, fMRI activation also correlates with neuronal metabolism. In monkeys and humans, the fMRI blood oxygenation-level dependent (BOLD) signal is directly proportional to average neuronal firing rates (Heeger et al. 2000; Rees, Friston, & Koch 2000). In humans, the activation map is dependent on the signal-to-noise ratio (Parrish et al. 2000).
Using PET in six women with color-word synesthesia, Paulesu & colleagues (1995) found activation in visual association areas (postero-inferior temporal [PIT] and parieto-occipital [PO] junction [BA 20/37 & 19/7]). Activation also occurred in the right prefrontal cortex (BA 46/10 & 44/9), insula, and superior temporal gyrus (BA 22), areas with rich limbic projections. In addition to this asymmetrical activation of visual and nonvisual, nonauditory sites by auditory stimulation, the authors found focal deactivations in the left lingual gyrus (BA 18, an upstream visual area) and insula during word stimulation. Taken with the foregoing evoked-response trials (see §4.9.8), this landscape may reflect inhibition.

The posterior activation in MW (probe T0) is consonant with the posterior activation found by Paulesu’s group. Recent PET studies with emotionally valenced olfactory, auditory, and visual stimuli show increased rCBF in the left orbitofrontal cortex, temporal pole, and superior frontal gyrus regardless of the stimulating modality. Only valenced olfactory and visual stimuli activated the hypothalamus and subcallosal gyrus, with olfaction additionally activating both amygdalas (Royet et al. 2000). It is further noteworthy that olfactory stimuli that trigger hedonic or edibility judgments also engage primary visual areas (Royet et al. 2001). Orbitofrontal and visual areas appear to have a complementary interaction during odor processing depending on whether the task involves judgments of familiarity or comestability (Royet et al. 1999).

We revisit the PET results in spoken word-color synesthesia in chapter 6, §§6.5 and 6.6. For now, Paulesu & colleagues point out that the rCBF deactivations in the left lingula (a visual association area) and insula (a transmodal integrating entity) “occurred in the absence of any direct stimulation of the visual system…” The authors have illustrated a cerebral landscape during chromatic-lexical synesthesia that I believe is consistent with the earlier discussion regarding relative relations between high vs. intermediate levels of neurologic processing. That is, the most differentiated (or “highest”) unimodal areas such as V1 and V2 did not activate in their subjects. The authors do state that chromatic-lexical synesthesia “is a one-way process,” synesthesia being evoked “from language to color but not vice versa, and because no direct visual stimulation occurred … the activity observed in at least some of the visual cortices (e.g., the lingual gyrus) might result from … inhibitory feedback.” These results will hopefully be clearer after we have discussed synaptic hierarchy and cerebral topology, and revisit these functional images, in chapter 6.

As recent years have seen a revived interest in synesthesia, a simplistic dichotomy has developed, mostly among reporters and non-scientists, seeking to describe the phenomenon in terms of either “limbic” or “cortical” brain function. I say more about this unfortunate
oversimplification in chapter 6, §6.6 where I hypothesize a neural basis of synesthesia. For now, let me point out that the words “cortex” and “limbic” are shorthand terms that refer to a complex assortment of neural structures and their projections. There exist, for example, five kinds of cortex, even though neuroscientists typically mean “neocortex” when they employ the term “cortex.” Likewise, parts of the limbic system are either cortical or corticoid entities. The word “limbic” refers to a broad collection of neural entities of varying histologic type—Nieuwenhuys, Voogd, & van Huijzen’s atlas (1988) requires twenty-four separate illustrations to convey the limbic system’s pertinent anatomical features and forty-three pages of text to detail its connections. This is why working scientists need terms to distinguish one entity from another, this concept from that. Besides, neither neocortical nor limbic entities operate in a vacuum; any cognition partakes of each. It is only because of the customary emphasis on logic and reason and the historical neglect of emotion by neuroscience that I emphasize limbic contributions to cognition. But I do not do so with the intent of excluding neocortical elaborations.

What is most remarkable about Paulesu’s study is that the primary visual area does not activate during the stimulus task, thus demonstrating—for the first time—that it is possible to have a conscious visual experience without the participation of V1, the classic primary visual area. Neither high-level idiotypic cortex (i.e., V1) nor the surrounding unimodal isocortex (V2, V4) activated. Inasmuch as V4 is identified as the color region and we assumed it participated in synesthetic color, we must ask, From where does the experience of color arise? This failure of V1 activation shatters the contemporary explanation of blindsight (Cowey & Stoerig 1992; Zeki 1993). It is not surprising that conscious visual perception without the engagement of V1 results in photisms whose location in the visual field is vague and of uncertain distribution in Euclidean space. The authors suggest that neurons having a “much looser representation of the visual field” than V1 or even V4 are engaged. (Work performed subsequent to their paper shows the V4 complex to have two subdivisions: the posterior V4 unit is retinotopically organized whereas the anterior V4a is not [Bartels & Zeki 2000].)

The authors propose scanning the PIT and PO areas as a possible test for synesthesia. Whereas this might suffice if one were interested only in the rare instances of chromatic-lexical synesthesia in which a spoken word evokes color, this strategy would not apply to all sensory permutations or those in which color is not an element. When proposing a neural mechanism, I believe a general theory that is consistent across all types of synesthesia is desirable.

This functional metabolic study and the one performed a decade earlier on MW, aside from being technically different, perhaps represent different extremes. Whereas MW’s is a single case study of a robust
case of spatially extended polymodal synesthesia, Paulesu & colleagues average the results of their six subjects with a rather mild type of synesthesia and use the method of PET-MRI coregistration. PET itself has poor spatial resolution, and the six MRI images were first individually transformed onto a stereotactic template and then averaged. In other words, the raw data have been multiply transformed. Furthermore, in the majority of "colored hearing" cases the range of auditory stimuli is fairly broad. Paulesu’s group used subjects who experience colored shapes only upon hearing a spoken word, a very small subset. However, within the scope of colored hearing evoked by language, “speech only” does represent a pure, albeit small, category. The noteworthy feature of their synesthetes “is the link between word sounds, orthography, and specific colors.” Last, the authors do not state what affect, if any, accompanied their subjects’ synesthesiae. The possible lack of affect in contrast to MW’s marked affect during synesthesia makes comparing the two studies difficult.

Part of the problem in knowing whether averaging or the single-case study is better is knowing whether intermodal associations (synesthetic metaphor) and the perceptual synesthesia whose diagnostic criteria were enumerated in the previous chapter lie along a continuum. Similarly, does it matter whether an experimenter uses robust instances of synesthesia, such as MW or those who are polymodal, or whether milder cases involving, say, only colored letters that are not spatially extended are equally valid? We do not yet have answers to these questions.

The sensitivity of evoked potentials and the resolution of positron scanning generally make averaging necessary. However, fMRI is suitable for single-case methodology. Emrich et al. (2001) used fMRI in their pilot studies of synesthetic subjects. The cerebral landscape during synesthesia differed in different subjects; on the other hand, the patterns of activation and inhibition for any individual synesthete were easily replicated. As Emrich states, “Every synesthesia proband has his own brain.”

Averaging can eliminate differences, which is why I fear doing so may be premature given our meager hard data. Until we know better what the neural basis of synesthesia is, we should question assumptions that synesthetes are homogeneous, no matter which subgroup they may belong to.

In term of Emrich’s hypothesis of hyper-binding, he interpreted the evoked potential studies (see §4.9.8) as demonstrating a prefrontal associative coupling between cortical, prefrontal, and limbic entities. Single-subject studies with fMRI showed very specific cortical arousal patterns that could be replicated in single subjects. Combining individuals in one study, however, may average out these changes (Weg-mitteln, i.e., individual differences, “fade away” when an averaging
procedure is performed). Emrich suggests that an as yet unidentified limbic entity acts as a “bridge” (Brücke) between representations of two cortical association areas, “constituting a binding in the actual sense, so that both cognitive unity as well as evaluative unity coalesce as a coherent whole.” A plausible supposition, Emrich claims, is that these bridge functions proceed over hippocampal structures. If so, the intermodal unit in each case would involve memory context, which is perhaps why synesthesia is so memorable. Further exploration will show whether his concept is valid.

4.10 rCBF REDISTRIBUTION IN SYNESTHESIA: ANALOGY TO MIGRAINE THEORY

Hypothetically, one way to regard synesthesia is as a recurrent, stimulus-induced redistribution of neural activation. The only experimental support for this are the odd redistributions of rCBF in MW and Paulesu et al.’s subjects, so my remarks in these next two sections are necessarily speculative.

All subjects have shown marked and unexpected perturbations of cerebral metabolism in response to mundane sensory stimuli. On reflection, this reaction is not so different from the conventional mechanism of migraine, wherein the clinical manifestations parallel the redistribution of rCBF and an electrical spreading depression (Hachinski 1987; Oleson 1987; Skyhøj-Olsen, Friberg, & Lassen 1987; Welch 1987). This explanation has been repeated since the mid-1800s, although no cogent reason exists why this should occur in susceptible patients, or indeed what specifically makes some individuals “susceptible.” Because this so-called explanation appears in countless texts, its lack of cogency seems not to bother anyone. Furthermore, its appealing simplicity has allowed the hypothesis to be grasped easily by both students and patients.

The debate over neurogenic versus vascular causation of migraine reaches back more than 100 years. Abundant data show that both the changes in blood flow and the spreading depression cross boundaries—both vascular and anatomical ones. This is logically inconsistent with the standard explanation, even though vascular changes are well documented in, and are currently accepted as, the cause of metabolic depression. The spreading depression of Leão (Lauritzen et al. 1982; Leão 1944) is a surface-negative slow potential that spreads, like a wave in a pond, across anatomical boundaries such as the central sulcus. It is similar to contingent negative variation, an event-related slow cerebral potential modulated by central catecholaminergic systems. Unlike synesthesia, which is evoked, migraine does not appear to have an identifiable provoking stimulus. However, we currently accept as fact that
biochemical and vascular alterations happen in migraine for no apparent reason whatsoever and then resolve (Hadjikhani et al. 2001).

Like synesthesia, migraine can be influenced by drugs. Noordhout & colleagues (1987) showed normalization of contingent negative variation in migraineurs treated with beta blockade. Their findings support a direct effect of beta blockade on the neural generators of contingent negative variation. Apropos of the upcoming discussion of temporal lobe-limbic structures in chapter 6, Reznikoff & colleagues (1986) demonstrated by quantitative autoradiography that beta blockers are most concentrated in all subfields of the human hippocampus. Beta blockade, then, might be a fruitful manipulation to explore in synesthetes.

There has never been consensus among headache specialists as to the definition of migraine let alone its cause. Although rCBF changes (both ischemia and hyperemia) are well documented, the neurogenic school believes these changes to be secondary to neurotransmitter release: adrenergic sympathetic systems in medulla, pons, and hypothalamus are one candidate; serotonergic release from the midbrain raphé is another. Given no consensus, I will extend the analogy to synesthesia no further. I have also not discussed migrainous photisms in this section on overlapping phenomenon, but the well-known lines, grids, concentric circles, and zigzag fortification spectrum should be borne in mind during the upcoming discussion of Klüver’s form constants.

4.10.1 Speculation Regarding Disconnection and Confabulation

A number of authors have weighed the idea that intersensory associations are relatively inconspicuous and, with the development of conceptual thought and language, tend to be suppressed (Boring 1942; Hayek 1952; Werner 1948). Hayek believed that the development of transmodal metaphors rested on more than just a turn of phrase and was a product of actual perceptual experience, an approach that was later extended by Lakoff & Johnson (1980), as well as Marks (1987).

What happens when we invert this argument? The inverted point of view, which is conceptually similar to microgenetic theory (Brown 1988; Hanlon 1991), would hold that synesthesia results from disconnection of language modules and the ensuing emergence of unelaborated cross-modal percepts.

The inferior parietal lobule (IPL) would have to be central to any concept of synesthesia as a disconnection. Because the IPL figures prominently in language, is athalamic, and receives afferents only from association cortices, disconnection or suppression of this region is consistent with my idea of relatively reduced neocortical influence (homotypic isocortex) during synesthesia. It is precisely in this region of the IPL where intermodal associations between primary nonlimbic sensory
modalities are powerful. The maturity of this region may also be important. In keeping with its late development, the IPL has a highly variable gyral structure. Flechsig (1901), Yakovlev (1962) and Yakovlev & Lecours (1967) showed that it is late to myelinate, matures late cytoarchitectonically, and is one of the last cortical areas in which dendrites appear.

Accepting this premise leads us to consider confabulation. Based on at least a partial disconnection of the IPL or other association cortex from the speech region, a person is left to confabulate, for example, that something heard is really something seen, hence synesthesia. Concomitantly, disconnected language implies a relative enhancement of anterior temporal-limbic entities to provide a sense of validity that the percept experienced is real rather than a hallucination, an image, or a dream (see §9.6).

Clinically speaking, confabulation takes us far afield from synesthesia, given than the former only appears in pathologic settings (Weinstein, Cole, & Mitchel 1963; Weinstein, Kahn, & Slote 1955; Geschwind 1965b). That is, confabulation does not occur in the absence of a deficit; it is less marked in the presence of aphasia; it is more likely in the presence of some general impairment of awareness such as dementia or encephalopathy; and it is more likely to occur with disease of association cortex or association fibers (either commissural or interhemispheric) than with injury to primary sensory pathways up to and including primary idiothetic cortex. Pursuing confabulation on theoretical grounds, however, does lead to thought-provoking conclusions.

Conceptually, confabulation is the filling in of gaps, a recitation of imaginary experiences to compensate for impaired perception or lost memory. Now, split-brain patients and those who confabulate taught us that the ability of the speech area to describe something is no guarantee that we get an accurate description of events going on in another part of the brain. Clinically, confabulation is an attempt to explain what the patient cannot understand. Part of the problem lies in perceiving the patient as a unified entity. Those with clinical disconnection syndromes demonstrate that the person who speaks is not the same as the one who perceives. They are distinct even when typically unified. Why should a speech area disconnected from a site of primary perception elsewhere be able to describe accurately what is going on? It cannot.

Clinically, confabulation is similar to release hallucinations. As Geschwind noted, the conventional model assumes that association areas never fail to send a message to the speech region and always send positive messages regarding circumstances. If the primary visual cortex were destroyed, the speech area would still remain innervated by visual association cortex. In this case the association cortex, receiving no stimulus from calcarine cortex, would send the “message” to the speech area that there is no visual “message”—that is, everything is black.
Destruction of association cortex or its projections is an unphysiologic state—one in which no message is received. In this abnormal state, the speech area may react to its own spontaneous firing or to random inputs from subcortical pathways. A partial disconnection would mean that neural signals are inadequate to convey all the information for the “true” stimulus to reach conscious perception. This may lead to errors less bizarre than those that occur with total isolation of the speech cortex. Thus, sound may be misspoken of as something seen, as in synesthesia.

Release of the anterior temporal cortex (which is paralimbic tissue and not neocortex; see chapter 6, figures 6.5 and 6.6, and table 6.4), and which communicates to the opposite side via the anterior commissure (another limbic structure) rather than the corpus callosum (the primary commissure for neocortex), implies that connections to medial temporal structures, particularly the hippocampus and insula (which communicate with all sensory modalities), may be particularly enhanced. Frontal disinhibition operative during this state may explain the affective tang of synesthesia and the surety in individuals’ minds that what they are perceiving is valid and true.

I have spun out the above conjectures with the intent of stimulating thought along the lines of general principles.

4.11 RELATION OF SYNESTHETIC PERCEPTIONS TO KLÜVER’S FORM CONSTANTS

At this point, it is helpful to review the characteristic features of synesthesia. Synesthesia is (1) involuntary but elicited, (2) spatially extended, (3) memorable, (4) emotional, and (5) discrete and consistent. It appears to be attenuated by CNS stimulants and accompanied by perturbations of cortical metabolism (deactivations and activations). The discrete nature of synesthesia, particularly the generic and restricted nature of synthetic percepts, brings to mind Klüver’s “form constants”² (Klüver 1942b, 1966). Synesthetes never see pictorial dreamlike scenes or otherwise have elaborate percepts. They perceive blobs, lines, spirals, lattices, and other simple configurations. Starting in the 1920s Heinrich Klüver identified four types of consistent hallucinogenic images: (1) gratings and honeycombs, (2) cobwebs, (3) tunnels and cones, and (4) spirals. Variations in color, brightness, symmetry, and replication

²The use of the word “form” by Klüver is unfortunate, since what is really constant is the shape of the percept or, even more precisely, the configuration of its elements. Form refers to the larger construct of a work, such as the sonata form in music, or the form of composition in a painting. Because of its historical context, however, I use the term “form constant” to refer to this constancy of configuration, which is characteristic of all imagery and hallucinations.
provided further gradation of the subjective experience. The point is that given a wide variety of stimulation, the brain seems to respond in finite ways.

Klüver’s work was repeated and extended by Siegel (1977) and Siegel & Jarvik (1975). Klüver showed that a limited number of perceptual frameworks appear to be inherent in the fabric of the CNS. They may be part of our genetic endowment.

The analysis … has yielded a number of forms and form elements which must be considered typical for mescal visions. No matter how strong the inter- and intra-individual differences may be, the records are remarkably uniform as to the appearance of the above described forms and configurations. We may call them form-constants, implying that a certain number of them appear in almost all mescal visions and that many “atypical” visions are upon close examination nothing but variations of these form-constants. (Klüver 1966, p. 22)

Unaware of Klüver’s work, Horowitz (1964, 1975) rediscovered the redundant elements of hallucinations and argued similarly that a “perceptual nidus” resides within the visual system itself. There are “certain constancies” that the visual system itself contributes to illusory and hallucinatory phenomenon as well as to objective perception.

Cognitive and perceptual disturbances occur if metrizamide (a radio-opaque contrast agent) penetrates cerebral tissue. For example, patients have seen brightly colored geometric patterns and cloud formations following metrizamide cisternography of the posterior fossa, thought by the author to result from chemical penetration into the temporal lobe (Bachman 1984). Likewise, similar generic images occur during sensory deprivation (see §4.5). McKellar (1957) showed that form constants are present in a wide range of states, including drug-induced, hypnagogic, psychotic, and delirious states. V. Kandinsky (no relation to the artist) reported such configurations during a feverish delirium: “pictures, microscopic preparations, or ornamental figures were drawn on the dark ground of the visual field” (1881, pp. 459–460).

Klüver’s analysis was a reaction to the vagueness that others interested in hallucinations and imagery had resorted to in their descriptions. Klüver suggested that the novelty of the visions and vivid coloration captured the subject’s attention more than the shape did, and that subjects were often overwhelmed by the “indescribable” nature of the vision and simply yielded to cosmic or religious explanations.

Figures 4.9 to 4.13 demonstrate that the form constants, often demonstrating axial or radial symmetry, are found in diverse settings—from art to the world of natural phenomena—from the kinds of medical images I have discussed, to the artwork of synesthetes, and even to the craftwork and cave paintings of primitive cultures. The form constants evident in the variety of images discussed differ from the shapes seen in entoptic (“within the eye”) phenomena, such as an individual’s abil-
Figure 4.9 The generic shapes of Klüver’s form constants are common to hallucinations, synesthesia, imagery, and other cross-modal associations. (From Cytowic [1996].)
Figure 4.10 Eyes-open projected visual images in cocaine-induced hallucinations, showing the typical grid, lattice, and linear configurations featuring axial and radial symmetry. The circular figure in the lower right-hand corner is identical to the “fortification spectrum” seen during the aura phase of migraine. (From Siegel [1977] with permission.)

ity to see his own retinal blood vessels, vitreous floaters, or muscae volitantes. Although retinal vessels and floaters bear some resemblance to the cobwebs and amorphic categories of form constants, their appearance is fixed and they can be attended to or ignored at will. Many adults have opacities in the vitreous of the eye that can project images outward onto the environment.

Entoptic perceptions move with the eyes, whereas perceptions of cerebral origin are independent of eye movement. Afterimages result from fatigued retinal photoreceptors and are complementarily colored; images of cerebral origin are often chromatic. Retinal vessels and floaters look like cobwebs or blobs, are fixed in appearance, and can be viewed or ignored at will. The muscae volitantes are the actual corpuscles coursing through vessels near the macula. It is normal to see one’s own, particularly when looking at a bright sky, a patch of snow, or other area of high contrast. They travel in lines or arcs, then disappear. Awareness of one’s own normal retinal circulation is termed
Figure 4.11  Tunnel form constant. (Top) “Bright light” with explosion from the center to the periphery. Color may change with the dynamic development of the form. (Bottom) Spiral form constant, also with pulsation and rotation. Drawn by the patient from a drug-induced hallucination. (From Siegel & West [1975] with permission.)
Scheerer’s phenomenon (1924). Traction of the vitreous or retina causes flashing lights, arch-shaped and achromatic phosphenes called “Moore’s lightning streaks” (Moore 1935). They result from mechanical deformation of the retina. Macular edema or hemorrhage will produce distortions such as heat waves, and glaucoma causes halos and rainbows around objects. Certain maculopathies can also cause dysmorphopsia.

Visual illusions and hallucinations may be either positive or negative symptoms that occur in drug reactions or withdrawal, delirium, epilepsy, and mass lesions. They may be elementary or formed. Epileptic discharges in Brodmann areas 18 and 19 (lateral occipital) are said to cause twinkling or pulsating lights. Striate lesions produce elementary
visual sensations of dark shapes, phosphenes, and flashes that may be stationary or moving, colored or achromatic. Gowers (1893, p 166) noted that red is perceived most often, followed by blue, green, and yellow. These visions may appear straight-ahead or in the visual field opposite the lesion.

Some individuals have a rare ability to see their retinal vessels and other internal ocular structures, and to produce a projected image of a cluster of balls or “geode,” often bluish or purple in color. Exactly what they are viewing is not clear, but may be an elevation of the optic disk. There is ample tissue between the surface of the eye (the cornea) and the retinal ganglion cells that actually responds to the incoming flux of light. The retina itself has 10 layers, nine of which stand in front of the ganglion cells. In front of these 10 layers are the aqueous and vitreous humor, and the corneal strata.

Figure 4.13 Four samples of Huichol Indian embroidery, showing geometric lattice forms. Lattice form constants are commonly found in the hallucinatory visions induced by peyote, a hallucinogen that holds a stable place in Huichol Indian culture.
With time, Klüver’s notion of form constants gained acceptance. “There are fewer mechanisms than etiologies of hallucinations. There is thus no reason for surprise if different precipitants give wholly or partly similar hallucinatory experiences” (Keeler 1970). The tendency to attach supernatural meaning is now understood as attributable to the referential nature of the perception along with its emotional content. For example, Adler (1972) said, “To attach cosmic meaning to these events is a presumption. We are more likely confronting here the projection of affect onto the outside world. The response that one thinks he recognizes is his own projected and reflected image.”

4.12 CONCLUSION

The discrete and generic nature of synesthetic percepts should be more evident now that we have examined various perceptions that overlap synesthetic experience. The simplicity of the parallel synesthetic sense is consistent with a neural mechanism operating at an intermediate level of the neuraxis.

*Note added in proof:*
Smilk & Dixon (2002) recently reviewed the subjective-objective relationship between synesthetes’ experiential reports and experimental investigation of their phenomenology. Interpreted in the context of subjective, objective experiment synergistically advances our understanding of synesthesia. The authors argue for combining first-person and third-person perspectives. They review protocols using Stroop interference as well as the apparently incommensurable results from priming experiments (Mattingly et al. 2001), i.e., the time frame during which binding occurs. They argue against averaging subjects, and suggest a feedback scheme for the influence of synesthetic photisms on the perceptions of digits. They also touch upon concept-driven synesthesia.

The psychology of spatial cognition has long been dominated by the study of visual input, whereas experience shows spatial perception to be a superordinate category. In semantic evolution, spatial adjectives are among the first to extend their domain of meaning to other modalities (Williams 1976). For example, the fundamentally spatial adjectives of “high” and “low” become metaphorical when applied to auditory pitch.

Vision, hearing, touch, and smell can be spatially extended (Klüver 1966; Siegel & Jarvik 1975; Sacks 1992). We distinguish near from far in the spatial territory of the immediate limb axis as opposed to telecepcion (i.e., perception at a distance, as in vision or hearing). Additional concepts regarding proprioception, body schema, vestibular orientation, and auditory scene analysis illustrate the belief that our sense of self occupies Euclidean space. (See figure 5.1 as well as, perhaps, Edna St. Vincent Millay’s sonnet, “Euclid alone has looked on Beauty bare.”)

Our thinking about objects (qua representation) and Euclidean space (qua attention) is not entirely clear, so I will elucidate a model that is more hypothetical than I prefer but one that at least is based on clinical observations rather than abstractions.

A number of clinical deficits involving spatial knowledge appear qualitatively similar on the surface but have disparate neuropathology. For example, the inability to identify an object’s formal characteristics (agnosia) dissociates from the inability to represent it or localize it in space. Because we are not certain whether humans possess an Aristotelian common sensibility of “configuration,” we are left with one list describing specific performance deficits and another list of lesion sites. Table 5.1 will refresh your memory as to some general anatomical correlations of spatial aptitude.

It may be that Gestalt psychology, sometimes considered passé, can yet provide some fruitful ideas.
Figure 5.1 Euclidean coordinates in human sensation hark back to the bilateral symmetry that exists in all vertebrates. Not only is the body organized in this frame of reference, but so also are the brain and special senses, including the rotational axes of the semicircular canals.

Table 5.1 General correlations of spatial ability

<table>
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<th>Distributed</th>
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<td></td>
<td>Right hemispheric network for directed attention = reticular (arousal) plus 3 separate representations in frontal, parietal, and cingulate cortices for movement, spatial maps, and direction of attention to emotional targets.</td>
</tr>
<tr>
<td></td>
<td>Unimodal visual association cortex</td>
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<td></td>
<td>Loss of motion, spatial orientation, stereopsis, depth</td>
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<td></td>
<td>Unimodal auditory association cortex</td>
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<td>Acoustic spatial discrimination</td>
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<td>Unimodal somesthetic association cortex</td>
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<td>Asomatognosia, right-left confusion</td>
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<td></td>
<td>Unimodal motor association cortex</td>
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<td>Scanning and exploring contralateral hemispace</td>
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<td>Heteromodal premotor cortex</td>
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<td></td>
<td>Difficulty directing attention to targets</td>
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<td></td>
<td>Heteromodal (temporo-parieto-occipital) association cortex</td>
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<td></td>
<td>On either side: unilateral neglect (anosognosia, r &gt; 1 parietal)</td>
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<tr>
<td></td>
<td>Language hemisphere: constructional apraxia, finger agnosia</td>
</tr>
<tr>
<td></td>
<td>Nonlanguage hemisphere: dressing and constructional apraxia, loss of geographical knowledge, spatial misalignment of the body in Euclidean space</td>
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From Cytowic (1996) p 419.
5.1 LEGACY OF GESTALT PSYCHOLOGY

The German word *Gestalt*, meaning "form" or "shape," can also be translated as "configuration," and refers to a perceptual object whose structure comprises a unified whole incapable of being expressed simply in terms of its parts. An example is a melody, as distinct from the notes that constitute it.

The central tenet of Gestalt psychology is that the whole is different from the sum of its parts (Kubovy & Pomerantz 1981; Palmer & Rock 1994). The Czech psychologist Max Wertheimer (1880–1943) published a paper on apparent motion in 1912 that usually is cited as the birth of Gestalt psychology. An illusion of apparent motion occurs when stationary images such as the frames of a movie are viewed in rapid sequence. According to Wertheimer, the movement of the whole is qualitatively different from perceiving the static images of its component frames.

The very idea that humans perceive not the summation of experiential bits but rather the entire configuration went against the then-prevailing school of structuralism, which held a Cartesian view that complex perceptions could be dissected into elementary parts that are individually comprehensible. A square, they said, was "nothing but" the experience of a particular pattern of retinal points being stimulated, and a melody was "nothing but" the experience of a sequence of tones. (Up-to-date students will recognize a similar argument today by those who maintain that consciousness is "nothing but" neurons oscillating at 40 Hz. This view insists that a final and wholly physical theory of mind is not only possible but inevitable. This reduction also denies the existence of subjective qualia that cannot be accounted for in purely objective terms, something "it is like" for a person to smell a rose or feel pain, for example.)

Gestaltists explained perceiving a square or a melody in terms of emergent properties, overall qualities of an experience that are not inherent to its components. Emergent properties are common enough in the physical world. Wetness, for example, is an emergent property of H₂O molecules, and table salt has properties not possessed by its constituent ions sodium and chloride.

One of the Gestaltists' enduring contributions was pointing out that object perception could not be achieved solely by the image cast on the retina, because light rays coming from different parts of an object are no more related to one another than are rays coming from two different objects. Far from being obvious, their conclusion that the nervous system had to organize sensory elements—such as those caused by light rays falling on retinas or sound waves pushing on tympanic membranes—was rather controversial at the time. The concept that a
retinal image is passively transmitted to visual cortex for analysis has a long history, and was probably reinforced by the superficial resemblance of the eye to a camera (figure 5.2).

Gestalt psychology proposed an organization based on grouping or configuration, elements being perceptually grouped if they were similar, proximate, formed a closed contour, or moved in the same direction (figure 5.3).

A moment’s reflection reveals that even mental concepts have spatial qualities, though perhaps they are somewhat difficult to define formally. The Gestaltists claimed that everyday problems contain certain configurational demands that are readily grasped, a feature that inhibited random solutions to a problem (figure 5.4). The chief obstacle to insight, they believed, was becoming fixated on implicit assumptions
without realizing it. Once the fixation on one configuration was abandoned, the premise of a problem could be dramatically reorganized and accompanied by a self-evident solution (see figure 5.21 for a solution to the problem presented in figure 5.4). Aside from examples such as that in figure 5.4, it is common experience that once you see something a certain way you cannot revert to not seeing it in that particular configuration. This shift in how you see a problem is related to the shifting patterns experienced when faced with rivalrous groupings (see figure 5.3).

5.2 AUDITORY SCENE ANALYSIS

Sound source determination, or auditory scene analysis, yields knowledge of the environment, including spatial knowledge (McAdams & Bigand 1993). Unlike vision or proprioception, audition does not directly transduce the source sound. Mechanical transduction by the middle ear provides a time-frequency code of the acoustic field, and the central components of audition perform something like a spectral analysis. Perceptual regularities govern the temporal (sequential) and spectral (simultaneous) organization of sensory information necessary for auditory perception. The existence of harmonics, for example, exposes the fundamental nonlinearity of the ear, which transforms the purely sinusoidal vibration of the original source into a more intricate periodic wave, the Fourier analysis of which reveals it to contain frequency multiples of the original stimulus.

Although one could argue that peripheral audition is purely perceptual (even though evidence has accrued against this), central audition clearly requires attention, memory, and the transformations that we customarily label cognitive in making use of information gained about the auditory scene. Analytical hearing implies well-focused selective attention that is aimed solely by central processes. Furthermore, central

Figure 5.4 Without lifting your pen from the paper, connect the dots using only four straight lines. (See figure 5.31 for solution.)
descending pathways actually modulate the centripetal ones from the periphery and determine what we are to hear in the first place.

Whereas the auditory organ (the external ear or its analog) varies dramatically from fish to mammal, the labyrinthe architecture is nearly identical throughout the phylogenetic range of vertebrates (Buser & Imbert 1992, p. 124). Its afferent architecture is almost as complicated as that of the retina, though it differs in being markedly divergent (3000 inner hair cells support 20,000 output fibers to the CNS). A standard atlas will provide illustrations of the parallel and recursive auditory pathways.

The localization of sound identifies its origin in Euclidean space, whereas laterality distinguishes right from left. Auditory psychophysics tells us that the accuracy of human localization is frequency-dependent and nonmonotonic, maximal errors occurring between 2 kHz and 4 kHz. The complex folds of the external ear play a role in localizing sounds, as do movements of the head. (Animals can additionally move their ears; the horse pinna, for example, has 17 muscles.) Mostly, however, localization is accomplished through auditory means.

Lateralization in sound space begins to be coded at the level of the olivary complex, whereas sound localizing relies on two distinct processes. At low frequencies, one detects phase differences between the sound waves reaching the two cochleae, but at high frequencies one relies on interaural intensity differences. The latter is measured by binaural cells that respond to both cochleae. Some binaural cells are excited by binaural inputs, whereas other cells are excited by inputs from one ear and inhibited by inputs from the other ear. Usually, the contralateral ear is inhibitory.

Auditory projections are tonotopic in the medial accessory and superior olivae, the trapezoid body, and the inferior colliculus. Although the inferior colliculus has conventionally been considered the main integrative auditory structure, all these structures have a role in localizing sound. It is somewhat surprising to learn that the superior colliculus, conventionally known for visual integration, is an additional midbrain site that contains a topography of acoustic space. In addition to its well-known visual projections, the superior colliculus receives auditory and somatic inputs in its middle and deep layers (Buser & Imbert 1992, p. 283). Figure 5.5 illustrates some tonotopic and retinotopic projections.

In contrast to the strict tonotopic organization found in the auditory inferior colliculus, each sound-responsive cell in the visual superior colliculus has a spatial receptive field to which it responds. Some cells are frontal or hemispheric in their orientation. Others are omnidirectional. Whatever its auditory spatial field, a given cell has an optimal response in both azimuth and elevation. The spatial orientation and
Figure 5.5  (Top) The boundaries and different frequency ranges (in kHz) in the superior olivary complex. LSO, MSO, the lateral and medial olivary nuclei; MTB, medial trapezoid body. (From Buser & Imbert [1992] with permission.) Similar tonotopic arrangements exist in the colliculus, geniculate, and auditory cortex, although our knowledge of auditory space is premature compared to what we know of visual space and retinotopic projections, some of which are pictured (bottom).
most responsive area of these spatial cells are independent of the intensity of the sound stimulus.

Coexisting direct and crossed auditory projections assure that each cochlea is represented bilaterally in auditory cortex. A tonotopic representation projects sound frequencies in a regular and serially ordered way to auditory cortex. The cochlea also has a point-by-point representation in auditory cortex, as well as multiple maps. That is, many serial maps coexist within auditory cortical areas. Our knowledge of multiple sound representations is premature compared to analogous knowledge about multiple visual representations. Figure 5.5 conveys this comparative shortcoming.

The auditory system constantly receives a variety of sounds with different intensities and temporal disparities while also coping with reverberation and echoes. From this chaos, a spatial sound field is somehow synthesized and comprehended. Sometimes, we are surprised when we actually discover how part of this is accomplished. For example, although speech contains many high frequencies, it is the envelope of speech sounds that we exploit for localization, a succession of brief variations of temporal disparity, rather than the individual frequency components of speech.

We have yet to appreciate fully the sophistication of the auditory system. One distinctive feature, for example, is its descending efferent projections that can modulate many lower pathways from the cochlear nucleus to the receptor hair cells. Moreover, the descending connections are in register with the ascending tonotopic layout. The ability of these connections to influence the initial auditory inputs to the CNS is another example of how the brain is an active explorer rather than a sessile blob. Together with the previously mentioned gustofacial reflex (§3.4.1), these examples of how even lower brainstem processes can “decide” about incoming stimuli reflect my point that our hoary distinction between sensing and understanding needs overhauling. For a long time, our notion of this distinction has played a powerful role not only in how we imagine the nervous system but also in how we interpret the data flowing through it.

The olivocochlear bundle is the best-studied of the descending projections. Its efferent fibers from the superior olive directly influence both the inner and outer cochlear hair cells. Other descending pathways include corticothalamic neurons projecting to various divisions of the medial geniculate, auditory cortex projections to both inferior and superior colliculi, and projections from the inferior colliculus to the cochlear and olivary nuclei. All in all, the receptor hair cells of the inner ear can be influenced from levels ranging from the reticular formation to as high as the thalamus and cortex (Buser & Imbert 1992, p. 323).

Lastly, there is tentative evidence that audition has distinct “what” and “where” systems in a manner analogous to vision. Part of the an-
terior cochlear nucleus and the superior olive may form the anteriorly placed spatial auditory detector (the “where” component), whereas a dorsal system consisting of the posterior and dorsal cochlear nuclei, inferior colliculus, medial geniculate, and auditory cortex may be sufficient to decode or recognize acoustic patterns (the “what am I hearing?” component).

5.3 FORM CONSTANTS REVISITED

If I asked, “How many of you are fond of smoke and explosions?” I suspect that few would respond. If I asked instead, “How many of you enjoy fireworks?” the affirmative response might be unanimous.

Why do we enjoy fireworks so much? Millions of pounds of entertaining explosives go up all over the world, and millions of people turn out to watch them. What are they, these colored lights, moving flashes, and bangs? They are not real things in nature or representations of anything else, nor do they remind us of anything on an intellectual level. They are as abstract as Piet Mondrian or Jackson Pollock—and yet they provoke a strong emotional reaction, inducing millions to watch and walk away satisfied. Onlookers exclaim, “That was wonderful!” without being able to say exactly what “that” was. No other form of abstract visual expression is so popular.

It may be that the form constants can help explain the satisfying appeal of something as unnatural as fireworks. I touched on form constants earlier (§4.11) in the context of release hallucinations, synesthesia, and kindred subjective experiences that, at first glance, seem ineffable. It is often frustrating to those who would understand the neurology of such phenomena that subjects tend to be overwhelmed and awed by the “indescribability” of their experiences.

The spatial connotations of the term “form constant” give the false impression that what is perceived is stationary and invariant, when in fact the elements are highly unstable, continually reorganizing themselves in an incessant interplay of concentric, rotational, pulsating, and oscillating movements through which one pattern replaces another. This kaleidoscopic transition occurs at the approximate rate of 10 movements per second (Siegel & Jarvik 1975). These spatial and kinetic properties are readily seen in synesthesia, number forms, and the auras that herald migraine and seizure. They have less commonly been noticed, probably for lack of looking, in sensory deprivation, intoxications, febrile delirium, insulin hypoglycemia, and hypnagogic states.

What synesthetes experience is often projected in peripersonal space, rather than being in the mind’s eye. Subject DS provides an example of spatial extension in vision. On hearing music, she also sees objects—falling gold balls, shooting lines, metallic waves like oscilloscope
tracings—“floating on a screen” 6 inches from her nose. Her favorite music, she explains, “makes the lines move upward.”

A spatial extension of touch is expressed by the polymodal taste-smell-touch synesthete MW, when describing the tactile shapes he feels when tasting mint and reaching out to rub “cool, glass columns” (see §4.9.1 and 4.9.1.1). He spoke of “reaching through” rows of columns or of “turning my hand” to rub the back curvature. Even MW’s ordinary sense of taste has a spatial quality. He often remarked on tasting flavors in different locations in his mouth and head in a manner that professional chefs, for example, never acknowledge (see, e.g., Dornenburg & Page 1995). A spatial extension of taste also appears in the few reports of synesthetically colored taste (Downey 1911).

The elementary quality of such experiences, in contrast to a pictorial or verbal elaboration, is the essence of the form constants. In addition to the basic hallucinatory constants of lattices, cobwebs, tunnels, and cones, there exist movement constants of rotation, pulsation, and concentric organization that further describe the spatial and temporal flow of the hallucinatory experience, whereas variations in color, brightness, symmetry, and replication provide finer gradation. The geometrizing described by Klüver extends beyond the basic form constants in that the configurations multiply and reiterate themselves. (The term to describe this, pareidola, literally means “an image within an image”.) The self-organization of self-similar structures that differ chiefly in scale is, of course, now familiar from the study of fractals. The configurations of the form constants are not just visual phenomena but sensory form constants that can become manifest in any spatially extended sense (figure 5.6).

What is so striking about the fortification spectrum of migraine, for example, or the geometrizing of synesthesia and number forms is the orientation of their constituent parts. Initially, we believed these spatial and dynamic configurations reflected some anatomical structure such as the cortical columns or ocular dominance columns; later, we tried mapping it to some prototypical mental function. Recently, we have returned to anatomy in asking whether the activation of neuronal pools that respond to different orientations is responsible for perceiving these configurations (Lance 1986, 1993). The study of nonlinear dynamics tells us that self-organizing systems are far from equilibrium, a property that may underlie their capacity to change radically and unpredictably. In the brain, this property might underlie the kaleidoscopic and scintillating transformations that individuals report as part of these unusual experiences.

At present, we are still not sure what the physical correlates of the form constants are, although we do think that their existence points to some fundamental aspect of perception. This inkling is reinforced by the elementary quality of the perceptions themselves. The distinction
between elementary and elaborated percepts was previously illustrated by reference to epileptic synesthesia (§4.6.1).

In mapping his own scintillating migrainous scotoma, Lashly (1941) observed that its configuration remained constant as it expanded, as if some steady centrifugal force were pushing it outward. He noted a scintillation rate of ten flashes per second and calculated its pace of cortical spread at 3 mm per minute. The spreading depression of Leão (1944) later confirmed these features, as have the contemporary technologies of magnetoencephalography (Welch 1987) and fMRI (Hadjikhani et al. 2001) in showing a slow wave of excitation and inhibition during migraine.

5.4 NUMBER FORMS

The association of color, movement, and spatial configuration with concepts involving serial order was noted more than a century ago (Suarez de Mendoza 1890; Holden 1891; Flournoy 1893; Calkins 1893; Bos 1929; Weller 1931; Kloos 1931), but one hears little of this today in psychology. The British polymath Sir Francis Galton (1822–1911), best known for his studies of human intelligence, remarked on number forms in 1907:
The pattern or “Form” in which the numerals are seen is by no means the same in different persons, but assumes the most grotesque variety of shapes, which run in all sorts of angles, bends, curves, and zigzags . . . The drawings, however, fail in giving the idea of the apparent size to those who see them; they usually occupy a wider range than the mental eye can take in at a single glance, and compel it to wander. Sometimes they are nearly panoramic.

These forms . . . are stated in all cases to have been in existence, so far as the earlier numbers in the Form are concerned, as long back as the memory extends; they come “into view quite independently” of the will, and their shape and position . . . are nearly invariable. (Galton 1907, pp. 80–81)

Number forms occur with sufficient regularity among synesthetes that they might conceivably be regarded as a special instance of synesthesia. I was initially surprised when a number of synesthetes disclosed their number forms, and I later began to inquire routinely of new subjects. Ascertainment of number forms in synesthetes, therefore, is incomplete (table 5.2). Figure 5.7 illustrates several number forms collected by Galton; it is typical that the lower integers receive more psychophysical space than higher numbers.

As with form constants, number forms also have a dynamic quality. One student complained to her mathematics teacher, “I’m having difficulty because the digits keep going up to their places (Bowers & Bowers 1961, pp. 244–247). Like synesthetes, those who possess number forms express amazement that not everyone “sees” numbers as they do or that anyone should find such spatial configurations odd. As my subject MP remarked, “It never occurred to me that it might be unnatural to visualize the whole alphabet (or numbers),” and subject CS states, “My entire life, everything, has a place that goes all around my body.” Nobel physicist Richard Feynman (1988) saw colored equations projected in front of him, just as many synesthetes see colored integers (see e.g., SdeM). They claim that the color helps them perform accurate calculations. Bowers & Bowers (1961) estimated that 3% of the population experiences unique configurations for serial items. Shanon (1982) estimated that 4.5% of the population has automatic and consistent color associates for concepts with linear order (e.g., numbers, days of the week, music). Eighty-three percent of his respondents were women. These estimates are about ten times the current population estimate for synesthesia.

Neither Galton nor Bowers & Bowers speculated on the origin of number forms. They do not indicate high mathematical ability or defi-

<table>
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<tr>
<th>Subjects with synesthesia only</th>
<th>Subjects with both synesthesia and number forms</th>
<th>Subjects with number forms only</th>
<th>Number form projected?</th>
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<td>33</td>
<td>4</td>
<td>5</td>
<td>6/9</td>
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ciency, nor do they seem to be correlated with any specific intellectual
talent or mental dullness. The current data do suggest a relative defi-
ciency in arithmetical competency. Subjects DS and MW, however, are
frankly acalculic and have some other features of Gerstmann’s syn-
drome. The forms help greatly in remembering numbers, and in spell-
ing, organizing personal calendars, and time management. None of the
current subjects have been impaired by possession of a form; all find it
beneficial.

Some people have forms for entities other than numbers. Galton
mentioned forms for the months and the alphabet: “It is a common

Figure 5.7 Number forms collected by Galton (1907). Note the greater psychophysical
space often given to the more frequently used integers. The elements of a number form
almost never occupy equal spaces. The elements often are colored, and sometimes have a
kinetic quality.
peculiarity that the months do not occupy equal spaces, but those that are most important to the child extend more widely than the rest. There are many varieties as to the topmost month; it is by no means always January.” Bowers & Bowers collected an elliptical form for the days of the week, with the weekend days being close together. They cited, but did not illustrate, examples dealing with ancestry and education.

The Canadian subject DB illustrates the uneven spacing for each contained segment of her number forms. Although one might expect at first that weekends or vacation months might occupy more psychophysical space, the examples from Galton and those of the current patients show no such orderliness. Figure 5.8 demonstrates this for DB’s months, wherein the first 6 months have equal vertical spacing, the last 6 are horizontally unequal, and December is uniquely upended. The form has existed since she can remember, and clearly before she recalls the regularity of school vacations or the arrival of warm weather in Canada. Figure 5.9 shows her form for the days of the week, which contains an internested time form for the hours. The detail of her time form is shown in figure 5.10.

Number forms need not exist in isolation. DB, whose forms for decades and months are shown in figure 5.8, also has number and alphabet forms. All of these are colorless. The complexity of these makes one wonder what use they could serve. Why not just rely on a calendar like the rest of us or count on one’s fingers if need be? The presence of DS’s upside-down time form internested within the day-of-the-week form is particularly complicated and would seem to require an undue amount of mental gymnastics to utilize. On inquiry, quite the opposite is true. “How else could I think? How would I know where anything is?,” she asks incredulously. DB is highly organized, efficient, and detail-oriented, much to the envy and admiration of her colleagues at the television station where she works. “We can all take lessons from her,” admits one coworker who finds DB’s forms amusing but concedes that she is highly organized and never relies on the bulletin board-type production calendar that the rest of the television crew uses.

This synesthete EW, whose chromasthesia extends over four generations, has number forms, as did a paternal uncle:

My father’s brother, a history professor who died at 90, told me shortly before he died that he saw things in space as I did. He did not see in color. His younger brothers died before I thought to ask them, but maybe that shows further that it is hereditary. He said things arranged themselves in a pattern before him like on a chart.

EW has patterns for the months, the days of the week, and for numbers.

I don’t know how anyone with synesthesia could be anything but artistic, in a way, because it has so much to do with color and symmetry and relationship to other appreciations. I find myself rearranging things in a more symmetrical
Figure 5.8 Decade and month forms of subject DB. (Top) Decade forms. Decades 1500 to 1800 take less psychophysical space. (Bottom) Uneveness of month spacing. See text for further details.
form at home and, mentally, outside! My study of languages (I was a Latin and French major) has been aided by it, I think, because the "amo, amas, amat," etc. was so easy for me to place in space as I studied them. Can you understand my meaning here? I also think I can be annoying to others sometimes when I want things to be just right, as I see them. It makes me more exacting and "prissy," but I can't seem to help it! (9/19/85)

DS, with colored hearing and hypermnesia, describes several ways of spatially perceiving items, from simple to complex. For her, time assumes the circular arrangement of the clock. "For example, 3:00 is always viewed as a physical space in its location on the traditional clock dial." The days of the week are linear, however, "perceived on a number line" [sic]. Referring to the months, which are arranged in a rectangle, DS says, "I always perceive myself somewhere on this month form."

Other aspects of DS's spatial perception are worth noting here. One is the visual perception of pain, which can be a thin, metallic vertical line

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**Figure 5.9** Days of the week and time of day, subject DB. (Top) Days of the week. Weekdays are equally spaced, with Saturday and Sunday given disproportionate psychophysical space. (Bottom) Time of day. Close inspection shows each day of the week to contain an upside-down time cell. Noon and 6 PM have more space than other hours, which are equal. Evening hours from 7 PM to midnight are fluid without distinct boundaries. Relative orientation of time is different for the weekend and weekdays.
or a dense, low, dark foglike sensation. DS’s visualizations are sometimes the making of schadenfreude:

I also experience pain visually. Pain (and pleasure) sensations evoke visual/spatial perceptions which are also in color. In fact, I was recommended for psychological counseling in high school because I told the assistant principal that when I kissed my boyfriend I saw orange sherbet foam.

Persons with synesthesia and those with number forms both claim a need to visualize in order to “think” or to “comprehend.” They are aware of the incongruity between their obvious intelligence and their apparent density in getting the gist of more abstract discourse or even the content of a lecture or business meeting. DS expresses this well:

I have discovered that I am a visual rather than an auditory learner. I MUST convert oral directions to the visual mode or I cannot function. When someone gives me a set of directions or informally tells me to do more than one thing, I cannot successfully complete the task unless I write it down or mentally visualize the words.

Figure 5.10  Detail of weekday time cell in DB’s days-of-the-week form. DB does a “mental conversion” when she sees the time cell in detail (cf. figure 5.9, bottom).
I see words when I talk, when others talk, and when I think. The words are similar to a [digital] clock display where each number flips down and is replaced by a new one. When someone asks me how to spell a word I must either write it or close my eyes and visualize it, letter by letter. (I am an excellent speller.) However, I have often left meetings without the vaguest idea of what was said. (9/17/84)

This visualization apparently contributes to synesthetes’ excellent memories. For example, “I remember words in print very well, including their location on the page.”

To summarize the features of number forms is to point out their similarities with synesthesia, for which reason I presently consider the form an instance of synesthesia. The forms are vivid; subjects talk about them matter-of-factly and in the present tense; they accept them as real and express surprise that everyone does not see numbers and other ordinal concepts in space. The shapes and positions are durable and consistent, although the point of view may change depending, for example, on the time of year or the subject’s age (see MP below). That is, although the viewing perspective may change, the relationships between items in the form remain constant over the subject’s lifetime.

Memorability is another shared feature of number forms and synesthesia. One recalls that Luria’s mnemonist remembered limitless amounts of material by recalling the synesthetic image that the item produced and particularly by recalling “where he put the image.” When he did make errors, it was usually because he “placed” the synesthetic image somewhere where it was later difficult to “see,” where it was poorly illuminated or blended into the background. His deficits of “memory,” then, were really “deficits of perception” as Luria stated.

Sometimes I put a word in a dark place and have trouble seeing it as I go by. Take the word box, for example. I’d put it in a niche in the gate. Since it was dark there I couldn’t see it … The same thing happened with the word egg. I had put it up against a white wall and it blended into the background. How could I possibly spot a white egg up against a white wall? (Luria 1968, pp 36–37)

The need to visualize seems strong in synesthetes, particularly if they wish to remember.

DS  Reading is not sufficient if I want to remember information. I MUST write down what I want to retain. This is true also with taking directions. In my Tae Kwando [sic] class I must translate each “form” [set of prearranged stances involving both arm and late movements] to a written code which I then VISUALLY memorize. I also verbally rehearse constantly when I need to remember, either vocally or sub-vocally depending on the situational appropriateness of talking to myself. (This was also evident at our meeting.) (3/1/87)

Klüver (1928, 1966) described numerous instances of individuals perceiving the form constants by touch as well as sight. “This quickly
rotating spiral is moving back and forth in the visual field. At the same time ... one of my legs assumes spiral form ... one has the impression of somatic and optic unity.” In another case, “The subject states that he saw fretwork before his eyes, that his arms, hands, and fingers turned into fretwork and that he became identical with the fretwork.”

A visual and haptic fusion is not uncommon in migraine auras (Sacks 1992) in which visual gratings are also felt as nets or cobwebs on the body. Even the fractal–like “mosaic vision” mentioned by migraineurs is a misnomer because the spatial extension, iteration, and kaleidoscopic transformations extend to touch as well as sight (see figure 5.6).

5.5 SENSATION OF MOVEMENT

I seem to have yoked our discussions of spatial knowledge and knowledge of movement, but this is all right. Akinetopsia, the inability to (visually) perceive motion, is extraordinarily rare, although admittedly examiners do not often seek out the defect. Since the days of British neurologist George Riddoch, it has been noted that patients with scotomata can often detect movement in their otherwise blind fields (Riddoch 1917; Zeki & ffytche 1998). Presumably, alternate geniculate pathways reach V5 without passing through V1. Remarkably, there exists just one unimpeachable case report of akinetopsia (Zihl et al. 1983). This patient lost all knowledge of her visual world when it moved:

She had difficulty, for example, in pouring tea or coffee into a cup because the fluid appeared to be frozen, like a glacier. In addition, she could not stop pouring at the right time since she was unable to perceive the movement in the cup (or a pot) when the fluid rose. Furthermore the patient complained of difficulties in following a dialogue because she could not see the movements of ... the mouth of the speaker. In a room where more than two people were walking she felt very insecure and unwell, and usually left the room immediately, because “people were suddenly here or there but I have not seen them moving.” She could not cross the street because of her inability to judge the speed of a car, but she could identify the car itself without difficulty. “When I’m looking at the car first, it seems far away. But then, when I want to cross the road, suddenly the car is very near.” She gradually learned to “estimate” the distance of moving vehicles by means of the sound becoming louder.

In humans, the downstream unimodal area concerned with motion is V5, a distinct feature of which is an ipsilateral field representation. Furthermore, ipsilateral V5 is activated by motion signals transferred from contralateral V5. Time delay analysis reveals that the signals related to visual motion are transferred from one V5 to the other through two segregated pathways (ffytche et al. 2000). This time differential together with the normal temporal disparity in consciously perceiving other visual qualia may explain the “suddenness” of objects appearing
or disappearing as in the above-mentioned patient. That is, attributes are normally perceived at different times such that color is perceived before orientation, which is perceived before motion, with approximately 30 ms and 40 ms lag times, respectively (Zeki & Bartels 1998b).

Though akinetopsia speaks of selective visual motion perception, it should be evident that the perception of motion per se is possible via other modalities (e.g., through sound and touch, as in the patient of Zihl et al.). The complementary observation is found in Riddoch’s report, which is based not on the loss of visual motion perception but on its retention in an otherwise blind field (a similar preservation of motion detection occurs in blindsight [see chapter 6, §6.5.2.1]). Furthermore, object recognition and movement dissociate, and shape can be derived from movement, a cognitive ability known as structure-from-motion (Rizzo, Nawrot, & Zihl 1995).

Akinetopsia, number forms, and the form constants of synesthesia, migraine, seizure auras, intoxications, and so forth reveal an elementary quality of movement that is nearly as difficult to elucidate as is space. As Klüver (1928, 1966) experienced in one of his own intoxications:

Sparks having the appearance of exploding shells turn into strange flowers . . . gold rain falling vertically . . . rotating jewels revolving around a center . . . feeling there is motion per se.

Above all, the form constants are abstract, independent of personal experience, free of context. They are just configuration, pulsation, flicker, drift, rotation, perspective . . . Do fireworks remind you of anything? Do they trigger a feeling of salience, of recognition? Their configuration and movement are strikingly similar to visual targets used to probe receptive fields (Zeki 1999), and thus may evoke strong salience and attentional responses. Perhaps the “that” of “That was great!” is an automatic experience of recognition.

5.6 SYNESTHETIC CONFIGURATIONS

Following are detailed examples of synesthetic configurations involving (1) uncolored spatial patterns for multiple concepts; (2) a simple color form for the days of the week; (3) an elevated memory for colored numbers with spatial extension; and (4) an extraordinary case of so-called memory maps that combines all of these elements.

5.6.1 Multiple Visual Forms

Subject CS: Multiple Visual Configurations, Projected, without Color
The letter-color associations of JM and others in chapter 2 showed that sometimes there is not so much color in the perceptions of those with
colored hearing. But there is no color at all in the synesthetic configurations of the following subject, CS. There is not even much variation in light and dark. What her patterns lack in chroma they make up for in profusion. CS is a 23-year-old right-hander with 16 years of education, employed in an advertising agency. She has never used drugs. She "discovered" that others did not have spatial forms.

I have only been aware of my "patterns" as something special when I tried to explain to a friend how I see the days of the week (each with its own peculiar positioning and three-dimensional shape), and he did not understand. My patterns have always been second nature to me, and that was my first attempt at vocalizing. (11/06/86)

Table 5.3 lists the kinds of patterns that she sees. These, she says, are some of her more common ones; she could enumerate more if she took the time to think further about it. Examples of these patterns appear in figures 5.11 and 5.12. Characteristically, the forms have been present as early as she can remember and are invariable. They appear automatically without any conscious volition on her part. As she ages, those forms that relate to her personal history grow from their terminal end, like a vine. Her diagrams do not convey a satisfactory sense of their expanse or three-dimensionality, but are rather like snapshots that afford only a single point of view. The perspective changes, however, as she moves about within the forms.

CS describes how the patterns are projected. Unlike afterimages, they do not move when the eyes or head change position. The form can be scanned. In explicating her pattern for shoe sizes (see figure 5.11), she says "the arrow points in the direction I'm facing, but not just the direction I am looking. For example, if I turn my head to the right the

<table>
<thead>
<tr>
<th>Patterns seen by subject CS</th>
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<tbody>
<tr>
<td>Numbers</td>
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<tr>
<td>Months of the year</td>
</tr>
<tr>
<td>Shoe sizes</td>
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<td>Height</td>
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<td>Salaries</td>
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<td>Time</td>
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<td>Grades—a grading scale and pattern for GPAs</td>
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<tr>
<td>My life</td>
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<td>My ages</td>
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GPAs, grade point averages.

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patterns don’t move with me—they stay fixed around my body. They are fixed in space (around my body). Make sense?"

Clarification discloses that it is not, for her, so much a shape that is projected as it is a spatial location to which she goes or reaches. “I’m not sure that I really see anything, but I go to a place where she number 1 or whatever is.” For the days of the week, she has a sense of being inside something. The “wall” separating Friday and Saturday is very tall, for example, and on Friday morning she can “look up” at Friday night. Similarly, the alphabet is always on her right-hand side and goes back over her shoulder (figure 5.12).

Though drawn by CS, the simple line drawings in figures 5.11 and 5.12 fail to convey the mental panorama they encompass or their depth. “These patterns aren’t accurate because in my mind they are three-dimensional: either lying flat in a single plane or else coming at me at an angle and crossing through other horizontal planes.” Below are some of the characteristics of her visual forms.

**Figure 5.11** Shoe sizes, height, weight, and body temperature patterns for CS. “Whenever I think of a shoe size larger than 10, I imagine the tip bent, and if somebody says they have a temperature—my mind goes to the area above 100°—to that corner.”
Location
I have always seen things in patterns—a sort of 3-dimensional map that stretches out in front of me at different levels and sometimes wraps around my head. They have always been there.

Durability and Change in Perspective
The patterns are very defined, have always been in the same place (and are constantly getting longer) as I get older. History is a good example: I cannot think of a period in history (or my past) without simultaneously (but not necessarily consciously) thinking of where it is 3-dimensionally in my mind! For

Figure 5.12  Patterns of her own age for CS. (Top) “My pattern up until high school.” At this younger age, the pattern faded into the foreground. (Middle) “My pattern now—my perspective has changed.” At age 23, the psychophysical space has enlarged posteriorly. (Bottom) History patterns. The direction of growth is opposite that of her personal chronology.
example, the Renaissance [see figure 5.12] is on a curve down to the left of my body. The idea, or thought, and the position are inseparable.

**Chronology and Magnitude**

Those periods that I know little or nothing about, but I know exist (something should be there on my time-line), are hazy. They are sort of gray, out-of-focus areas, but definitely not empty.

I have a different time-line for all chronological events—history, my life, the days of the week, etc. but I also “see” things like a geographic map, shoe sizes, and body measurements. These also have a linearity to them, with increasing and decreasing sizes and shapes, but why do I see my shoe size about a foot away from my right arm?

Some schools of philosophy believed that thinking and perceiving are inseparable. Luria certainly thought so for his synesthete, S. For CS, her forms also appear inseparable from thinking. They have always been present. They are fixed in space independently of head or eye movement and occupy intersecting planes. The absence of color, which is so prominent in synesthesia, makes CS doubly valuable. Here was the first case without coloration, and her prolific spatial forms should not overshadow the fact that color can be independent of the synesthesia itself. (Subject DB also has uncolored forms.)

CS provides her own best summary: “My entire life, everything, has a place that goes all around my body.”

### 5.6.2 Colored Spatial Forms

Compared to CS, other synesthetes may rely more on the color than the shape of their form as both a memory aid and for personal organization.

#### 5.6.2.1 Subject AC: Colored Days of the Week

AC is a 30-year-old right-handed female physician who has an autistic brother. There is no family history of sinistrality or synesthesia. She has never used drugs.

AC has always seen the days of the week in an unchanging configuration. The days form a rectangle of cells with equal space and with Monday leftmost. The color blocks are “baby blue, lavender, light green, maroon, blue, green, and white.” She has never mentioned her form to teachers or colleagues because “they would throw me out.” Likewise, she feels that she would lose credibility with patients should they discover she possessed such a form. She realizes such sentiments are irrational but “can’t help it.”

Her week form is useful for organizing her professional and personal schedule. It is primarily by color that she keeps track of “what I am doing and where I am supposed to be.” She boasts a good memory.
(revised Wechsler MQ = 125). Her MMPI shows no elevation of clinical scales.

5.6.2.2 Subject SdeM: Forms, Memory, and Navigational Incompetence  This 48-year-old right-handed woman, born in Yorkshire, England, holds a doctoral degree in urban planning and organizational studies. She is widely traveled and has lived among many cultures. She has no history of psychiatric illness, hallucinations, or use of recreational drugs. Family history is negative for mental illness and synesthesia.

She has three sisters (two artists, one nurse) and she, herself, has two fraternal twin boys; there is no other familial incidence of twinning. A younger sister is left-handed and all girls have mathematical difficulties. SdeM is the first in her family to go to university. Her synesthesias are an indispensable part of her life. Aspects are cataloged below.

Colored Numbers, Weekdays, and Months  SdeM was self-referred after seeing a television program on which I appeared called “I See Music.”

Unfortunately, I only caught the tail end of the program, but what I did see absolutely astonished me. I am 48 years of age and in spite of talking to anyone who would listen, I have never come across anyone who, like me, vividly sees numbers in colours and uses the consistency of those colours as a memory aid.

These are my colours:

1 = gray black       6 = yellow
2 = white            7 = light rust/brown
3 = green            8 = very pale blue
4 = deepish blue     9 = earthy brown (04/06/86)
5 = pink

Age of Onset; Spontaneity; Psychophysical Locale

I’ve always had it. I’ve never not had it. It was very intense as a child and got in the way of doing arithmetic. I’ve contrived to repress it because when I started putting formulae together [while studying physics], all I saw were colours and they would get in the way of the conceptual basis of what the formulae were about.

When someone says “2,” I see white. The number is incidental to the white. I know it’s 2 because it’s white. I’m disquieted if I see an advertisement with a 2 in the “wrong” colour. I can’t remember it. In school, if the teacher asked “what is 2 times 2?” I would blurt out, “Blue.” I couldn’t disaggregate it. The teacher and classmates thought I was very silly. The colour would come to mind first and I would have to consciously think of the answer.

My children had a book—Learn Your Numbers—but the colours of the numbers were all wrong. The world was wrong.
Integers larger than 10 combine their effects. She explains:

Zero has no color, only a space. With 21 I see the black and white. Beyond 100 it gets very confusing. It’s helpful when I can see the individual colors. For example, if I’m knitting and the phone rings and I’m on stitch 95, I can remember brown and pink and pick back up when the conversation is over.

The apparent labor involved in such thinking is striking. Why not simply remember “95” instead of remembering the translation to brown and pink? The difficulty in thinking is revealed when the colors are not there to help.

I have great difficulty with real numbers over a thousand. I have to think hard because the colors aren’t there to help me. If someone said, “Write down 4226” I have to think about it. It’s difficult.

**Spatial Extension** When asked where the numbers and colors are seen, SdeM replies that they seem “internal,” but there is a sense of looking at a screen down on another plane, about waist level. “It’s like an aura around a number, but the 2 is down on the screen. If I try to draw it, it goes away. It becomes very hard for me to see.” That is, she experiences rivalry between her mental spatial image and the perception of the written item. This is, of course, reminiscent of the examples of color competition both in synesthesia and eidetic imagery as discussed in §§2.5.2 and 4.3.2. Music is perceived as “colours, moving like dots, like people in a crowd at a football game when the camera zooms in on them.”

**Failure of Volition** SdeM can manipulate or suppress her images very little if at all. They can often get in the way and, as they did in Luria’s patient S, interfere with the semantic and meaningful attributes of everyday conversation. Also like S, her thinking tends to be concrete.

I can do nothing to alter my immediate reactions. If I tried to change the colour of the number—at least in my mind—it always slips back either to its own **colour** or to the **number** usually seen as the colour I tried to change it to. If someone gives me a particular number coloured in the “wrong” colour and I close my eyes to see the number I feel I have to struggle to get the world right again. I’ve had to impose other things on it for me to understand numbers for what they actually are instead of just these colours. I’m not good at math. I could conceptualize the physics, but I always got the answers wrong. As a not very able physics student at high school, the laws I had to learn would stay in my mind **only when I could “see” images of perfect spheres on perfect planes,** or density varying with pressure. Numbers mixed with letters in the physics formulae were very confusing.

**Durability** The colors never change—their luminosity and intensity are constant, and all numbers are equally easy to visualize. Written and spoken numbers are perceived the same. Note the absence of any red
hues; refer as necessary to the discussions regarding achromatopsia (§6.5.1) and color competition (§§2.5.2 and 4.3.2).

**Features of Her Memory: Eidetic Memory; Color Memory**  SdeM’s memory is vivid, durable, and appears to be equally good in auditory and visual modes. It is also highly detailed such that she can recall the doctor’s complicated instructions by “seeing him speak,” or she can visually re-create every schoolroom or house she has ever been in “right down to the cracks in the wall, or a piece of wallpaper coming off.” Her conviction is firm: “I know it is totally, absolutely undistorted.”

I have a very, very accurate memory of environments, colours, people, clothes or whatever. I never have to take a swatch to match colours. I can carry a colour in my head for years. For example, mother has had a favourite dress for years, and she was coming to visit [from another country]. I went out and bought her some beads that matched the dress exactly and I hadn’t seen it for seven years.

I can remember people’s appearances very vividly and if I were an artist I would be able to paint almost everyone I know right down to the blemishes on their faces. Strangely, this facility has lessened since I lost my sense of smell.

(10/01/86)

She supplied an apt definition for eidetic memory, although she had never heard the term before. She describes this memory, which can be visual or auditory, as “that memory that does not require me to conceptually understand it but simply to recall it.” She fills Haber & Haber’s criteria (1964) for an eidetiker.

I remember places very, very well. We were in Europe this summer. When I close my eyes, I can actually see the hotel rooms, the furniture, the pictures, even though we were always in different places.

I always used to win those party games with covered trays and things. I can remember conversations I want to. As part of my research at . . . University, I have to interview people and I recall the words they say and even the inflection in their voices as long as I need to. I don’t often take notes. At the doctor’s, if he gives complicated instructions, I have no problem remembering because I have to. But I remember it because I remember hearing him saying it. I don’t remember it conceptually. I can recall conversations down to the last jot, but they’re always important conversations . . . I hear them all over again, like a record.

If I’m studying and need to refer to something, I can go to that book and know exactly where to look for it. Yes, I can conjure it up in my mind, but I can’t see it word for word. I can remember it in substance but not read it back. I can see the same, and how many lines the idea takes up, and where it is on the page, I can remember conversations word for word better than I can things I have read.

**Olfactory Trigger for Memory; Loss of Memory after Pituitary Tumor**  SdeM received radiation and bromocriptine treatment in 1977 for a pituitary tumor that had caused amenorrhea. She was still taking bromocriptine when I examined her. She has lost her sense of smell, but
claimed that her sense of taste returned to normal. Recall that what we normally speak of as “taste” is actually a combination of taste, smell, temperature, and texture discrimination (Cytowic 1983).

Her ability to “re-create,” in minute detail, prior environments was particularly facilitated by olfaction. She also attributes the intense sense of conviction that her memories were “absolutely undistorted” to the olfactory facilitation. Upon encountering an odor, an image would flash in her mind.

The feeling was explosive. “Aha,” I would say, “there’s the bakery shop or the lake.” It was a pleasant feeling, but I don’t recall that there was any other physical sensation.

Now anosmic because of her tumor, these visualizations no longer appear automatically, although the memory does remain accessible. She has to think about it, much as we all do, and even then her recollection is qualitatively different.

It’s not that the memory is diminished, but it has affected the way my memory works because I have to consciously imagine it. It doesn’t come spontaneously like it used to before the operation.

You might erroneously conclude that SdeM’s memory impairment following loss of olfaction is no surprise given the common knowledge that the entorhinal cortex and rhinencephalon participate in memory. For example, the olfactory cortex is markedly involved in senile dementia of the Alzheimer type, a disease whose hallmark is memory loss. Degeneration predominates in large cells, greater than 90 μ, and those of association cortex (i.e., those neurons that make corticocortical connections). The primary isomodal cortex is little involved. But SdeM does not have a cortical lesion. Neither does she have a temporal lobectomy nor a hippocampal resection. She is likely anosmic from radiation and not the pituitary tumor itself. Her figurative memory remains normal and her current revised Wechsler MQ is 135.

Her preoperative “memory explosion” illustrates a point often confused. Taste and smell are senses with low Gestalten. With the possible exception of a vintner or a parfumeur, one never remembers a smell; rather, it is a smell that triggers reminiscence. It is the spontaneous, explosive emotional memory that was triggered by a smell that abandoned SdeM after she became anosmic. For her, this memory was different from that which a smell might evoke in you or me. Only synesthetes MW (geometric taste) and DS (polymodal) claim to remember actual scents; the remainder function as we all do, remembering events or contexts rather than a given olfactory event.

Some memories are more vivid and carry more emotional baggage than others. The memory of what one did at work yesterday is likely to be bland. Recollection of a faux pas or a humiliating childhood experi-

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ence can be accompanied by a physiologic flush or the feeling of acute embarrassment. SdeM’s postoperative experience illustrates how there can be dissociation between the content of memory, the emotion of memory, and the conviction of a memory. It is useful to remember that memory is not a unitary event, in either cognitive or neural aspects (Fuster 1995).

**Physical Reaction to a Particular Color** SdeM has an “inexplicable” and visceral feeling of “dropping too quickly in an elevator” whenever she sees a particular shade of cobalt blue (“the colour of airport landing lights but without its luminousness”). For as long as she can recall she even experiences this feeling when merely thinking about the color. What is one to make of her compulsion to look at the color, yet never to wear it or possess anything in that hue?

What’s strange is that occasionally I’ll see people in the street with a scarf or a coat that colour and I have to follow them. I don’t mean physically, but I have to look at it, look at them repeatedly. It’s very attractive, and I have to do it. It’s like bees going to a flower or something. I don’t know. I feel it. It’s not unpleasurable but it’s not pleasurable. And I like the colour but I never buy it and I never wear it. I don’t know why.

I saw a car when we were in Europe this summer that was that colour. And I had to keep looking at it for a while. My family thinks it’s very odd.

5.7 MEMORY MAPS

MP uses the term “memory maps” for lack of a better term to describe how she views the alphabet, numbers, months, and days of the week (figures 5.13 through 5.15). Because they appear to her in a “flexible moving 3 dimension,” her drawings are a representation and not a reproduction of what she sees.

In 1983, MP sent me a 25-page typewritten explication of her “memory maps.” It is characteristically difficult to describe their panorama and three-dimensional quality. It is also difficult to describe their color. Though she painstakingly rendered her drawing with colored pencils, they remain nonetheless inaccurate because neither the transparency nor other subtleties are possible to render. Importantly, MP’s diary, as far as it reflects her personality, gives no suggestion of a philosophical or cosmic orientation.

Her drawings for the alphabet and numbers are rendered on black backgrounds, which approximates her actual vision. The letter x’s in the figures denote points of view from which the form can be perused. “Looking back at my illustrations they look ridiculous, even to me … I’m not used to seeing the map in one dimension or so finite with such limiting borders. The maps are larger than my visual range, like looking at the horizon.” She likens her memory maps to a geographical map.
wherein one can take in an overall view without much detail and then zoom in to a specific, enlarged region of interest.

Her earliest recollection of the alphabet is from age 4, when she recalls spelling M-I-L-K from a milk carton. She has a recollection that when her grandmother asked her how to spell TEA, she recalls that the letter “T” was in the dark part of the alphabet that she could not yet see. Her alphabet was only just beginning to take shape and was still clouded in darkness. She learned to read before she began school, by

Figure 5.13 Subject MP, the alphabet. In this and subsequent reproductions of MP’s crayon drawings, the colors, of course, cannot be appreciated.
which time her alphabet pattern was firmly fixed. The days of the week appeared shortly after the alphabet and her form for the months was in place at approximately age 7.

It is difficult for her to say exactly what the letters or numbers look like (i.e., typeset, handwritten, or Roman style). It is as if she is more aware of the shape, spacing, and color than the graphology of the Latin alphabet or Arabic numerals. “It is like looking at your speedometer—you are so used to it that you don’t really ‘see’ the numbers.”

MP did not disclose her maps to anyone until she was in college. “I figured everyone did it this way! It was too much to fathom that it might be unique with me. Once I was asked why I would need to see the alphabet as a whole—my first response was, Doesn’t everybody? It never occurred to me that it might be unnatural to visualize the whole alphabet (or numbers).”

### 5.7.1 The Alphabet

MP’s alphabet forms a loop projecting out of the blackness, with A and Z anchored in the shadows and letters J through S emphasized as though lit by a spotlight. This highlighted section includes several letters in her name (M, R, L, O, P, K). When learning a new word as a child she would play with and recombine the letters as in a scrabble set. With time, this process became automatic and she is naturally an ex-
Figure 5.15 MP, months of the year. (Below) The days of the month for November. The usual integer color blends into an overall brown, the color for November. This identifies the numbers as belonging to that month.
cellent speller. As an adult, the only occasions wherein a word’s component letters appear one by one is when she is asked to spell or define a word.

5.7.2 Words and Names

For MP, a word’s first letter influences the overall color (figure 5.16). The pale color of vowels can shade a word’s color: A and I darken it, E and O lighten it, and U is neutral. TIN is darker than TAN, TAN darker than TEN (although “10” is different), TEN darker than TUN. TUN (a large cask of wine) is in between TIN and TAN or TAN and TEN. If E is added to TUN to make TUNE, the word becomes much lighter. Next in importance are letters that MP perceives as spatially big (e.g., B has more color than C, and K has more color than L) or have more sound (e.g., S more than R, G more than H). Hers is a good illustration of how synesthetes and those with number forms often allot unequal psycho-physical space to their numbers and letters.

MP compares the process to threads in a tapestry:

The letter colors appear like fabric; pull the individual threads apart and you can see the various colors. Woven together, they become one, i.e., predominantly green (“T”), but influenced by the other “strands.” For example, say you are looking at a rug. One or two strands out of 5 will be brown, the rest green. Look at the fibers running through the strands. Some are red (A—TAN), or perhaps yellow (E—TEN), or gray (U—TUN), or maybe black (I—TIN). Standing on it, you say that the carpet is green; sitting on it you might notice the brown, and examining it closely, you may see the red, yellow, etc.

The colors are helpful in remembering names, particularly if they have less common spellings. “Cathie” looks entirely different from “Kathy”; even “Brown” is different from “Browne” (figure 5.17). Thinking about someone produces a different visualization than talking about that person. She will visualize the individual’s physical features
if imagining a conversation with that person or recollecting him or her performing some task. But if speaking about someone (e.g., “he believes such and such”), then MP will see their name. She will also visualize the name and color in searching for it on a list.

The colors are totally objective. I put no meaning into them. People frequently ask me to tell them what color their name is. If someone thinks “Ugh, what a terrible combination of colors; she must not like me,” that is not at all true. I don’t relate it with a person it that way at all. The colors have no meaning.

Colors will change if someone changes his name by marriage or, more commonly for MP, who works in a film studio, if an actor changes a role. “It seems to be rather easy to jump back and forth between the character and the actor (both the name and the personality). Actually it helps establish the new personality or character in my mind.”

5.7.3 Numbers

The visualized numbers (see figure 5.14) do not interfere with simple arithmetic, but they do interfere with more complex mathematics, such as algebra. “The numbers cannot be visualized for complex calculations. For one thing, they are not evenly or consistently spaced. There is also some fluid or jelly-like movement to them.” The number 6 and numbers containing 6 represent the highest degree of magnitude for her because 6 is physically the highest in her visual representation. When thinking of someone older than herself, she looks “up;” younger people are seen not “down” but “in back” of herself.
The color of numbers can vary if they represent time. Decades (figure 5.18) do not have the same color as integers (see, e.g., 50 and 80 in figure 5.14). Times before her birth year, 1954, are dark. The 1950s are black to gray; the 1960s, yellow; the 1970s, bright blue; the 1980s, orange; and the 1990s, dark blue. The decades of the centuries take on the shading of the century. As a whole, the 1900s are black; 1800s, yellow; 1700s, blue; 1600s, red; and the 2000s, pink. On close examination, the individual decade color becomes manifest. This is an example of her map analogy describing how she views the large picture and then is able to zoom in to view the details.

5.7.4 Months, Weeks, and Days

Figure 5.15 shows MP’s months. Considering a particular month shifts the configuration of the numbers 1 to 30—colored not with their integer color-value but with the overall color of the month. Birthdays and similar special dates are remembered first by the color of the month, followed by the picture of the number.

Weekdays have the least pattern of any of MP’s maps (figure 5.19). They are simply a string of days. If MP is in a particular room regularly enough, the room will take on an aura depending on what weekday it is.

Figure 5.20 illustrates the hours of the day and minutes of the hour. Again, she sees time as space. “Digital clocks drive me crazy.” She looks upward at time in a spiral, and when planning a day she sees blocks of time as sections of the spiral. The density of the spiral’s hue
changes if she has to do something at a particular time. “The difference is like that between a print and a solid—the more free my time is the more ‘solid’ color the time is. Sewing or vacation time is quite solid in color.”

MP is obviously quite organized and her spatial and color scheme has practical benefits. Like any rigid scheme, however, it has its drawbacks. There are noticeable differences with a change of her routine schedule, or the change of seasons. For example, were she to alter her schedule because of a new job, the appearance of the days of the week “would change radically. Even if things are going fairly routinely, there is a gradual change with the seasons ... so over a four to six month period there is a noticeable difference.”

Figure 5.19  Weekdays memory map of MP. She can see ahead 2 weeks and backward 1 week. Appointment days are “marked” with a hump and a spotlight—“they are different in a way I cannot explain.”

Figure 5.20  MP’s hour-and-minute memory maps.
5.7.5 The Utility of MP’s Memory Maps

MP’s memory maps are important in her career as a librarian. Her specialty is cataloging, and she finds her maps essential for remembering patrons’ names, trivial facts, page and call numbers, and for filing. When someone stands in front of the card catalog reciting a portion of the alphabet, “it amazes me that people know the alphabet only auditorily.”

One of the restrictions of such visualization is that, like Luria’s patient, images tend to guide MP’s thinking rather than thought guiding her figurative memory. When reading a book, she cannot describe the plot or characters without picturing the surroundings, usually by taking a room or a setting that she is familiar with and changing it to fit the description of the book.

A store in the book may be visualized as the living room (rearranged) of someone I knew at one time, especially one in which I had often visited. Of course, most frequently, it is my own house, either as I have it now or as I remember it when it was my grandmother’s house.

Like the physical card catalog drawers that she uses in her daily job, her memory maps are becoming full and the material more cumbersome to manipulate. “The older I get the more I have to store—there just is not enough room for everything.” Nor does she have a cross-reference system. “The maps are not connected in any way. I cannot see one from the other. They are completely separate, like different slides.” (DS makes a similar comment: “I visualize everything. There’s always so much junk in my mind.”)

The emergence and retreat into the darkness is almost primeval. MP has often asked herself what lies “behind” the maps, what lurks in the darkness? When considering the blackness anchoring each end of her maps, her deduction is that behind the map’s blackness is actually someone else’s mind! To lose her mind or to have her thinking impaired would be to have all of her maps vanish into the darkness.

5.8 CONCLUSION

Knowledge of space and movement may be served by a distributed system whose main entities lie outside of primary idiotypic motor or sensory cortices—a system with strong attentional and limbic contributions but whose exact reaches are yet to be determined. I include limbic entities in the network because synesthetes report not only a noetic sense of certitude but also an affect (usually pleasure or satisfaction) that accompanies these experiences.

The failure to perceive motion visually, called akinetopsia, is caused by lesions in unimodal visual association cortex, but the cerebral basis
of the other foregoing entities I have enumerated is much less certain. What is certain is that our concepts regarding brain organization must be sufficiently broad to accommodate new observations as they occur. The occasional bizarreness of these observations invites easy dismissal in light of our prevailing doctrines and treasured ideas about the brain. We would do well to remember history and the nature of science. Concepts that we now consider clear, coherent, and final are unlikely to appear to posterity as having any of those attributes.

Figure 5.21 reveals the solution to the Gestalt puzzle posed earlier in section 5.1 (figure 5.4).

**Figure 5.21** Solution of the Gestalt puzzle given in figure 5.4. Once we loosen ourselves from the assumption that a border exists beyond which the connecting lines cannot extend, we see the problem in a new configuration and can try novel solutions. The Gestalt principles of grouping were said to prevent random solutions to everyday problems.
The Neural Substrate of Synesthesia

In preceding chapters, especially chapter 4, I presented evidence for localizing synesthesia. Those data suggest that synesthesia is lateralized to the left hemisphere. Perhaps this has to do with the preponderance of language-related synesthetic associations (colored numbers, letters, and words). Additionally, the existing data place the neurological level of the synesthetic link above brainstem but below heteromodal homotypical association isocortex. (These terms are explained below for readers unfamiliar with them.)

Perhaps Paulesu & colleague’s (1995) PET scans during word-color synesthesia appear, at first glance, to vitiate the position of the neurological level stated above. Such a false impression results from the oversimplified dichotomy between limbic and neocortical entities mentioned earlier. Of course V4, V5, and other unimodal isocortex can participate in synesthetic experience, but it is an error to identify association cortex itself as the neural substrate of synesthesia. I believe the link is more likely effected by transmodal entities. In discussing the narrow subset of spoken word-color synesthesia, Paulesu & colleagues make association cortex key and hypothesize vestigial connections between visual association cortex and unspecified language areas (as Ramachandran & Hubbard did later [2001]). However, what is needed is a general model of synesthesia that (1) applies to all synesthetic combinations, (2) accounts for the salience, certitude, and memory of synesthetic percepts, (3) explains synesthesia’s spatial extension, (4) addresses the observation that the trait may first manifest or be intensified at puberty, and (5) can account for the genetics and neuropsychological profile of synesthetes as a group.

We get so impressed with brain pictures that we forget these are only models of reality and that any model is necessarily a simplification that omits details. Functional imaging can tell only part of the story, the part that is played by long-wiring circuits of the brain. Similarly, general principles are easily forgotten when studies focus narrowly on a given brain region. This can be especially confusing to nonspecialists
who may mistake the part for the whole and who are unlikely unfamiliar with basic organizing principles of the brain.

In order to explicate substantive issues regarding synesthesia in a way that does not discuss details out of context (especially for readers who come upon neuroscience from nonbiological backgrounds) I will first review how neural tissue comes to be organized the way that it is. I will be referring back to both general principles and details later in this chapter, and in the next. Once having laid out the anatomical picture, I can then address the five clinical questions posed above.

What follows is both an anatomy and a history lesson. I will highlight how persistent but now outdated enthusiasm for neocortex has led a majority of brain researchers to emphasize the cortex’s purported salient feature, “reason and logic.” In redressing the balance, I will demonstrate how emotion is an integral component of mentation, how diffuse chemical messengers link not only brain regions but also the brain with the body, and how the limbic system and subcortical entities are orchestrated along with the neocortex to give rise to the net product we are all interested in—one’s state of mind. These matters will then finally be related to synesthesia. Although it is customary in neurology to start with specific regions of brain damage and catalog the behavioral consequences, I shall for the most part travel in the opposite direction, grasping phenomenology and attempting to trace it back to a cerebral origin. See Cytowic (1995, 1996) for further details.

6.1 CONCEPTS OF NEURAL TISSUE

I have chosen to present not one but two views of the big picture, starting with the “standard,” or hierarchical, concept of neural tissue. This is the plan with which most scientists and knowledgeable laypersons are familiar. Unfortunately, while a number of its concepts are no longer tenable to those working intimately in the field, they are still widely believed by those who are not. This is a matter of dissemination rather than contention. I follow the standard hierarchical model with the current “multiplex” one that is based largely on functional topography.

6.1.1 The Standard Hierarchical Model

Typical surveys that one might call Neurology 101 explain how the brain works in terms of how we conceived its organization several decades ago. One would think that time had made this model no longer standard, but outdated notions of strict hierarchy persist. Its three prime concepts are (1) that information flow is linear, (2) that physical and mental functions can be localized to discrete parts of the cortex, and (3) that a hierarchy exists in which the cortex dominates everything below it.
This dated concept conceives of perception as a one-way street, traveling from the outside world inward, the five sense organs transducing energy flux and dispatching a linear stream of neural impulses from one relay to ever more complex ones, so that the process is metaphorically like a conveyor belt running through stations in a factory, until a perception rolls off the end as the finished product.

Both sense impressions coming in and motor commands going out of the brain were conceived in this way: The sense organs transform the flux of electromagnetic energy (vision), mechanical energy (hearing and touch), or chemical energy (taste and smell) into nerve impulses. These impulses then travel to various relays in the brainstem and thalamus, and thence to progressively more complex stations of the cortex where different aspects of the external stimulus are sequentially extracted from the stream. These aspects are somehow assembled at the end of the line into a conscious experience so that we understand what it was in the external world that triggered our sensory transduction in the first place.

Localization of function is the standard model's second major tenet. For example, the occipital lobe is concerned with vision, the parietal lobe with touch, and the temporal lobe with hearing. The division of the brain into "lobes" was done so long ago as to retain no current validity, though the four lobe names are still used as a general point of physical reference. (As late as 1844, the brain's lobes numbered only three.) The twentieth century's several schemes for dividing the brain into some fifty discrete units are based either on its microscopic patterns of cellular arrangement (the technical term is cytoarchitecture) or on patterns of myelination (myeloarchitecture). Those who mapped the brain's architecture at the turn of the last century were surprised to discover that the discrete areas they had found by looking through their microscopes did not at all follow the natural boundaries of the brain's bumps and fissures.

The word cortex, meaning "rind" or "bark," refers to the bumpy surface of the brain. Of all brain parts, the surface cortex has the most differentiated architecture. It also is the youngest component in evolutionary terms. For these reasons, together with the fact that human cortex was assumed to be more advanced than that of other mammals, the standard model pointed to it as the essential entity distinguishing us from other creatures. In our efforts to understand the brain, however, we have emphasized the cortex to the near exclusion of everything underneath it. Perhaps one practical reason for its emphasis historically is that it was the surface and so could be easily approached experimentally.

In 1949, the American neurologist Paul MacLean originated the triune brain model, an embodiment of what was known as the accretion hypothesis at its height. This view, long popular but now much modified,
held that newer structures were added onto those of the reptilian brain and were accompanied by correspondingly new mental skills and behaviors. MacLean’s conceptual refinement of three-brains-in-one proposed that human brains contain three neural systems, each of different evolutionary age and each governing a separate category of behavior. The oldest “reptilian” brain, represented by brainstem and basal ganglia, deals with self-preservation. The middle “paleomammalian” brain is our inheritance from the mammal-like reptiles and is concerned with preservation of the species (e.g., sex, procreation, and socialization), plus supposedly unique mammalian behaviors such as nursing, maternal and paternal care, audiovocal communication, and play. The components of the paleomammalian brain are collectively called the limbic system, which in humans deals mostly with emotion and memory. The evolutionarily youngest “neomammalian” brain is embodied in the great expanse of cortex that is seen as a chief executor. MacLean originally questioned the role of paleocerebral structures in behavior and was most interested in showing that subcortical structures were vital for the expression of species-typical behavior. No one would argue with this today. However, the triune brain’s apparent agreement with the standard model’s concept of hierarchy and cortical dominance is evident from figure 6.1, even though its originator did not intend to perpetuate those ideas.

In 1902, the British neurologist Lord Sherrington had shown that the brain’s central fissure separates a precentral motor area in front of it, and in 1909 the American surgeon Harvey Cushing showed that a postcentral sensory area lies behind it. A central fissure dividing a motor brain in front from a sensory brain in back exists in all placental mammals. In 1952, Woolsey showed by electrical mapping that the organization of the sensory area behind the central fissure is a mirror image of the motor area in front of it. The existence of two spatially separate maps, each with its own function, became a fundamental concept of neuroscience. Later, detailed electrical mapping of the cortex during surgery held out the hope that we might establish a point-to-point correspondence between brain tissue and function, both physical and mental.

Within the sensory half of the brain, the primary sensory areas were determined for vision, hearing, and touch. Those for taste and smell were debated for a long time, but the point is that all sensation was believed to have a cortical representation. The primary area for a given sense was its first cortical relay station, and damaging it caused total loss of function—such as blindness, deafness, and tactile anesthesia. Secondary association areas were soon found for each sense. These additional maps were conceived of as relays further along on the conveyor belt of perception that received more highly transformed information. Damage to these secondary areas caused a distortion of a given sense
rather than its loss. An example is the failure of recognition called agnosia ("not knowing"). In visual agnosia, for example, one can see and describe an object but neither recognize what it is nor understand its use. Agnosia can occur in any sense. At the end of the line was the tertiary association cortex in the parietal lobe. This was where sight, sound, and touch converged and where associations between and among the senses were assumed to occur. Though each sense had its own primary and secondary association areas, there was but a single tertiary area, where the highest, most abstract levels of association were believed to take place.

Note that smell and taste do not fit this model because their cortical representations are removed from the tertiary association area. Another function that received scant attention was emotion, a human trait known to be served in great part by structures beneath the cortex. If earlier scientists considered emotion at all, they conceived of it as a detour branching off the linear stream of neural flow. Even then, emotional calculations were thought of as secondary to those that took place in the cortex itself.

These three ideas (linearity, localization, and hierarchy) melded to inspire the further assumption that the cortex is the seat of reason and the mind. Perhaps they persist among the general public as well as the average scientist because the standard model is easy to grasp and use-

Figure 6.1 The triune brain represents the accretion hypothesis of brain evolution and conceives of three-brains-in-one, each segment relating to particular categories of behavior and reflecting a distinctive inheritance from earlier life forms. (Reproduced from The Neurosciences: Second Study Program, 1978, p 338 by copyright permission of the Rockefeller University Press.)
ful to a point—just as Newton’s mechanics are still useful even though everyone has known for decades that Einstein’s relativity is a more accurate description of the universe.

A historical parallel might be the Renaissance astronomers who kept piling epicycle upon epicycle to explain the retrogression of Mars’s orbit until their scheme of planetary reaches was a patchwork that no longer held together. Kepler’s conceptual shift of planetary orbits from circular to elliptical explained all observed facts much better and without the need for piling on special exceptions. The standard model of brain organization similarly collapsed: It could no longer bear the weight of having to explain the avalanche of observations made in the recent past. We now know that as a model its generalities are true, whereas its specific predictions are often erroneous.

Finally, neuroscientists have just lately come to acknowledge how important emotion is in our mental life. In believing reason to be the superior and dominant force that guides our thinking and behavior, we simultaneously hold the dichotomous view that emotion must be primitive and disruptive, an interference to clear logical thinking. People who think of their brains at all usually imagine a computer in their heads, a reasoning machine that runs things. This is consistent with the hierarchical model of brain organization. However, like the carnival barker who pretended to be the Wizard of Oz, hiding behind the curtain while shouting, “Pay no attention to the man behind the curtain,” placing reason and the neocortex foremost overstates the case because emotion and the mentation not normally accessible to self-awareness are often what’s behind the curtain pulling the levers.

6.1.2 The Multiplex Model

The contemporary concept of neural tissue puts the role of the cortex not at the top but more in the middle of multiplex, parallel, and recursive pathways. “Highest,” when used to describe cortex, is a meaningless attribute. Cortex is just one of several types of brain tissue. (Besides, there are five kinds of cortex, as detailed below.) Intense but recent interest in consciousness and emotion, after decades of disinterest, has led neuroscientists to reevaluate the role of the limbic system (sometimes called the emotional brain).

Paul MacLean’s triune brain captured popular attention over the last 40 years for several reasons, one being that it is easy to understand. Like Gall’s phrenology, the idea of three-brains-in-one was appropriated by others for purposes that MacLean never proposed. It is best taken today as a useful metaphor rather than a faithful model of brain organization. The triune brain did help to show that specific categories of behavior could be assigned to different types of brain tissue, each of which had a distinctive evolutionary history. It was enormously help-
ful in showing that tissue below the cortex was not just inert filler that could be neglected but that subcortical tissue was essential to behaviors that could not be dismissed as merely “instinctual” (MacLean 1990, pp 228–244).

MacLean coined the term *limbic system* in 1952 because of the extensive relation of entities below the cortex to the limbic lobe of the brain. Broca first defined the limbic lobe in 1878 in structural terms, as the inside rim (*limbus*) of the hemispheres where they meet the brainstem. Because he pictured the neomammalian brain (the neocortex) as enfolding everything else, MacLean’s illustration of the triune concept inadvertently led people to still cede the cortex prime importance. Whether a neural structure is visible on the surface or tucked out of sight has no bearing on hierarchy or whether it is controlling or controlled. Function is what matters. As the contemporary model clarifies, the complex anatomical connections between cortical and subcortical entities are reciprocal and thus interdependent.

The contemporary model has three main points: First, neural propagation is not strictly linear but is also parallel and multiplex, including transfer of information that does not even travel along nerves; thus, the idea of strict hierarchy makes no sense. Second, we no longer speak of localization as a one-to-one mapping, but of the distributed system, a many-to-one convergent-divergent mapping in which a given chunk of brain tissue subserves many functions and yet, conversely, by which a given function is not strictly localized but is distributed over more than one spot. Third, although the cortex contains mental representations (our models of reality) and analyzes what exists outside of ourselves, it is the limbic brain that determines the salience of that information.

6.1.2.1 Nonlinear Information Flow

Information is transferred through the nervous system in more ways than most people realize. Multiple communication channels exist in addition to what we typically know of as nerves, synapses, and the hard-wired circuitry familiar from classic neuroanatomy. This abundance of alternative routes is denoted by the word *multiplex*.

The multiplex ways of transmitting information in the brain is not hierarchical, as would be the case if flow were straightforwardly linear, but involves parallel, recursive, feedforward, and feedback connections. There also exists a wide assortment of molecules, such as hormones and peptides, that likewise act as information messengers. More than 50 are known and more are being discovered annually, not only in the brain but also throughout the body. Information can therefore be transmitted throughout the body not only by neurons and axons (the traditional long wiring system of the brain) but also through the extracellular fluid that surrounds the entire system itself. This method

Think of electrical transmission along nerves as a train traveling down a track; volume transmission is the train leaving the track. The idea that molecular messengers communicate information over short or long distances, and at rates that can be very fast (up to 120 m/sec in axon fluid) or slow (e.g., the diffusion of peptides in cerebrospinal fluid), has opened up our understanding that the human brain has systems, which are much more complex than we had ever supposed, communicating at different ranges, different velocities, and by different methods. It is most noteworthy that peptide receptors are associated with sensory pathways, not motor ones. They therefore act like filters.

The stuff conveyed by volume transmission is indeed concerned with cognition; the two systems are integrated via reciprocal neurochemical links. The hypothalamus, for example, participates in both the hard-wired and volume-transmitted transfer of information and is a good example of the inseparable interplay between cognitive and visceral forces. A good deal of its input arises from either direct physical or chemical stimulation (e.g., light, temperature, circulating steroid hormones, and the concentration of glucose, salt, and other substances in the blood). Likewise, its outputs are both conventional (synapses) and neuroendocrine. Some hypothalamic hormones modulate the secondary release of pituitary hormones, while others directly affect distant targets. An example of the latter is oxytocin, a participant in orgasm (in both sexes), parturition, and lactation. These three experiences obviously have both physical and mental components.

Lymphatic tissue has sophisticated innervation (Felton & Felton 1991), and in humans the integration of the hard-wired and volume-transmitted systems is easily seen in the “neuro-immune-endocrine network,” wherein synergistically acting transmitters and peptides regulate endocrine and immune activity as well as chemical feedback to hard-wired portions of the nervous system (Cotman et al. 1987; Husband 1992). In addition, immune functions are coupled with sleep and similar circadian rhythms.

Both the nervous and immune systems have a remarkable capacity to receive and react to specific events in both internal and external milieus. Neither system is autonomous; complex homeostatic relationships integrate behavioral, neural, endocrine, and immune processes. Together with an increased synaptic distance between sensor and effector, it is such integration, rather than just an expanded cortex, that made it possible for human brains to develop from more primitive and highly deterministic organisms (Ommaya 1994; Mesulam 1998). To successfully reproduce the flexibility that this kind of integration affords, artificial intelligence will have to incorporate some kind of reg-
ulating system to organize the different means of information transfer (Agnati & Fuxe 2000).

In the human brain, it is the limbic system that performs this regulation, a fact confirmed only in the last decade or so (Armstrong 1990, 1991). It is becoming clearer how the wiring transmission and volume transmission systems are integrated (Nieuwenhuys 2000; Bloom 2000; Agnati et al. 1995). One might wonder why it has taken until now to figure out something that seems rather fundamental. It is because only recently have anatomical techniques emerged that permit neurotransmitter molecules to be tagged with special markers that can be seen microscopically. One can now follow the journey of neurotransmitters through both nerve fibers and the extracellular spaces in which volume transmission takes place. Classical anatomy at first allowed us to map the brain’s general circuits, but having accurate knowledge now of the direction of flow as well as the precise origins and targets of various transmitters has forced us to make revisions. It turns out that every major division of the nervous system, from the frontal lobes to the spinal cord, contains some physical limbic structure related to emotion. In the neocortex are the prefrontal lobes; in the mesocortex are the cingulum, insula, orbitofrontal cortex, parahippocampal gyrus, and temporal pole; in the archicortex, the hippocampal formation; in the basal ganglia, the amygdala; in the diencephalon, the dorsal thalamus and hypothalamus; in the midbrain, the central gray matter; in the pons and medulla, the nuclei of the integrated autonomic relays; and in the spinal cord, the cell column nuclei. In other words, the limbic system forms an emotional core of the human nervous system.

6.1.2.2 Function Is Not Strictly Localized

The idea that circuits rather than “control centers” support the expression of emotion was first suggested in 1937 by the American anatomist James Papez. Major entities of what we now call the limbic system were hooked together into the Papez circuit, through which cognitive, visceral, and motor aspects of emotion were expressed. The implication for the neurologist’s habit of localization was profound: Emotion was no longer localized in a discrete control center but was spread out over pathways. Of course, the pathways must be somewhere, and so some localization is involved. However, it is qualitatively a much more diffuse localization than that imagined by the standard model.

Over the next 40 years, this approach caused a fundamental and permanent change in how people conceived of information traveling through the brain. The linear idea of discrete workstations along a conveyor belt yielded to the concept of multiple mapping (modularity) in which a brain with multiplex communication channels can transform information in several locations simultaneously.
Multiple mapping is possible by linking one input to several outputs. As soon as nervous impulses from the sense organs synapse in their respective primary sensory cortices, they simultaneously branch out to multiple areas of association cortex for further transformation, each area being concerned with a different facet of the experience. In vision, for example, each of some two dozen areas handles a different aspect of seeing (Van Essen, Anderson, & Felleman 1992; Zeki 1993). The job of analyzing whatever it takes to yield the experience of color goes in one direction. The many things that constitute shape, the recognition of an object, or the space where that object is located, are handled somewhere else. The neat image that the geometry of foveation casts on the retina is shattered as the world is multiply mapped in the brain, a different map in each of several areas per sense. In addition, collateral branches to both cortical and subcortical entities form recursive feedback and feedforward circuits that contribute to a massively parallel "digital" transformation of the original analog image.

The ability of a discrete brain area to process several uniquely different maps of the world arises from the complicated pattern of its inputs and internal connections in each architectural region, and the linking of this calculation to several outputs. This convergent-divergent arrangement is what we call a distributed system, which means that the many aspects of complex functions (e.g., vision, audition, memory, or emotion) subserved by a particular circuit are not rigidly located in any one of its segments but rather in the dominant process occurring at any given time in the circuit itself. The number of distinct regions transmitting to and receiving from other cortical areas varies from 10 to 30. The exponential level of complexity is apparent and far beyond that inherent in the conveyor-belt progression of the old view.

It seems that the globalists and the localizationists of the nineteenth century were both right, but in a way that neither could appreciate at the time. Any complex ability depends not on a single lump of brain but on an array of underlying processes, each of which confers but a single facet to the ability. Simpler processes are localized, whereas complex abilities are distributed (Farah 1994).

6.2 ANATOMICAL DETAILS

Now follows an elaboration of the different schemes by which neural tissue is organized. We will need this later in §6.3 onward in explicating the neural basis of synesthetic perceptions. Familiarity with microscopic sections is not assumed. Readers would be helped by reference to an atlas of the nervous system showing gross structure, cell bodies (Nissl stains), and tracts (myelin stains). I recommend Nieuwenhuys, Voogd, and van Huijzen’s The Human Central Nervous System (1988).
Knowledge of gross brain dissections in horizontal, coronal, and sagittal planes should be correlated with corresponding radiographic and magnetic planar images.

The principles of neuronal function are remarkably similar in animals as far apart as the snail and the human. The human brain resembles the brains of “lower” animals much more than it differs from them (Sarnat & Netsky 1981). It contains roughly $10^{11}$ (100 billion) neurons and $10^{14}$ synapses (100 trillion), give or take a factor of 10 (Pakkenberg & Gundersen 1997). A typical neuron has a cell body 5 to 100 μm in diameter from which emanate one major axon and a number of dendrites. The axon usually branches extensively near its end and may give off branches near its beginning. Generally, the dendrites and cell body receive incoming impulses: The cell body averages these signals, and the axon distributes the result to a new set of neurons. Circuitry is not serial but richly cross-linked. Elements operate at slow speeds of thousandths of a second. Neuron processes are intertwined in a dense thicket with adjacent branches separated by fluid films only 0.2 μm thick. Virtually all the space is filled with cells and their various processes.

Comparing the above magnitudes, you will note that the average number of synapses per neuron is only 1000, an amount 8 orders of magnitude less than the total number of neurons. Even if each of a given neuron’s 1000 synapses were with a different neuron, it could still connect to only a small fraction of all neurons (roughly 1 in 10 million to 1 in 100 million). As a network, the brain is vastly under-connected despite popular notions otherwise. Furthermore, most of a given neuron’s synapses exist within a surrounding area of just 1 to 2 mm. Thus, the energy transformations that concern any individual neuron, or group of neurons, are predominantly local. I return to this fact shortly.

6.2.1 Three General Arrangements of Neurons

Many scientists have pondered how to arrange the galaxy of nerve cells. The Russian-born physician Paul Yakovlev organized them into three arrangements that can be found in all vertebrate brains, the operational representations of which, in humans, he derived empirically (Yakovlev 1948, 1970). His is a very broad view of neural organization and therefore quite helpful to those learning their way around the forest of neuropsychology. The three arrangements of neurons are reticular, nuclear, and laminar. As an a first approximation, different behaviors can be associated with each type.

The three types of neuronal arrangement are shown in the coronal brain slice of figure 6.2. The reticular system (from the Latin rete, “net”)
Figure 6.2  Gross anatomy (top), cell bodies (bottom left), and myelin tracts (bottom right) in a section cutting through the thalamus, cerebral peduncle, and the pons showing that most nuclear aggregates are centrally placed. Simple laminar arrangements occur in the colliculi and amygdala; four layers exist in hippocampus, six layers in neocortex. The six-layered cortical ribbon, shown here in dark gray, is only 1 to 2 mm thick. Much of the brain’s bulk comes from connecting fiber tracts (bottom right). Lamination (layering) is easiest to see with a cellular stain (bottom left). The reticular system is visible only microscopically.
is an aggregation of loosely arranged cells having an expansive vertical
distribution within the central core of the brainstem. The dendrites of
these cells are arranged in bundles that form a netlike pattern. The re-
ticular formation continues caudally as the intermediate substance of
the spinal cord, while rostrally it projects to the intralaminar thalamic
nuclei. The reticular formation is concerned with consciousness and
arousal (so-called state functions, as opposed to channel functions that are
carried by more self-contained sensory or motor pathways) and the
internal homeostatic milieu.

Nuclei are clumps of neurons, just as galaxies are aggregates of in-
dividual stars. Nuclei range in size from a grain of sand, containing
perhaps a few thousand neurons, up to the size of an almond, which
would contain tens of millions of cells. Examples of nuclear aggregates
are the thalamic nuclei, medial geniculate body, red nucleus, and sub-
stantia nigra. Nuclear aggregates are either the cells of origin of a single
entity or a sensory ganglion of second-order or third-order neurons.

A laminar (layered) arrangement of neuron groups permits more
complex interactions such as feedforward, feedback, facilitation, re-
current inhibition, and defacilitation. Structural complexity increases
through the five types of laminar tissue in the cortex. The corticoid tis-
sue of the amygdala and the four-layered hippocampus, for example,
are simpler than the six layers of the neocortex (figure 6.3).

In his classic 1948 paper, Yakovlev reduced behavior to movement
(which it fundamentally is) and conceived “three spheres of motility”
comprising (1) movements in the internal milieu, which he called vis-
ceration, (2) the physical expression of internal states (emotion), and
(3) manipulation of the external world (effectuation). Yakovlev drew a
correspondence between neuronal arrangements and behavior as fol-
lows: (1) The reticular arrangement yields movements of the body
within the body (the essence of autonomic and visceral action); (2) the
nuclear arrangement yields movements of the body upon the body
(axial and postural action of the extrapyramidal system); and (3) the
laminar arrangement yields movements of the body outside the body
(the pyramidal action of effectuation). Yakovlev’s scheme is beautifully
concise and remains generally valid.

Three corresponding clinical examples of Yakovlev’s organizational
scheme would be (1) hemiplegia caused by a stroke in the laminar cor-
tex, impairing operation on the external world; (2) Parkinson’s disease
caused primarily by degeneration of the substantia nigra nucleus,
which impairs movements of the body upon itself, especially postural
and axial adjustments; and (3) destruction of the pontine reticular acti-
vating system causing coma or sleep-wake disturbance.

Table 6.1 lists seven ways of arranging the cerebrum that I discuss in
this review.
6.2.2 Phyletic Development

There exists a basic blueprint from which all vertebrate brains are built. Phyletic development compares the elaboration of fundamental neural components across species. This very traditional view, peppered with evolutionary theory, says that as we ascend the phylogenetic scale we find an increasing separation and elaboration of neural building blocks. This is how discrete faculties supposedly evolve out of a less specialized brain. That is, with increasing phyletic development the senses should become more physically separated. According to this scheme, synesthesia should not exist.

Figure 6.3 Vertical chains and horizontal lamination in the cortex. (Left) A Golgi stain, which shows branches. (Center) A Nissl stain, which shows cell bodies. (Right) A myelin stain, which shows pathways of axonal projections. (From Brodmann K. [1909] Vergleichende Lokalisationslehre der Großhirrinde. Leipzig: JA Barth.)
Phyletic elaboration is how lateralization and multiple specialization emerge in human brains, which reputedly rest at the top of the phyletic scale. Of course, some features of complex organisms, such as lateralization (asymmetry), are present in simpler forms such as fish and even plants. What matters to phyletic theory is the degree of a feature’s development and its relevance to cognition in a given species. At its simplest, there is a conceptual parallel between the complexity of neural development and its correspondingly sophisticated mental expression the “higher” we travel on the evolutionary scale (table 6.2).

The behavior of simple organisms has little or no plasticity because there is little if any synaptic distance between sensation and action. The brains of simple creatures tend to react immediately to the stimuli in their environment with a limited, invariant repertoire. They are unthinking brains that, because of their hard wiring, have little room for flexible responses or for assembling information from several senses. For example, the hydra or sea anemone (phylum Cnidaria, class Anthozoa) has a mostly reticular nervous system. Neuroepithelial cells located on the body surface make direct contact with underlying

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Table 6.1  Seven ways to arrange the cerebrum

| 1. Reticular, nuclear, and laminar arrangements are each associated with specific behavior (movements of the body within the body, movements of the body upon itself [e.g., posture], and movements outside the body, respectively). |
| 2. State vs. channel functions highlight general behavior and distinguish those functions more dependent on chemical or hormonal activation from those subserved by more self-contained pathways. |
| 3. The cortical column, orthogonal to the surface, is the basic unit of the cortex. |
| 4. The distributed system, a complex of reciprocally interconnected dynamic systems, allows us to conceive of multiple mapping of psychological functions. |
| 5. Patterns of neural connection in cortex can be reduced to five types: limbic, paralimbic, heteromodal homotypic, unimodal homotypic, and idiotypic. |
| 6. Subcortical vs. cortical categorization of behavior emphasizes that cortex is not necessary for many types of behavior or sensory discrimination. |
| 7. Lateralization and hemispheric specialization reminds us that brain function segregates in utero, probably under hormonal influence. Cognitive ability is unevenly distributed in the general population. |

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Table 6.2  Phyletic development

<table>
<thead>
<tr>
<th>Species</th>
<th>Developmental feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humans</td>
<td>Separation of projection areas, marked lateralization</td>
</tr>
<tr>
<td>Primates</td>
<td>Developed association cortices</td>
</tr>
<tr>
<td>Mammals</td>
<td>Separation of motor and sensory areas, multiple specialization</td>
</tr>
<tr>
<td>Marsupials</td>
<td>Overlap of primordial zones</td>
</tr>
</tbody>
</table>

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muscle cells. By poking the animal, as any marine aquarist knows, stimulating one cell stimulates all of them, and the anemone recoils and closes up.

This simple reflex arc between sensor and effector has been replaced in higher organisms by a series of interneurons poised between the sensor and effector cells. More advanced animals such as the crown jellyfish (Ctenophora) or tube worm (Phoronida) retain throughout their bodies the reticular nerve net, which stimulates undulating contractions that guide food into the mouth. Additionally, however, isolated conduction in a separate ring of neurons around the rim of the creature’s umbrella causes the synchronous contraction of the marginal lappets by which the jellyfish swims and the tube worm withdraws into its tube. You now find conduction of a nervous impulse over a long distance without stimulating all the neighboring or intervening cells (i.e., it does not stimulate the reticulum). This separation of a wide-band reticular system from a narrow-band conducting system in the ring represents a major advance in neural architecture. An analogy could be drawn with the separate human pathways serving channel and state functions. It is in the great proliferation of these intercalated neurons (interneurons) that central nervous systems of higher organisms find a corresponding plasticity of behavior. Stated differently, behavioral flexibility results from an expansion of the synaptic bridge that links sensation to action and recognition.

The American Nobel laureate Roger Sperry performed a famous experiment in which he caused a visual displacement in a newt by surgically rotating its eyeball. The relatively inflexible wiring between the creature’s retina and its visual brain kept it from ever finding food targets or behaviorally adapting to its new visual orientation. Humans (and subhuman primates) can experience similar, though reversible, visual displacements by wearing prisms that reverse the up-down and left-right orientations. These more flexible brains with their cloud of uncommitted interneurons can adapt within 15 minutes of donning such spectacles so that the subject can operate fully in the new visual environment. (I have ridden a bicycle while wearing such prisms and can vouch that it is indeed an exciting experience.)

Ascending the phylogenetic scale, the gradual elaboration of interneurons that eventually gives rise to association areas is considered a later stage of the process by which the primary motor and sensory areas first became individuated out of a less specialized brain, such as that of sea anemones and jellyfish: that is, cytoarchitectonic differentiation increases as associative activities become separated from receptive and motive ones. Patterns of cellular organization and connection become more distinct, and the topographic relationships among individual types of organization are highly ordered and regular. Such constant
relationships allow derivation of principles about neural organization and its relation to specialized behavior.

Even though the evolutionary trend seems to be toward increasing separation of function, the dividing lines are not perfectly sharp. In many species, including humans, we can stick an electrode into what is supposed to be a visual neuron and discover that it also responds to sound or touch. In addition to such multimodal cells, unit recording also reveals modality-specific ones amid cells responding to a different modality. Rather than all or nothing, it is a question of degree that a cell responds robustly to a specific modality and not very much to other kinds of input. On the macroscopic scale, electrical stimulation studies have proved that the boundaries of functional regions (e.g., language) are not as sharp as conventional diagrams usually suggest (Ojemann & Whitaker 1978; Penfield & Jasper 1954).

In sum, "the synaptic volume dedicated to intermediary processing shows a marked increase in phylogeny and occupies the great majority of the cerebral cortex and advanced primates and cetaceans" (Mesulam 1998, p 1015). Neurons dedicated to such intermediate processing lie principally in association and limbic areas of the cerebrum. Because my focus is on functional topology, I must omit discussing the important integrative contributions to behavior of such subcortical structures as the thalamus, striatum, claustrum, and the brainstem.

### 6.2.3 Cortical Columns

Our conceptualization of nervous tissue has changed radically over a short time from an amorphous reticulum to an arrangement of intrinsic power modules raging a battle of excitation and inhibition. In addition to the six major layers of horizontal lamination that Brodmann clarified in 1908, Lorente de Nó (1943) discovered that neurons were also arranged in vertical chains throughout the depth of the cortex (see figure 6.3).

Investigations by the American physiologists Vernon Mountcastle (1957) and David Hubel & Thorsten Wiesel (1972) showed that neurons in tiny columns orthogonal to the cortical surface responded similarly to highly specific afferent inputs. These sharply defined columns for feature detection have an average cross section of 0.1 mm$^2$. Szentágothai & Arbib (1975) elucidated the structural basis for what has come to be called the modular organization of these neuronal columns. In both structure and function, the column of specific cell types was conceived as the basic unit in all cortical areas. The basic circuit of the columnar module is (1) afferent fiber input, (2) complex interactions within the module, and (3) output through the axons of the pyramidal cells. Major functional differences exist between connections in laminae I and II, and connections in laminae III, IV, and V (figure 6.4).
Figure 6.4 Sketch of cortical columns, their various neurons, and the endings of a specific afferent fiber. At right is pictured a specific afferent cylinder and, in longitudinal section, two slabs of adjacent cortico-cortical columns. Note how cortico-cortical afferents synapse in all layers except IV before branching extensively in layer I. Cross-hatched and black cells are inhibitory. Note how their axons inhibit pyramidal cells of adjacent columns, and branch to all laminae, even layer I. (Reprinted from *Brain Research*, vol 95, Szentágothai, "The module-concept in cerebral cortex architecture," pp 475–496, copyright 1975, with permission of Elsevier Science.)
Cortical layers are numbered from the surface inward and are arranged as follows: Layer I contains mostly horizontally directed dendrites from other layers and other areas; it has few cells. Cells in layers II and III project to deeper cortical layers as well as horizontally outside the cortical column. In turn, these cells in layers II and III receive input from the deeper layers and adjacent cortical columns. Layer IV receives the direct projection of specific afferents from thalamic nuclei. Not surprisingly, therefore, this layer is best developed in primary sensory cortices and least so in motor cortex. The giant pyramidal cells of layer V provide the main exit from the cortical column; they often give off recurrent axons that engage in feedforward or feedback operations. Layer VI contains spindle cells whose dendrites travel only in the lower three layers.

To summarize, the modular concept is of well-defined groups of cells (approximately ten thousand) with a unitary existence as a result of their mutual connections. They build up power within themselves and inhibit the cells of nearby columns. There are two levels of performance: a powerful one in laminae III, IV, and V, involving specific afferents and pyramidal output, and a finer grain of influence in laminae I and II that is exerted mainly by association and callosal afferent fibers. The delimitation of internal power and inhibitory surround is what defines a module. Each column tries to overcome its neighbor by building up its own power through its vertical connections and by projecting horizontal inhibition onto neighboring columns (Szentágothai 1974).

Note how these neuronal interactions, especially those of sensory specific afferents, are overwhelmingly local, and that the input from other areas is largely restricted to the modulating layers I and II. These facts of neuronal organization—vertical and largely local—are hard to reconcile with speculations that synesthesia results from “connections” or “cross-wiring,” possibly retained by neoteny, occurring at the border between sensory entities. Rather than require the existence of wholly new synaptic architecture and fiber projections, it would seem simpler to explain synesthesia based on anatomical relations that already exist. Contemporary concepts of functional brain organization, detailed below, suggest how this might be done.

Although the general principles of contemporary neural organization are now a quarter-century old, knowledge of them has barely filtered down to the general scientist let alone the interested public. Also, parochial single-mindedness on so-called cognitive modules and their underlying anatomy seems increasingly the norm, the result being that such a narrow focus sometimes conflicts with general principles. Furthermore, natural laws follow general principles much more often than they violate them.
It is not easy for the beginning student to reconcile changing concepts of nervous tissue. Over a half century, the concept of an amorphous network yielded to that of hierarchy in which commands from supposedly higher centers were carried out by less complex brain systems. Cytoarchitectonics became increasingly complex as it divided the cortex more finely on the basis of number or type of cell, packing density, or degree and temporal sequence of its connecting fibers’ myelination. At present, we think of the cortical column as the brain’s basic functional unit. Beyond the fundamental unit of the cortical column is the distributed system that sees the brain as a collection of widely and reciprocally interconnected dynamic systems (Mountcastle 1979; Mesulam 1998).

6.2.4 The Distributed System

A highly repetitive structure is characteristic of cortex. Though an expert eye (with the help of a microscope) can distinguish one region from another, the sameness of cortex suggests that it repeats the same task over and over. This repetition is in space rather than time, however, given evidence that different regions of cortex perform roughly the same transformation on their given inputs.

The distributed system develops this idea that there is nothing unique about the structure of one region versus another. Rather, it is the pattern of connections among entities, any one of which can belong to several distributed systems and onto which multiple variables can be mapped, that constitutes the distributed system. You will likely need repeated reading of this section because the distributed system is not easy to understand. However, the idea of multiple mapping is its essence (table 6.3).

The classic reticular, nuclear, and laminar divisions (such as the reticular formation, dorsal horn, basal ganglia, and neocortex) are re-

<table>
<thead>
<tr>
<th>Table 6.3 The distributed system</th>
</tr>
</thead>
<tbody>
<tr>
<td>• A cortical area is defined by its cytoarchitecture, its extrinsic connections, and its function.</td>
</tr>
<tr>
<td>• Distinct cortical areas can be homologized over a series of mammals.</td>
</tr>
<tr>
<td>• Every neocortical area that has a distinct cytoarchitecture also has a unique function in the conventional sense.</td>
</tr>
<tr>
<td>• Every distinct neocortical area also has a unique set of extrinsic connections (thalamic, corticocortical interhemispheric, and long descending).</td>
</tr>
<tr>
<td>• Several variables can be simultaneously mapped through an area while still preserving an area’s topology.</td>
</tr>
<tr>
<td>• The distributed system does not preclude the operation of other systems, such as those serving state functions.</td>
</tr>
</tbody>
</table>

226 6. The Neural Substrate of Synesthesia
ferred to as \textit{entities} that, as such, are composed of local circuits that are similar within any given entity (Szentágothai 1974). Modules are grouped into entities (e.g., nuclei or regions of laminated cortex) (1) because of their specific external connections, (2) owing to the way they interact within a module, or (3) by cloning a particular function over a topographic region. The function of modules is everywhere the same, with nothing inherently motor about the motor cortex or sensual about sensory cortices.

Phylogenetically, the neocortex of primates achieved its enormous size with hardly any change in its vertical organization, one feature that led to the \textit{vertical minicolumn} being regarded as the basic structural unit in this part of the cerebrum. This $30 \times 25$-µm cylinder of cells, perpendicular to the brain surface, forms as neurons migrate from the germinal zone of the neural tube along the radial glial cells to their destined locations in the cortex.

Different species of mammals all have an invariant 110 cells in each minicolumn of different neocortical areas, except for the striate cortex where the fixed number is 260. The number of pyramidal and stellate cells, the two main classes of neurons, is a constant 2:1 ratio in such diverse cytoarchitectonic and functional areas as motor, somatic, and visual areas of different mammals (Gatter, Winfield, & Powell 1980).

Just as atoms form molecules, several hundred structural minicolumns join to form the larger, fundamental functional unit of the \textit{cortical column}, onto which several variables can be mapped. The human neocortex contains approximately one million of these larger columns, each of which is a complex summating and distributing unit that links a number of inputs to several outputs. The number of other regions transmitting to and receiving from a traditionally defined cortical area varies from ten to thirty. The cells of origin of different output pathways are sharply separated horizontally by layer.

Note how several features from the hierarchical and cytoarchitectonic approaches to brain organization can be subsumed under the newer concept of a distributed system: (1) Distinct cortical areas exist that are homologous over a series of mammals, (2) each distinct architectural region has a unique function (in the conventional sense), and (3) each neocortical area that has a distinct architecture and function also has a unique set of extrinsic connections (i.e., it has its own pattern of thalamic, corticocortical interhemispheric, and long descending connections). These three variables of cytoarchitecture, extrinsic connections, and function define a cortical area.

One great advantage of the distributed system is that several variables can be simultaneously mapped onto it while preserving the area’s topology. Many variables can be mapped through a single area while preserving orderly relationships among (1) sets on the input side, (2)
those within the area, and (3) those in the target. Thus, a number of
distributed systems can be mapped through a given area of cortex,
allowing an integration of their functions with other properties of the
area that are determined by some different input to it. In this way, for
example, selective processing (feature extraction) is possible via inter-
columnar pathways that diverge to different outputs.

Neither the horizontal laminar nor the vertical columnar organiza-
tion of the cortex precludes other systems (e.g., nuclear, reticular) from
operating throughout the cortex in different ways. This is seen particu-
larly in systems that subserve state rather than channel functions. The
noradrenergic system arising from the locus coeruleus of the pons, for
example, reaches every cortical region and all cortical layers. Immuno-
histochemistry reveals a fine web of noradrenergic fibers at 30- to
40-\(\mu\)m intervals, indicating that any single cell of the locus coeruleus
sustains an immense and divergent axonal field. Catecholamine-
containing neurons are phylogenetically old and relatively few in
number, and their terminals are found both with and without synaptic
connections, implying dual transmitter and modulating functions. The
noradrenergic system is, in fact, capable of directly modulating the en-
tire neocortex (Gold & Zornetzer 1983).

The functions of various distributed systems were elucidated through
three discoveries (Mountcastle 1979). First, it was determined that a
distributed system’s major entities are built by iterating identical mul-
ticellular units joined together by complex intermodular connections.
Hundreds of structural minicolumns are packed together to form the
functional unit of the cortical column. Second, extrinsic connections
between large entities of the brain are far more numerous, selective,
and specific than previously was supposed. Third, the many modules
of a large entity do not each contain all the connections known for that
entity. Instead, a large entity is split into subsets of modules, each
linked by a particular pattern of connections to similarly segregated
subsets of other large entities. The linked sets of modules of the several
entities thus define the distributed system.

In contrast with earlier models of brain organization, the number of
distributed systems in the brain is perhaps several orders of magnitude
larger than previously thought. By definition and empirical observa-
tion, distributed systems are both reentrant pathways and links to in-
put and output channels of the entire nervous system. Major entities
are, moreover, nodes of more than one distributed system, contributing
to each system, as Mountcastle explained it, “a property determined for
the entity by those connections common to all of its modular subsets
and by the particular quality of their intrinsic processing. Even a single
module of such an entity may be a member of several (though not
many) distributed systems.” The distributed system allows us to con-
ceive of multiple maps of a given cognitive function.
6.2.5 Topography: Patterns of Functional Neural Connection

In trying to correlate areas of nervous tissue (not just the neocortex) with behavior, one looks for patterns. Whereas architectonics stresses structure, topography stresses functional affiliations. Compared to the sameness and repetitive structure of the modules that constitute distributed systems, topological organization stresses a region’s common characteristics. Topology bears the same relationship to topography as geology does to geography. It means a science of place, a qualitative geometry. This section should be fortified with standard anatomical references, as necessary, depending on the reader’s familiarity with cerebral anatomy.

The topological approach divides the cortical mantle into just five common types that display a progression in structural complexity and differentiation. Figure 6.5 shows this topological schema on the right and, on the left, these same topological regions superimposed upon conventional Brodmann areas. As the figure graphically depicts, the functional topologic zones widely overlap structural architectonic divisions. The five topological types of nervous tissue are listed in table 6.4 and are shown schematically in figure 6.6, where their relationship to extrapersonal space and the internal milieu is also indicated.

With reference to table 6.4 and figure 6.6, we can see that brain tissue becomes more differentiated as we proceed from limbic tissue on the one hand to the primary motor and sensory areas of idiotypic cortex on the other. Note that the simplest structures have an in-between architecture that is partly nuclear and partly laminar. These are the corticoid tissues of the septum, the substantia innominata, and the amygdaloid complex. A substantial part of the amygdala has a nuclear architecture, though its location on the hemispheric vesicle actually makes it part of the cortical mantle.

Nomenclature proposed more than a century ago is still used next to more modern terms. Not much can be done to alleviate the resulting confusion other than to learn the terms, which roughly reflect the evolutionary age equivalence of laminated tissues as well as their increasing differentiation into granular and more distinctly laminated forms. The piriform complex is called paleocortex ("old"); the hippocampal formation, archicortex ("first," or "beginning"), and both are examples of allocortex ("other"). The entire paralimbic region is called mesocortex ("middle"), whereas homotypic and idiotypic cortex are known collectively as neocortex ("new"). Although all of these tissues are laminated, and thus are technically cortex, each is distinguished by a different level of organization and distinct set of inputs and outputs. The word cortex used without a prefix commonly means the neocortex.

Homotypical association isocortex is either modality-specific (unimodal) or heteromodal. Analogous older terms would be secondary
Figure 6.5  (Left) Brodmann’s cytoarchitectonic map of the left hemisphere in lateral (top) and medial (bottom) views. Compare with the topographic organization shown at the right. (From Brodmann [1909].) (Right) Distribution of topological and functional zones in relation to Brodmann’s map. Boundaries are not precise. (Adapted from Mesulam M-M, “Patterns in behavioral neuroanatomy: Association areas, the limbic system, and hemispheric specialization,” pp 1–70, in M-M Mesulam, ed, Principles of Behavioral Neurology [1985], Philadelphia: FA Davis, with permission.)
association cortex and tertiary association cortex, respectively. Heteromodal cortex actually is closer in structure to paralimbic cortex because it is less granular and its layers are less differentiated. Indeed, the columnarization and lamination of neurons is more conspicuous in unimodal than heteromodal areas. Such classification on anatomical grounds makes the highly granular and striated idiotypic cortex of the primary motor and sensory areas the most advanced of cortices. This view is
Table 6.4 The five topographic divisions of cortex

<table>
<thead>
<tr>
<th>Division</th>
<th>Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Limbic areas</strong></td>
<td>Septal areas, substantia innominata, amygdala complex</td>
</tr>
<tr>
<td>Corticoid</td>
<td>Allocortical</td>
</tr>
<tr>
<td>Allocortical</td>
<td>Hippocampal formation (archicortex)</td>
</tr>
<tr>
<td></td>
<td>Piriform (olfactory) complex, lateral olfactory stria (paleocortex)</td>
</tr>
<tr>
<td><strong>2. Paralimbic areas (mesocortex)</strong></td>
<td>Ento-, pro-, and peri-rhinal areas</td>
</tr>
<tr>
<td>Temporal pole, anterior commissure</td>
<td>Pre- and para-subicular areas</td>
</tr>
<tr>
<td>Caudal orbitofrontal cortex</td>
<td></td>
</tr>
<tr>
<td>Insula</td>
<td></td>
</tr>
<tr>
<td>Parahippocampal gyrus</td>
<td></td>
</tr>
<tr>
<td>Cingulum complex</td>
<td>Cingulate, retrosplenial, and parolfactory gyri</td>
</tr>
<tr>
<td><strong>3. Modality-specific (unimodal) homotypical association isocortex</strong></td>
<td></td>
</tr>
<tr>
<td><strong>4. High-order (heteromodal) homotypical association isocortex</strong></td>
<td></td>
</tr>
<tr>
<td><strong>5. Idiotypic cortex</strong></td>
<td></td>
</tr>
<tr>
<td>Primary motor cortex</td>
<td>Primary sensory cortices</td>
</tr>
</tbody>
</table>

**EXTRAPERSONAL SPACE**

- **primary sensory and motor areas**
  - **IDIOTYPIC CORTEX**
    - modality-specific (unimodal) association areas
  - **HOMOTYPICAL ISOCORTEX**
    - high-order (heteromodal) association areas
  - **PARALIMBIC AREAS**
    - temporal pole - caudal orbitofrontal anterior insula-cingulate-parahippocampal
  - **LIMBIC AREAS**
    - septum - s. innominata-amygdala-piriform c.-hippocampus

**HYPOTHALAMUS**

**INTERNAL MILIEU**

Figure 6.6 Schematic organization of the five topological types of nervous tissue. See text for further details. (From Mesulam [1985], with permission.)
opposite that implied by older concepts that traced neural impulses linearly from thalamus to primary cortex, thence to secondary association cortex, and onward to tertiary association cortex. Today we view primary (idiotypic) motor and sensory cortices as the most differentiated and the most advanced.

Three features define unimodal isocortex: (1) neurons in this area respond only to a single sensory modality, (2) input is by primary isotypic or other unimodal regions in the same modality, and (3) damage causes modality-specific deficits.

Heteromodal isocortex is identified by three contrasting characteristics: (1) neurons respond to more than one modality, (2) inputs are from unimodal areas in more than one modality, from other heteromodal areas, or both, and (3) damage yields behavioral deficits that are not modality-specific. Some neurons in heteromodal cortex are themselves multimodal, but the region is mostly a mixture of neurons that prefer different modalities. For example, the binding of vision and speech activates the middle temporal gyrus (MTG). About half of its neurons respond to speech (Vincent et al. 1997; Creutzfeldt et al. 1989), but visually presented faces, words, and objects activate it too (Vandenberghe et al. 1996). At present, it is not clear whether to classify the MTG as heteromodal or to partition it into unimodal auditory, unimodal visual, and heteromodal sections.

Idiotypic cortex contains the well-known motor and sensory areas: the primary visual area (V1) in the calcarine cortex of the occipital pole, the primary auditory cortex (Heschl’s gyri, A1) in superior temporal cortex, the postcentral primary somatosensory cortex (S1), and the precentral primary motor cortex (M1).

The most distal synaptic levels of sensory-fugal transformation are occupied by heteromodal, paralimbic, and limbic cortices, collectively known as transmodal areas. “Their unique role is to bind multiple unimodal and other transmodal areas into distributed but integrated multimodal representations.” Examples of transmodal areas include the midtemporal cortex, Wernicke’s area, the hippocampal-entorhinal complex, and posterior parietal cortex; they “provide critical gateways for transforming perception into recognition, word-forms into meaning, scenes and events into experiences, and spatial locations into targets for exploration” (Mesulam 1998, p 1013).

Figure 6.6 schematically represents the five cortical types in relation to extrapersonal space and the internal milieu. You can deduce quickly from this schematic, together with figure 6.5, that the physical arrangement of cortical types is highly ordered. For example, paralimbic cortex is always surrounded by isocortex on one side and allocortex on the other; primary sensory cortex is always separated from heteromodal areas by unimodal isocortex.
The five cortical zones also connect horizontally and vertically with one another, although the pattern is not at all homogeneous. The vertical connections of a given zone are strongest with the immediately adjacent zone. For example, though all areas receive some hypothalamic projections, the most intense projections connect limbic entities. Similarly, unimodal cortex may receive input from other association areas in the same modality, but there is no connection between areas belonging to different modalities, a thought to keep in mind regarding synesthesia. Instead, all modalities converge downstream in transmodal areas.

Because more than one entity in a distributed system participates in the sensory-fugal gradient of neural transformation for a given modality, the terms “upstream” (proximal) and “downstream” (distal) are used for clarification. Upstream areas are only one synapse away from the relevant primary sensory area whereas downstream areas are removed a distance of two or more synaptic units. In vision, for example, V2 or V5 are upstream whereas those cortical regions engaged in face recognition or spatial location encoding are downstream (in anatomical terms, downstream areas would be the fusiform, inferior temporal, and parts of the middle temporal gyri).

The architectural hierarchy so evident in functional topography is paralleled by a relative polarization of connectivity. Figure 6.7 illustrates this reciprocal monosynaptic polarity by the thickness of arrows. The drawing also illustrates that some connections cross levels to transmodal entities (e.g., superior temporal gyrus to entorhinal cortex). Such projections are not as prominent as those between adjacent levels, however.
Norman Geschwind’s classic papers in 1965 on the “disconnexion syndromes” introduced the idea that mental life depended on discrete cortico-cortical pathways between behaviorally specialized brain areas. At first, a straightforward serial and convergent sensory-fugal flow was assumed. But the emergence of powerful histochemical tools based on intra-axonal transport of markers demonstrated how primary areas such as V1 give rise to multiple parallel projections to upstream and downstream unimodal areas. This set the stage for a new kind of connectivity. Now, for example, we take the clinical dissociation of achromatopsia from akinetopsia as proof that the V1 projections to V4 and V5 are organized in parallel rather than in series.

6.2.6 Multiplex Communication

Figure 6.8 attempts to summarize the above patterns of neuronal connections. Obviously, no single illustration can successfully convey the rich multiplexing of the brain. Schemes organizing the brain into cortical versus subcortical, gray matter versus white matter, left hemisphere versus right hemisphere, and so forth are merely conceptual divisions that make comprehension a little easier for us.

In the multiplex model, sensory information undergoes extensive associative elaboration and intentional modulation as it becomes incorporated into the texture of cognition (Mesulam 1998). Connections from one topological zone to another are reciprocal and allow the convergence of afferents and the divergence of efferents. The resulting synaptic organization supports parallel as well as serial processing, and permits each sensory event to initiate multiple cognitive outcomes. Upstream unimodal sectors encode basic features of sensation such as color, motion, form, and pitch. More complex derivatives such as objects, spatial locations, and sound sequences become encoded within downstream unimodal sectors by groups of coarsely-tuned neurons. Each mode is encoded with when (time), where (space), what (identity), and why (emotional salience to the organism) (DeGelder 2000). The most distal synaptic levels of sensory-fugal processing are occupied by heteromodal, paralimbic, and limbic cortices, collectively known as transmodal areas. The unique role of these areas is to bind multiple unimodal and other transmodal areas into distributed but integrated multimodal representations. Transmodal areas provide critical gateways for transforming perception into recognition.

The reciprocal and recursive connections among topological areas explain the phenomenon in which touching your hand improves vision in the nearby area. The enhancement results from backprojections from multimodal parietal areas to unimodal visual cortex (Macaluso, Frith, & Driver 2000). That is, spatial queuing in one modality can affect
6. The Neural Substrate of Synesthesia

- **Outside World**
- **Not Self**

- **Sense Receptors**
  Mechanical, chemical or electromagnetic transducers.

- **Local Architecture & Centripetal Tracts**
  (e.g., retina, cochlea)
  Most cortical areas feed back to nuclei & end organs.

- **Nuclear Relays**
  One or more (e.g., thalamus).

- **Primary (idiotypic) Sensory Cortices**
  First cortical relay, each sense projecting to multiple & different association areas.

- **Sense-Specific (unimodal) Association Cortices**
  Highly concerned with external world.

**Above connections, mostly linear; those below, multidirectional.**

- **Bridges between external realities and internal urges**

- **Pari-Limbic Areas**
  (portions of temporal and frontal lobes)
  Behavioral relevance now more important than the physical aspects of a stimulus.

- **Limbic Areas**
  Memory, learning, modulation of drive, emotional coloring of experience, higher control of hormonal & autonomic tone.

- **Hypothalamus**
  "Head Gardener of Internal Milieu"
  Immune regulation, circadian rhythms, sexuality, temperature, metabolism, electrolyte balance, drives and urges for species- and self-preservation.

- **Internal Milieu**
  Sense of Self

- All areas project to striatum.
activity in structures that only receive afferent input from a different modality. In this example, reciprocal connections between occipital cortex, posterior parietal cortex, and multimodal areas in the inferior parietal lobe provide the anatomical substrate for cross modal interaction observed in the visual lingual gyrus. The modulation of vision by hearing has also been demonstrated (Shams 2000).

The human brain contains at least five anatomically distinct networks: spatial awareness, language, object recognition, explicit memory/emotion, and working memory/executive function. In keeping with the principles of selectively distributed processing, each epicenter of a large-scale network displays a relative specialization for a specific behavioral component of its principal neuropsychological domain. The destruction of transmodal epicenters causes global impairments (e.g., multimodal anomaia, neglect, or amnesia) whereas the selective disconnection from relevant unimodal areas elicits modality-specific impairments (e.g., prosopagnosia, pure word blindness, category-specific anomasias). Individual sensory modalities give rise to processing streams directed to transmodal nodes belonging to each of these five networks.

**Figure 6.8** The multiplex concept merges hierarchical, linear processing with parallel sensory processing in unique zones of different neural tissues. This is a complex and recursive pathway from the outside world (starting with the ribbon at the upper left) to an internal sense of self (indicated by the darkening gradient toward the figure’s rear plane). Think of processing as largely linear in early stages, whereas parallel processing of multiple maps starts roughly at the gray horizontal line, principally via vertical intercortical connections with other zones and horizontal intracortical connections within the same zone. There are no interconnections among primary sensory or sense-specific association cortices that belong to different senses. Yet in the multisensory, paralimbic, and limbic zones, strong horizontal connections exist with other components in the same zone. Hence, early on the emphasis is on rich linking that combines the neural transformations of many structures. The limbic system is what gives salience to any event. The effects of volume transmission, both widespread and specific, cannot be illustrated here.

*Idiotypic, unimodal, and heteromodal cortices are all kinds of neocortex. The curved 3-dimensional arrow indicates the one-to-many multiplex projections from idiotypic cortices characterized by the distributed system.

**Multisensory heteromodal and paralimbic types of cortex perform two kinds of neural transformation: (1) further parallel elaboration of multiple sensory maps and (2) integration of the result with drive, emotion, and mental content. Earlier cortical types are fairly homogeneous transformers of a single sense; later types of cortex have heterogeneous input-output relations, and no uniform type of behavior can be ascribed to them. Sense specificity gives way to intermodal associations. Even the distinction between what is motor and what is sensory is now lost.

The spiral curving inward toward the dark funnel of the internal milieu indicates that downstream entities contribute both divergent and convergent processes to the construction of consciousness and self. The sphere labeled “sense of self” appears self-contained and set apart from the aforementioned entities; yet it too is part of recursive multiplex systems and should be seen as emanating from the dark void. The most distal (interior) transformations can feed back to the most proximal members, the sense organs themselves.
Figure 6.9  Synaptic levels in topographic relations for vision and hearing. Each concentric ring represents a different synaptic level; any two consecutive levels are separated by at least one unit of synaptic distance. Primary sensory cortex occupies level 1. Small empty circles represent macroscopic cortical “nodes” one to several centimeters in diameter. The identity of many nodes of not specified because their exact anatomical location is not critical. Nodes at the same synaptic level are reciprocally connected by the black arcs of the concentric rings; the gaps at the first four levels indicate the absence of monosynaptic connections between modality-specific components of auditory and visual pathways. Broken lines represent reciprocal monosynaptic connections from one synaptic level to another. (a) Visual (dashed) and auditory (dotted) pathways in the human brain. The terms “dorsal” and “ventral” refer to the separation of visuo-fugal pathways, especially at the fourth synaptic level, into the dorsal ‘where’ and ventral ‘what’ streams of processing. (b) Transmodal nodes are indicated at the fourth, fifth, and sixth synaptic levels. Transmodal cortices have very few monosynaptic projections to primary sensory
The fidelity of sensory channels is actively protected through approximately four synaptic levels of sensory-fugal processing as figure 6.9 demonstrates. The modality-specific cortices at these four synaptic levels encode the most veridical representations of experience. If object identification were based on the serial extraction of features such as color, shape, or motion that are encoded at the first three synaptic levels, perception would take a long time. This problem is overcome at the fourth synaptic level, where neuronal groups tuned to categories allow rapid identification. Neurons tuned to similar object features form vertical columns ~0.4 mm in diameter (Tanaka 1996). Interconnected columns constitute a distributed system tuned to the canonical features that define an object class. My comments regarding categorical synesthesia is recalled in this regard. By the scheme illustrated in figure 6.9, synesthesia would result from the transmodal binding of unimodal entities at the fourth through sixth synaptic levels.

6.2.7 Subcortical Entities

Scientists and laypersons alike tend to overemphasize the neocortex for reasons already noted. It is counterintuitive to learn how much sophisticated behavior is possible without any cortex at all. For example, cortex is unnecessary for many kinds of auditory, visual, and somesthetic discrimination (e.g., Weiskrantz 1986, 1997; Diamond & Neff 1957). MacLean (1990) showed that cortex is unnecessary for the expression of many complex behaviors that are usually called innate, and Konrad Lorenz showed that birds, which have virtually no cortex, exhibit sophisticated behaviors such as imprinting, parenting, and socialization. These observations suggest that rather than being an obligate component of any meaningful behavior, cortex provides a finer grain of discrimination to other brain areas that might be the final effectors of behavior.

Figure 6.9 (continued)

areas, and send fewer projections to upstream than to downstream nodes of unimodal areas. Sensory fidelity is actively protected through the first four synaptic levels; the first two levels are relatively protected from value-based modulations. Convergent-divergent organization intensifies from level three onward. The first synaptic level is finely tuned to a primary sensory dimension. The second synaptic level participates in more complex integrations and extracts attributes such as color and motion. The third and fourth levels play critical roles in categorical identification. Abbreviations: A1, primary auditory cortex; V1, primary visual cortex; V2, V4, V5, upstream visual areas; f, area specialized for face encoding; wr, area specialized for word-form encoding; s, area specialized for spatial-location encoding; v, area specialized for identifying individual voice patterns; W, Wernicke’s area; T, heteromodal lateral temporal cortex; L, hippocampal-entorhinal or amygdaloid components of the limbic system; P, heteromodal posterior parietal cortex; Pf, lateral prefrontal cortex. (Modified from Mesulam [1998], with permission.)
In §3.4.1 I cited the gustofacial reflex and the counterintuitive conclusion that “decisions” can be made at the lowest human brainstem level. The gustofacial reflex is even present in anencephalic monsters, babies who are born without any cerebrum but only a brainstem and diencephalon.

Subcortical tissue does more that just hold up the surface. To confuse cortex with the whole brain is a bad case of synecdoche. The human neocortex constitutes only a fraction of the brain’s bulk. Although gyral folding confers on it a large surface area, cortex averages only 1 to 2 mm in thickness compared to a thickness up to a hundred times that for the whole brain. Readers interested in the behavioral correlations of subcortical lesions can consult Cytowic (1996 pp 254–257).

6.2.7.1 Channel and State Functions  Multiplexing denotes diverse means of communication in the brain. In contrast to the chemical messengers of volume transmission, it is the self-contained tracts of the long wiring system of axons and synapses, operating on a narrow band, that carry what are called channel-dependent functions.

The anatomical substrate of channel-dependent functions usually has a point-to-point correspondence, or topographic arrangement. For example, the projection of retinal neurons to the geniculate nucleus, the striate cortex, and beyond maintains at each stage a retinotopic arrangement. The orderly point-to-point correspondence of cochlear hair cells projecting to the transverse auditory gyri is tonotopic; the lemniscal system of touch is somatotopic. The disruption of pathways at different points in a channeled function produces clinical syndromes that often are so characteristic as to be pathognomonic.

In contrast, there exist seven groups of nuclei that sustain huge terminal fields in either cortex or thalamus (table 6.5). Each one of these small cell groups can modulate rapidly the state of the brain as a whole. Arousal, vigilance, and even some aspects of mood and memory

<table>
<thead>
<tr>
<th>Table 6.5  State functions and wide-field projections</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Cholinergic neurons in the septum (Ch1–Ch4) project to the entire cortex, with overlaps.</td>
</tr>
<tr>
<td>• Hypothalamic neurons project widely to cortex.</td>
</tr>
<tr>
<td>• Serotonergic neurons in the brainstem raphe project diffusely to the entire cortex.</td>
</tr>
<tr>
<td>• Noradrenergic neurons in the locus coeruleus project to the entire cortex.</td>
</tr>
<tr>
<td>• Cholinergic neurons in the pontomesencephalic reticular formation project to the entire thalamus and, less robustly, to the entire cortex.</td>
</tr>
<tr>
<td>• Dopaminergic neurons in substantia nigra and ventral tegmentum project to the striatum, limbic, paralimbic, and heteromodal association areas.</td>
</tr>
<tr>
<td>• Intralaminar thalamic nuclei project diffusely to the cortex.</td>
</tr>
</tbody>
</table>

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are referred to as state-dependent functions. These broadband pathways can affect the efficiency of channel functions without affecting the content of those channels.

The distinction between state and channel functions, of course, also concerns the psychology of nothing, a fascinating topic that I can refer to only briefly (Hearst 1991). Absence, deletion, and nonoccurrence can be physical as well as psychological, though we are far more likely to note an event’s occurrence than to notice either prevailing conditions or something that does not occur. Yet human judgment often requires consideration of events that fail to occur. Because we are biased to accentuate the positive and because we give little weight to disconfirming instances, we often draw overly strong conclusions regarding causality.

When the Gestalt psychologist Kurt Koffka wondered why we “normally see things and not the holes between them,” he was pondering why we associate things with one another rather than the spatial or temporal emptiness that envelops them. To most people, this is an odd thought, though the spatial extension of synesthesia may render it germane to our discussion. Some individuals are simply attuned to the meaningful and aesthetic functions of gaps, pauses, open spaces, and intervals. Cultural differences matter too: where the Western mind sees nothing, the Japanese mind apprehends both the interval—or ma—between elements and the elements themselves.

6.2.7.2 Chemoarchitecture The term chemoarchitecture connotes chemical neuroanatomy and refers to the physical distribution of various neurotransmitters. At the moment, twenty-eight different neuronal populations, each of which contains a different transmitter, are generally recognized. These include acetylcholine, the various monoamines, the amino acid transmitters, and eighteen peptides. More such chemical systems are being discovered and characterized every year.

The relation between neuroanatomy and chemoanatomy is an area of inquiry that is developing vigorously, yet is still relatively young. So far, one text exists that summarizes what we know regarding how cellular components are assembled into functional entities (Strange 1993).

In the late 1950s, only acetylcholine and norepinephrine were known, and it was taken on faith that the brain could get by with one excitatory and one inhibitory transmitter. Times have changed, and classic synaptic transmission has been displaced. We now know that more than one transmitter can reside in a single neuron and that excitatory and inhibitory receptors exist for the same transmitter (so much for the binary analogy that a neuron’s only possible state was either “on” or “off”). An impressively large number of transmitters and peptides reside in transmodal areas. Explaining the molecular chain of events leading to behavioral change is a daunting challenge (Jacobs 1994).
Thus far, serotonin is the only neurotransmitter plausibly linked to synesthesia (§4.2). There are, however, at least fourteen serotonin receptors in the brain, many with distinct distributions. Little more can be said at this time.

6.3 LATERALIZATION AND HEMISPHERIC SPECIALIZATION

Cerebral lateralization refers to the capacity of each hemisphere to govern particular skills. Anatomical and chemical differences between the hemispheres underlie the brain’s capacity for multiple specialization. Endocrine, immune, and genetic factors affect the brain’s development, its structure, and its lateralization—which means the final distribution and robustness of different talents between the right and left sides. The accumulated evidence suggests that synesthesia is a left hemispheric function; the preponderance of female synesthetes should also make us reflect on sexual differences in the human brain.

The blueprint for preordained parcellation of mental talents often gets rewritten in intrauterine life as the fetal environment exerts forces that alter the properties of individual brains. Critical periods exist for the development of nervous structures during which they are particularly susceptible to external influences. In the adult, the primary role of circulating steroid sex hormones is to activate sexual responses. In the fetus, however, sex hormones direct the differentiation of sensitive body tissues. The brain is one of these steroid-sensitive tissues. Chemicals such as nerve growth factor or cortisol, for example, can influence a neuron’s fate, guiding it to become either a sympathetic neuron or an adrenal secretory cell. Either male or female genotype is compatible with a physical brain of either phenotype; the phenotype is determined by circulating sex hormones in utero.

Sexual differences in neural structures (called sexual dimorphism) and sexual differences in behavior are somewhat advanced topics (e.g., McWhirter, Sanders, & Reinisch [1990] discuss the biology of sexual orientation, while Halpern [1991] reviews gender differences in cognition). Given the preponderance of female synesthetes and a possible hormonal influence on synesthetic expression, however, the issue is at least worth raising. In The Sexual Brain, LeVay (1993) gives a broad but succinct biological overview of the hereditary and environmental factors involved in sexual differentiation—somatic, neural, cognitive, and behavioral. Among the topics he reviews are sexual behavior (e.g., reproduction, courtship, maternal and paternal care), sexual feelings, gender identity, sexual orientation (gay, bisexual, heterosexual), and differences between men and women that fall outside the sphere of sex itself. In particular, LeVay reviews evidence that sexual behaviors typical of men and women depend on distinct and specialized hypothalamic nuclei that are subject to sexual polymorphism. The influence
of hormones on both sexual and nonsexual behavior generally is referred to as behavioral endocrinology (see, e.g., Becker, Breedlove, & Crews 1992).

Lateralization is a central theme in biology and medicine, not something esoteric. Advantageous and disadvantageous consequences of cerebral dominance include the elevated rate of left-handedness in certain highly skilled occupations and its association with childhood learning disorders, immune disease, allergies, migraine, and twinning. For example, architects and the mathematically gifted tend to have superior right-hemispheric skills but are much more likely to be left-handed and afflicted with elevated rates of allergies and autoimmune diseases (Tonnesen et al. 1993; Dellatolas et al. 1990). These observations suggest that some of the processes that lead to lateralization also affect the development of the immune system and are in turn affected by it. The issues of lateralization are not yet settled, but it appears that processes which disturb cerebral lateralization frequently have widespread effects on other bodily systems. Hormone concentrations, especially of testosterone, also influence the development of various nuclear structures in the hypothalamus and limbic system.

### 6.3.1 Standard Brain Development

Neurons do not form in the cerebral hemispheres. They are generated midline in the neural tube and then migrate from the germinial center of the fetal brain to their future positions in the periphery. After furious DNA replication, cells move toward the lumen of the neural tube and proliferate in what is called the ventricular germinial zone. The differentiation of neurons begins at the sixth week of life. Cells migrate outward only after completing their last division and follow strict spatial and temporal gradients. Cells destined to populate separate architectonic zones have different origins and are produced in an ordered sequence of sizes, large ones migrating first. Phylogenetically older parts of the brain, such as limbic entities, appear earlier in development.

The brain forms inside out, with later-migrating cells passing through the inner layers that have already formed in order to reach the cortical mantle. The centrally situated ventricular zone becomes thinner as cells continue to migrate out of it, and the primitive cerebrum becomes increasingly layered. The deeper layers contain more mature cells that migrated first; the more superficial layers harbor later-migrating and more immature cells. Migrating neurons are constantly in motion and may pass back and forth several times through their eventual resting place (figures 6.10 and 6.11). Only after neurogenesis is finished does specification of cortical areas occur (Walsh & Cepko 1992). From the figures, it is evident that a vertical layout is one of the most fundamental features of neural organization.
Starting in the sixteenth week of life, neurons develop dendrites and axons and then compete for synaptic contacts. Neural migration, assembly, and synaptic connection are influenced by a variety of factors that together account for the uniqueness of every individual brain. The intrauterine environment is especially influential: Neuronal migration and assembly may be modified by circulating sex hormones as well as prenatal and perinatal stressors (e.g., prolonged labor, anoxias, Rh incompatibility, breech births, multiple births, prematurity). In every species studied, neurons are formed in huge excess only to die in utero and during the first years of postnatal life when they fail in the competition to connect with other neurons. This process is called physiologic necrosis.

The cell death of physiologic necrosis reduces the number of superfluous neurons produced in fetal life and is perhaps the most crucial factor in helping to match the number of neurons to available synaptic sites. That neural circuits can reroute themselves even across the midline is remarkable testimony to the developing nervous system's flexibility in that it can alter the availability and location of synaptic sites. A
variety of intrauterine influences, as noted, can cause anomalous segregation of standard mental skills and the emergence of special talents. The retention of natal synapses due to incomplete physiologic necrosis could, of course, be one possible basis for synesthesia. We consider this further in chapter 7. The genetic factors discussed in chapter 2 could be expressed in either a restricted or diffuse manner, potentially accounting for the heterogeneity of synesthetic phenotypes.

The right hemisphere begins its development before the left. We can posit a reason for its precocious development based on its specializations, which include the analysis of external space and the orientation of the body within it. The right hemisphere plays a major role in emotion, including its subjective experience, external expression, and the interpretation of emotion expressed by others. It also helps shift the focus of attention from oneself to external stimuli and exerts control over important autonomic functions. This further suggests that the right hemisphere plays a special role in behaviors essential for survival.
Thus, its early development relative to the left hemisphere may be advantageous.

Men and women normally differ, on average, in their patterns of abilities. As a group, women have superior verbal skills, whereas men are better at spatial perception. Normally, the male brain matures later than the female brain and the left hemisphere matures later than the right. Anything that delays the development of the left hemisphere will cause a nonstandard pattern of cerebral lateralization. It is such delays of left hemispheric cellular migration, synaptic target formation, and maturation of connections that produce left-handedness, so-called learning disabilities, and weakening of typical left hemispheric skills while prompting the emergence of superior right hemispheric talents (table 6.6). Though there is little doubt that sexual differences in cognition exist, they are not as robust as introductory texts often suggest (Halpern 1991).

Conditions such as Turner’s syndrome in which females are hypo-gonadal and therefore unable to produce estrogen have been fruitfully used to separate the role of sex hormones from that of genetically determined sex-linked characteristics in cognition (Johnson, Rorhbaugh, & Ross 1993).

Men have a higher frequency of left-handedness, a physical trait that is associated with mental ones. Stuttering and dyslexia, for example, are markedly higher among strong left-handed men than among strong right-handers (Smith, Meyers, & Kline 1989). Histologic examination of dyslexic brains has uncovered abnormal cellular architecture in the left parietal lobe, the left temporal speech region, and even in the right hemisphere. A delay in cellular migration appears to disrupt normal cytoarchitecture. Thus, genetic expressions such as we have discussed for synesthesia can easily alter sensory-fugal processing to yield anomalous perception.

6.3.2 Left-Handedness and Anomalous Dominance

The preponderance of females, left handedness, and the pattern of neuropsychological talents in synesthetes (§4.9.7) makes a causal mechanism of anomalous dominance hypothetically possible.
Frank left-handers constitute only one readily identified group with an anomalous (nonstandard) pattern of dominance. The basic pattern of the brain is one of strong left hemispheric asymmetry for language and handedness. Influences that delay left hemispheric growth therefore tend to reduce the customary brain asymmetry: as a result, many individuals experiencing delays in left hemispheric growth will have random handedness. Frank left-handers, therefore, constitute only about 30% of the population with anomalous dominance. Although there are other reasons why left handedness is not present in the majority of persons in whom left hemispheric growth has been delayed, it is the main reason, and left handedness can usually be taken as a sign of anomalous dominance.

6.3.2.1 The Pathology of Superiority Though we habitually think that a deviation from a prescribed pattern always results in abnormality, a superior outcome is not unusual, for reasons already cited. For example, a large proportion of those scoring among the top 1 in 10,000 individuals on the Scholastic Aptitude Test (SAT) are left-handed (Benbow 1988). Such superior outcome may or may not be a tradeoff with deficits in other areas, as we see in synesthesia.

Because the influences that produce delays in the left hemisphere lead to expanded growth of other regions, anomalous dominance may also be a mechanism of giftedness that could account for the elevated level of non–right-handers among male architects and other men with talent for spatial relationships, including athletes, sculptors, engineers, and mathematicians. Clinical instances of persons with remarkable artistic talents in the face of limited linguistic capabilities are even more illustrative (Galaburda & Kemper 1979; Gordon 1983; Sano 1918).

Instances of disjunctive neuronal migration may thus be not only a pathology of defect but also a so-called pathology of superiority, which explains both the presence of extremely high talents in many persons with autism, dyslexia, and stuttering, and the common occurrence of superior right hemispheric talents in dyslexics and their families. The analogy with synesthesia should be clear.

6.3.3 Hemispheric Specialization

Although humans appear to have an axis of external symmetry, our internal organization, including that of our brains, is asymmetrical. Most creatures, and even some single-celled organisms, have an asymmetrical nervous system. The further influence by the hormonal and volume-transmitted environment of the fetus produces even greater diversity than would genetic selection alone.

Asymmetries of the temporal planum, sylvian fissure, corpus callosum, and occipital lobe can easily be seen with the naked eye and
measured with rulers (Geschwind & Galaburda 1987; Geschwind & Levitsky 1968). Cytoarchitectonic asymmetries exist, too, just as there are chemical and pharmacological asymmetries throughout the brain. This means that drugs may act asymmetrically (LSD being a famous instance) or that asymmetrical symptoms may emerge during illnesses, such as depression, in which there are large changes in certain classes of neurotransmitters that themselves are asymmetrically distributed. Finally, the well-known asymmetries of the peripheral nervous system, especially the autonomic innervation of the grossly asymmetrical thoracic and abdominal viscera, imply corresponding differences in visceral outflow from the two sides of the brainstem and hypothalamus.

There is no single dichotomy that describes the organization of the hemispheres. Neither verbal-nonverbal, analytic-intuitive, nor sequential-gestalt will do. The left hemisphere has been variously characterized as linguistic, voluntary, linear, logical, and sequential, while the right has been described as spatial, automatic, synthetic, appositional, or holistic. During the first 20 years of split-brain testing, a cottage industry developed around the easy techniques of dichotic listening and tachistoscopic viewing. Predictably, a good number of experiments were ill-conceived and their claims regarding hemispheric specialization ill-founded (Efron 1990; Christman 1994). These naïve shorthand characterizations miss important nuances of hemispheric specialization. These distinctions should be borne in mind, especially when analyzing functional neural images.

Four general abilities relatively dependent on the right hemisphere are (1) nonlinguistic perception, especially that involving spatial configurations, (2) spatial distribution of attention, (3) expression of emotion, and (4) the nonlinguistic aspects of communication (e.g., the melodiousness or prosody of speech, facial expression, gesture, emphasis, intonational pitch, attitude, comprehension of situational context, and cues regarding the interpersonal dynamics of a conversation). The right hemisphere’s talent for visuospatial perception and manipulation have received the most attention, even though its skill at complex perceptual tasks extends to hearing and touch. The right hemisphere is also superior at depth perception, locating objects in space, identifying geometric shapes, and assessing spatial orientation by touch. The right hemisphere appears to be dominant in all aspects of emotional expression and experience.

6.4 THE LIMBIC SYSTEM

The limbic system is complex. The Nieuwenhuys atlas (Nieuwenhuys et al. 1988) requires twenty-four separate illustrations to convey its pertinent anatomical features, and forty-three pages of text to detail its
connections. Accordingly, I have decided not to try to illustrate it given that any image (especially the usual midline section) or handful of images would be inadequate. Readers are referred to standard atlases and anatomical texts.

Recall that Paul Broca (1878) used the term limbic lobe to designate the tissue of the inside rim (limbus) of the hemispheres where they meet the brainstem. Grossly, this includes the cingulate and hippocampal gyri, the tissue connecting them, and the various gyri that surround the olfactory tracts. This is what is usually shown in midline sagittal brain sections, although the three-dimensional span of the limbic system is much too great to be depicted in any single section.

Broca emphasized the common presence of a limbic lobe in all mammalian brains. Because natural selection has likely made existing animals considerably different from their long-extinct ancestors, it is most surprising to find uniformity in the connections among limbic structures in all vertebrates presently living. Two independent evolutionary trends in higher mammalian brains are an expansion of the neocortical surface and the development of limbic structures. A given species tends to be high in only one dimension, however. Monkeys, for example, show substantial neocortical development but little limbic enlargement; rabbits have the opposite trend of robust limbic elaboration but poor neocortical sophistication. Humans are unique in being substantially advanced in both limbic and neocortical dimensions.

Portions of the diencephalon, telencephalon, and mesencephalon are so structurally and functionally related that we consider them an autonomous functional unit called the limbic system. Its boundaries include the following:

- The hypothalamus, hypophysis, preoptic region, olfactory bulb
- Limbic cortex (corticoid and allocortical) including medial and lateral septal areas, substantia innominata, amygdala complex, hippocampal formation, piriform complex, lateral olfactory stria
- Paralimbic cortex: temporal pole and anterior commissure, caudal orbitofrontal cortex, insula, parahippocampal gyrus (entorhinal, pro-rhinal, and perirhinal areas), cingulum complex (retrosplenial, cingulate, and parolfactory gyri)
- Limbic striatum (olfactory tubercle, nucleus accumbens), parts of globus pallidus, ventral tegmentum, habenula, median forebrain bundle
- Limbic and paralimbic thalamic nuclei, mammillary bodies
- Fornix, stria terminalis and stria medularis, dorsal longitudinal tract, interpeduncular nucleus, mammilolateral tract, habenulo-interpeduncular tract, medial telencephalic fasciculus, ansa peduncularis

First note that each of these structures is more concerned with drive, emotion, homeostasis, autonomic control, and memory than with...
straightforward perception or action. What feeds into the limbic system is a highly processed and highly abstract transformation of neural signals from both internal and external environments. The paralimbic regions interpose themselves between external stimuli and the urge to act, they direct drive toward appropriate targets, and they add emotional coloring to thought and perception. The cingulum appears to direct motivation to the appropriate location in space. All these make it difficult to answer simply the question, What does the limbic brain do? Examining the above list of entities should make it apparent that sensual, motor, autonomic, and mental manifestations are all possible expressions of limbic activity. Still, what is fundamentally distinct about expressions of the limbic brain is a qualitative alteration of perception, of well-coordinated motor actions, or of consciousness itself. Why is this so?

The two major inputs to paralimbic and limbic cortices are (1) heteromodal association cortices and (2) the most distal synapses of modality-specific association cortices. Here is a convergence of highly abstracted qualities of the external world where, as the flow of figure 6.8 tries to convey, the relevance of a stimulus is more important than are its physical properties. Limbic dysfunction can severely disrupt the synergy among experience, thought, behavior, and emotion. Clinically, this causes the emotional coloration of mental life to be both unpredictable and incongruous. Feelings of unreality, distortion of perception, time dilation, the feeling of a presence or familiarity (déjà vu), memory flashbacks, out-of-body experiences (autoscopy), and a sense of certitude (the “this is it” feeling) are some of the experiential correlates of the limbic brain. Some of these qualia are precisely those of synesthetic perception. I elaborate a transmodal model of synesthesia in §6.7.

6.4.1 The Papez Circuit

Paul Yakovlev, James Papez, and Paul MacLean are three neurologist-neuroanatomists who proposed classic formulations of behavior and who each happened to divide brain and behavior into three categories. I reviewed earlier Yakovlev’s divisions of reticular, nuclear, and laminar tissue together with their corresponding “three spheres of motility.” Visceration, emotion, and effectuation corresponded, respectively, to autonomic movements “within the body,” the extrapyramidal movements of the body “upon the body,” and the pyramidal movements of the body “outside the body.”

James Papez first proposed the idea that midline structures were the anatomical substrate of emotion, a then-novel notion that sealed his fame (Papez 1937; MacLean, 1978c). Papez noted that the word “emotion” implies both a way of acting and a way of feeling. Since emotional actions were known already to depend on the integrating power of
the hypothalamus, Papez argued that emotional feelings require the participation of cortex. He convincingly showed that sensory afferents split at the thalamic level into three paths, each carrying “a stream of impulses of special importance.” The route conveying afferents through the dorsal thalamus and internal capsule to the striatum represents the “stream of movement.” The conduit from the thalamus through the internal capsule to the lateral neocortex of the hemispheres is the “stream of thought.” The third set, with one branch from the ventral thalamus to the hypothalamus and a second branch via the mamillary body and anterior thalamic nuclei to the cingulate gyrus, represents the “stream of feeling.”

The hippocampo-mammillo-thalamo-cingulate-hippocampal circuit is the classic Papez circuit (figure 6.12). Papez took pains to point out connections whereby all sensation could project to the cingulum through the mammillary bodies. In his often-quoted words, “It is proposed that the hypothalamus, the anterior thalamic nuclei, the gyrus cinguli, the hippocampus and their interconnections constitute a harmonious mechanism which may elaborate the functions of central emotion as well as participate in emotional expression” (Papez 1937, p 743).

The bottom of figure 6.12 shows that new knowledge has obliged an expansion of the original Papez circuit: (1) the hippocampal formation influences distant regions by acting on the subiculum, (2) the cingulate cortex receives multiple thalamic inputs, and (3) the nucleus accumbens is an important target in the basal ganglia for both cingulum and hippocampus, the two major cortical components of the Papez circuit. This link with the basal ganglia offers a new route for expressing behavior that is also consistent with Yakovlev’s correlation of nuclear structures with gesture.

6.4.2 Affective Valence

Limbic and neocortical entities perform different functions. Neocortex processes information that has too many fine details to be handled by simpler, more direct, and often evolutionarily earlier systems. The complexity of multiple mapping is one reason we have historically believed that the role of cortex is to analyze the external world and house our representations of reality. It is the limbic brain, however, that decides questions of salience and relevance and so determines how we act on the information we have.

The general blueprint that all vertebrate brains follow started to emerge in the reptilian line. It was with the appearance of early mammals, though, that the limbic system underwent major changes. It is now a constant feature in all mammals and is not seen in its developed form in submammalian species. Its robustness in humans makes the human emotional system more influential in terms of regulation than
Figure 6.12  (Top) The original Papez circuit, from 1937, loops continuously from hippocampus, to mammillary bodies (via the fornix), to anterior thalamic nuclei, to cingululate cortex and cortical areas, thence returning to the hippocampus. (From MacLean [1949], with permission.)  (Bottom) An expanded Papez circuit incorporates new knowledge. Dashed lines represent the original Papez circuit. See text for further details. (From Isaacson [1982], with permission.)
that of other mammals. Additionally, the transformation of impulses that constitute emotional information seems to be qualitatively different from the processing of other information. Engineers who design neural networks have actually modeled their regulator, called an adaptive critic, after human biology. For example, an effective critic must have high-speed recurrence. The limbic system performs calculations at the internal cycles-per-second rate of 400 Hz but is governed by an outer clock of 5 Hz, the rate of the theta rhythm. In other words, a high-speed calculator is embedded in a low-speed clock.

Neocortex also performs high-speed modular transformations and is governed by a low-speed clock of 10 Hz, the frequency of the alpha rhythm. This 2:1 ratio is what engineers require to adapt a critic. The network needs to hold, store, and reevaluate in a way that makes the cycle time of a critic twice as long as the model’s cycle. The 2:1 ratio exists between the limbic brain’s evaluation and the update of the neocortical model in the following way: the state of the world is pumped into the cortex and an evaluation comes out one-fifth of a second later, yet elements inside the limbic system cycle furiously 400 times a second to carry out the intermediate steps needed to derive that evaluation (Werbos 1994).

The insula receives information from all five senses (Mesulam & Mufson 1982) and everything converges on the hippocampus. All sensory inputs, external and visceral, must pass through the emotional limbic brain before being redistributed to the cortex for analysis, after which they return to the limbic system for a determination of whether the highly transformed, multisensory input is salient. If so, we will likely act; if not, we will ignore it just as we ignore as irrelevant most of the energy flux that constantly bombards us.

Although the relative volume of limbic structures is less in mammals with robust neocortical development, the number of axons in limbic fiber tracts is actually greater, both in absolute number and relative to other fiber systems in the brain. In humans, five times as many fibers travel in the fornix as in the optic tracts, which alone are customarily cited to carry 85% of sensory afferents into the brain (Isaacson 1982), yet the contributions of transmodal entities to behavior have been customarily minimized. The neocortex provides analytic space, as suggested by its structure, and contains our model of reality. However, it is the limbic brain’s drive that determines what we do with the analysis that the neocortex has carried out. Obviously, there is a reciprocal relationship between neocortical and limbic entities, each modulating the other and influencing mental life.

However, two clinical examples illustrate how powerful the force of emotional cathexis is. The first example concerns epilepsy originating in limbic structures of the temporal lobe (see also §4.6.1). These structures have a low threshold for seizures that do not spread outside of
the limbic brain. Temporal lobe epilepsy (TLE) can produce involuntary actions called automatisms that seem purposeful to an uninformed observer but of which the patient is unaware and has no recollection. TLE also can cause compulsive thinking, florid psychosis, and episodes in which one cannot distinguish between dreaming and reality. The overlap between the behavior of TLE and that of psychiatric disorders is striking: 50% of those with temporal lobe seizures show psychiatric symptoms compared to only 10% in all other types of epilepsy. Thus, the emotional brain seems physiologically able to overwhelm the rationality of the cortex.

My second example concerns patients in coma. In the sequence of recovery, coma patients first manifest automatisms, then voluntary movement and speech that is childlike and emotionally childish. If recovery continues, their behavior becomes what we would describe as more rational and adultlike. The pattern of recovery from all comas shows that intellect cannot be reclaimed unless emotion recovers first. We can conclude that affect plays an important and underappreciated role in our behavior.

6.5 COLOR AND SPATIAL ANALYSIS

Having finished our anatomical refresher, we return at last to phenomenology germane to synesthesia.

The cognitions of color and space are closely related. In fact, attending to a color stimulus entails directing attention to its location (Tsal & Lamy 2000). The relation between color and space becomes clearer on consideration of inferior calcarine lesions and achromatopsia, and superior calcarine lesions and spatial deconstruction.

Occlusion of the posterior cerebral artery infarcts the visual cortices on the medial aspect of the occipital pole (areas 17, 18, and 19). Such a patient (or animal) has a homonymous hemianopia, a completely blind hemifield. In lesions entirely below the horizontal calcarine fissure, area 17 is not damaged either in the lower or upper lip of the calcarine fissure (Damasio 1985; Beauchamp et al. 2000). Because the optic radiations are intact, visual information arrives undamaged at the primary visual cortex and is available to a variety of other cortices for processing. Such a patient has hemi-achromatopsia, an acquired loss of color perception in the contralateral field. Yet in that colorless field, shape perception and even reading ability remain perfect.

We find this remarkable dissociation between color and shape (and a variety of derivations from shape such as stereopsis, motion detection, depth, and texture discrimination). We have known since the time of Holmes (1918, 1919) that the visual field is retinotopically represented in the inferior and superior calcarine cortices. That is, there is a point-to-point correspondence. The inferior field is represented superiorly,
the superior field inferiorly, right maps left, and vice versa. Yet I just
described a lesion entirely below the calcarine fissure producing a ver-
tical defect in color covering the entire hemifield. Remarkably, the color
system is eccentrically distributed.

To such a patient, the world looks like a television picture whose
color is turned down. Once an object crosses the vertical meridian, the
grayish hues become normally colored (Damasio et al. 1980). Patients
do have some chroma left but complain that the colors are washed out,
dirty, or pale. Compare this to the photisms of synesthetes, who say
that their colors are often pastel or only tints (e.g., see §2.3.7). A greater
imperception for some colors than for others raises the possibility of
subdivisions within the color center. Such unevenness or particularity of
color assignment is of course also characteristic of synesthesia. The
anatomical lesion causing achromatopsia is inferiorly placed in the
fusiform and lingual gyri (Damasio 1985; Dejerine 1892; Verrey 1888).
These apparently constitute the minimal obligate substrate for color
perception; no case of central achromatopsia has ever been reported
without such lesions.

Patients with superior calcarine lesions have a different kind of
problem than patients with inferior ones. Their spatial construction is
severely disturbed, whereas reading, color perception, and recognition
of shape and faces remain normal. What they do see is not properly
placed in three-dimensional Euclidean space. Objects appear to be
broken, one part sliding over another or distorted in some way (meta-
morphopsia). They may lose the object and have to search for it in the
visual field after it disappears abruptly.

In general, the inferior cortices are directed toward object vision,
deriving a very fine description that allows us to interface with stored
memories. The superior visual cortices are interested in the construction
of space around us, and in placing a particular object at given spatial
coordinates. One can say that the lower part of the visual system is
interested in describing what is out there, whereas the superior part of
the visual system is interested in where the what is (Farah 1990; Rizzo &
Hurtig 1987; Levine, Warrach, & Farah 1985). Euclidean space is dis-
sociable from object vision. Apropos of this superior-posterior cerebral
participation in spatial placement are the spatial maps of CS described
in §5.6.1.

These examples of inferior and superior calcarine lesions show how
information from the retina remains retinotopic until V1, the primary
visual cortex. Segregation begins immediately beyond that, with the job
of doing this or that farmed out to different association areas. The cal-
culation that gives an experience of color goes in one direction, whereas
the properties that constitute shape and lead to the description of an
object, or to the description of a space wherein that object is inserted,
are calculated elsewhere.
Lastly, a relevant dissociation is reported in “the painter who became color blind” (Sacks et al. 1988; Sacks & Wasserman 1987). A patient who became achromatopsic following a head injury also lost his colored-hearing synesthesia as well as his ability to dream in color. Thus, these three capacities—seeing in color, dreaming in color, and hearing in color—may share an obligate neural element. Typically, nonsynesthetes state that they rarely or never dream in color, whereas synesthetes invariably claim that they “always do.” This apparent difference hinges on memory, however, because with careful interrogation close to the time of dreaming, 82.7% of subjects reported color in their dreams (Kahn et al. 1962). This may be another example of elevated memory in synesthetes. Conventional wisdom holds that color in dreams indicates heightened emotion.

More intriguing than even these triple symptoms, the painter also became acutely alexic. Numbers and letters “looked like Greek or Hebrew to him” (Sacks & Wasserman 1987, p 26). This implies an occipital lesion, which is consistent at least with the hemiachromatopsia. Without imaging or histological examination we can only speculate about the participation or lack thereof of various upstream visual nodes to his synesthesia.

6.5.1 Further Anatomy of Color and Shape Perception

Color is the psychophysical combination of chroma (hue), saturation (density of chroma), and luminance (brightness). These three dimensions, which can be selectively dissociated, enable us to perceive $10^6$ colors. What is it that becomes disrupted when we lose color perception?

Rizzo (1988) and Rizzo, Kritchevsky, & Damasio (1986) reported a patient with a right hemispheric lesion below and above the calcarine fissure, and a left hemisphere lesion in areas 18 and 19 below the calcarine fissure. The patient had a left homonymous hemianopia but an intact right visual field that was achromatic. In this right hemiachromatopic field his colors were drained out, but he could read, discriminate shape, and detect motion. He had a selective disturbance of chroma in the absence of saturation and luminance defects. Further research shows that central achromatopsia encompasses a range of color processing impairments with various psychophysical characteristics, such as target size, transparency, and other surface and light-source effects (Rizzo et al. 1993).

In animals, the color system is segregated in areas 17 and 18, and continues to be segregated as late as V4 in the lunate sulcus (Van Essen, Maunsell, & Bixby 1981; Zeki 1977, 1993). Microelectrode recording in V4 shows that a large number of cells respond to color, and that the distribution of color-sensitive cells is highly selective. In humans, a fMRI version of the Farnsworth-Munsell 100-hue test reveals that pas-
sively viewing colored stimuli activates the posterior fusiform gyrus. However, when the visual color information is behaviorally relevant, more anterior and medial color-selective areas activate in the collateral sulcus and fusiform gyrus (Beauchamp et al. 1999). These more anterior areas were not identified in earlier imaging studies, which used passive viewing of color stimuli.

We have also since learned that V4 varies between individuals in absolute terms (because it is defined functionally, just as Wernicke’s area is [Bogen & Bogen 1975]), but invariably lies in ventral occipito-temporal cortex (VOT), in the lateral aspect of the collateral sulcus of the fusiform gyrus (McKeefry & Zeki 1997). The color center is large, spanning 20 mm in antero-posteriorly. Anterior VOT, or V4a, is not retinotopically organized, whereas posterior VOT, or V4, is (Bartels & Zeki 2000). It is noteworthy that the retinotopic organization with the V4 complex could have been predicted by clinical evidence, has indeed was the case (Damasio et al. 1980). V4a concerns intermediate form vision, visual attention to the upper field, and chroma (Gallant, Shoup, & Mazer 2000), whereas fusiform areas beyond the V4 complex appear to be critical in relating color to object (Zeki & Marini 1998). All these areas have rich transmodal connections. So, three areas appear to activate during color perception: V1 (which is wavelength selective), V4 (which is retinotopic) and V4a (which has a degraded topography) (Beauchamp et al. 2000). Compared to other upstream unimodal visual nodes, only V4 has callosal projections sufficiently widespread to integrate spatially segregated points across the two hemispheres (Zeki 1993).

Livingstone (1990) and Livingstone & Hubel (1987) discovered sets of cells in areas 17 and 18 of the monkey that are unequivocally associated with color processing. They are packed in areas called “the blobs” because of their spatial arrangement. An electrode penetration in the blobs shows them to respond only to color and not to edge, orientation, contrast, or other visual derivatives, which means that they do not participate in the kind of detections that would be useful for computation of shape or spatial location. However, the cells in the interblob areas respond strongly to shape and orientation, but little to color. The two packets of cells have different anatomical arrangements and different geniculate inputs.

Once past the ten-layered retina, visual input segregates into a parvocellular chromatic system and a magnocellular achromatic system in the diencephalon; the chromatic system further splits in the cortex into a color system and a color-based form system. Each separate subsystem thus concerns specific visual aspects: one deals with the perception of shape, the second with color, and the third with position, movement, and depth. Responding simultaneously and independently, the three systems summate into a unified perception, “just as when you experience
a person speaking, you’re not really aware that hearing his or her words and seeing his or her mouth moved are processed independently” (Livingstone 1990b).

Regarding the cerebral locus of synesthetic color experience given the apparent failure of V4 activation in word-color synesthetes imaged thus far, we might ask to what extent the diencephalic chromatic system contributes to the quale of color. Nashold’s experience (1970, see §4.5.1), in which electrical stimulation of the colliculi produced spatially extended phosphenes superimposed on the visual scene, makes it worthwhile to at least inquire along this line.

Lastly, reports of so-called “new” color areas labeled “V4v” (Sereno et al. 1995; DeYoe et al. 1996) and “V8” (Hadjikhani et al. 1998) have not withstood scrutiny, and their Talairach coordinates turned out to be identical to those published earlier for V4 (McKeefry & Zeki 1997; Bartels & Zeki 2000).

In summary, a highly ordered anatomy exists at the cellular level that leads to the separation of color from other visual calculations, and this color area is large. The color-processing blobs stain with cytochrome oxidase, a mitochondrial stain indicating that these cell packets are metabolically very active. A high metabolism means they are quite sensitive to ischemia and hypoxia. At first, the high metabolic activity and susceptibility to ischemia appears provocative in light of the ischemic cerebral blood flow during MW’s smell-tactile shape synesthesia, the decreases seen in Paulesu’s six word-color synesthetes, and my hypothetical musings regarding a functional disconnection in synesthetes in general (see §4.10).

However, deactivation or failure to activate is precisely opposite to what is required if the V4 complex participates in the quale of synesthetic color. Whereas the above case of the color-blind synesthetic painter along with previous evidence implies an obligate shared component, the extant imaging data indicate that V4 is not the entity in question inasmuch as it registered no change during word-color synesthesia. Table 6.7 will refresh your memory regarding activations and deactivations during this study. The quale of color experience comes from elsewhere if we assume that PET would have detected bona fide activity in V4 if it occurred. The experience of vaguely localized color and shape must engage other brain entities at a different level that join the qualities in question. Some of the observed activations may actually be modulating inhibitory feedback, given that functional suppression of an area can be brought about by either activation of inhibition or deactivation (occlusion) of function. A release phenomenon is also possible (see §4.4).

Hold in mind that color is multiply mapped just as movement and somesthesis are. That is, a color stream exists in the brain. The minimal obligate component appears at first to be the fusiform gyrus, occlusion
of which yields achromatopsia. Yet wait: \textit{some chroma remains} in the pale, washed-out colors that patients perceive. The same is true of dyschromatopsia, a less severe form of central color imperception due to left parietal lesions (Capetani, Scotti, & Spindler 1978; Varney & Digre 1983; Guylas & Rowland 1991, 1994) or posterior VOT (Beauchamp et al. 2000). Temporal and superior occipital sites are also engaged in color perception (Corbetta et al. 1991). Therefore, the binding of any one ancillary visual area to another cognitive modality might explain the desaturated photisms that synesthetes perceive. The identity of that binding agent is discussed below.

Finally, Ramachandran & Hubbard (2001) have noted that both V4 and the grapheme-number region are both situated on the fusiform gyrus (Rickard et al. 2000; Pesenti et al. 2000). This has led them to postulate “cross-wiring” between the two based on proximity. One problem with this formulation is that number-graphemes can be perceived as objects or understood as (categorical) concepts, as we know so well from visual agnosia (Farah 1990) and as the phenotypic heterogeneity in synesthesia shows. I discuss this further in §6.6.

It is now possible to speculate about the absolute effects observed during psychophysical mapping. The consistency of synesthetic percepts might stem partly from topological organization regarding \textit{what} is experienced; \textit{where} it is experienced has a looser topography compared to objects stimulated by conventional sensory channels.

Table 6.7  PET activations and deactivations during word-color synesthesia

<table>
<thead>
<tr>
<th>Activation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right: prefrontal, insula, superior temporal gyrus</td>
</tr>
<tr>
<td>Bilateral: PIT (L &gt; R), parieto-occipital junctions</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>No change</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1, V2, V4 (the color area)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left: lingual gyrus, insula</td>
</tr>
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</table>

PIT, posterior inferior temporal cortex.
Note: The left PIT concerns color, kinesis (Bottini et al. 1994), and perhaps also size (Démonet et al. 1992). Conventional knowledge relates the right PIT to shape.
• V1 is wavelength-selective. Within the V4 complex, V4 involves color and is retinotopic; V4z is not retinotopic and concerns color and intermediate form perception. V5 relates to motion perception.
The human homolog of V4 lies on the fusiform gyrus; that of V5 lies ventrally at the occipito-temporal junction.
• Note the flip-flop of the right and left insula. The insula receives projections from all five sense modalities.
• Note that V4 lesions impair color perception (Beauchamp et al. 2000) but that synesthetic perception of color does not activate V4. Therefore, the color experience (quale) must come from elsewhere.

259  6.5. Color and Spatial Analysis
The topological organization of primary sensory cortex (retinotopic, tonotopic, somatotopic, gustotopic) does project in an orderly way to entorhinal cortex (area 28) and the rest of the limbic system, even as sensory fidelity is lost past the fourth synaptic level. This regular physical arrangement may underlie some of the absolute effects observed in synesthetic response mapping. For example, Heschl’s gyri in the temporal lobe demonstrate a linear tonotopic organization of frequency perception. Anatomically, the highest frequencies are perceived medially, whereas the lowest tones are subserved by more lateral tissue. Thus, topological organization may come to figure in the explanation for the relative intrasubject regularity of stimulus-response mapping in one part of the domain, as illustrated in §3.6.1.

The thalamus also maintains an intimate relationship with the limbic system, and for all senses except olfaction is the first synaptic relay. (Olfaction projects directly to piriform cortex.) It is not well known that the thalamus is topologically organized, as well as having areas that are modality specific, heteromodal, and paralimbic (Mesulam 1985, p. 43–46). The clinical cases from §4.5.1 showing brainstem lesions are recalled in this regard.

6.5.2 Space and Movement

Let us now add perceived motion to our consideration of synesthetic qualities. Color, movement, and spatial extension are prominent synesthetic attributes. Note, foremost, that the movement and spatial extension of synesthetic percepts are poorly localized in Euclidean space. Two examples of subception—cognition that occurs outside of consciousness—can help to elucidate the neural basis of visual synesthesia with eroded topography.

fMRI studies of visual motion unexpectedly discovered that visual activation of each of three subsets within V5 in turn activated non-overlapping areas of auditory cortex that are normally stimulated by speech perception. Regarding the PET studies by Paulesu’s group wherein spoken words elicited poorly localized color photisms, it is unexpected to find connections in this direction. Because synesthetic experience is usually a one-way street, going from speech to vision but not vice versa, we can presume that projections herein described are recursive. This at least suggests a neural basis for how sound can also lead to the perception of photisms, space, and movement.

Neologisms such as “blindsight” or “numbsense” convey how individuals who are conventionally blind or insensible can nonetheless discriminate visual or tactile test stimuli with near-perfect accuracy. Yet such patients insist that they can’t “see” or “feel” anything. Inquiry into subception usually concerns consciousness. We, however, are interested in these examples’ illustration of how motion perception, spatial
6.5.2.1 Phantom Vision  David Cogan of the National Institutes of Health collected a number of patients who have what he calls “phantom vision” (Bieganowski 1999). This entails the perception of visual phenomena such as brightness, lights, and shape that occur mainly after enucleation or injuries that sever the optic nerves (Gross, Wilson, & Dailey 1997). Less often, it occurs in patients with cortical lesions. Cogan never published this collection of videotapes. The cases cited below are from this collection.

**Patient CH: Geometric Photisms with Cyclical Lightness**  A few weeks after enucleation, CH saw drifting stars peripherally at 30° to 40° from central fixation. He also noted a cycle of light and dark, a variation in the sense of brightness that he perceived unrelated to the diurnal photoperiod. The perception of stars was intensified by caffeine or focused mental activity.

**Patient ER: Geometric Figures, Externally Projected**  After ER had her left eye enucleated, she saw moving geometric figures externally in front of her face and insisted it was the “left eye” that saw them. This is contrary to conventional experience. You cannot tell which eye is seeing an object unless you cover each eye alternately to determine that only one eye can see the object (when, e.g., your nose is in the way).

The geometric shapes were close to her face. She also complained of seeing “garbage,” floating blobs, rotating spirals, and parallel lines that were grayish or metallic, also moving in front of her face. Her explanation was that “the brain is deprived and it’s supplying its own stimulation. This is involuntary. The brain is doing it.”

**Patient JS: Synthesis of an Image**  JS had both optic nerves severed. He has no light perception, but closing the eyes dims the sense of brightness he perceives. Open areas, which he defines as “if there’s not a solid object there,” are described as a brightness.

He sees “objects” only when there is an actual object present, such as the sink when he shaves, the bed if he bumps into it, or parts of his own body. He palpates his legs when he says that he is able at times to see the outline of his legs. He is able to see his hand when he holds it up in front of his own face, but not Dr. Cogan’s hand when Dr. Cogan holds it in front of the patient.

There is a conviction in his spatial synthesis of an image. Cogan’s interpretation is that he relies on other sensory input, perhaps proprioception, in synthesizing a visual experience. This is particularly
suggested by the seeing of his own hand held in front of him, or by seeing his own body parts.

Patient CG: Image Analysis  This physicist is articulate and insightful. He has written about his phantom visions (Gillmor 1980, 1981, 1982). He sees at central fixation dynamic configurations that are very much like Klüver’s form constants. Sedatives and ethanol have no effect on his visions.

6.5.2.2 Striate Removal and Spatial Synthesis  Klüver (1942a) first indicated the importance of temporal structures in the spatial qualities of vision. Weiskrantz’s original monograph on blindsight (1986) described the vague but conscious perception of movement per se in patients with V1 damage. Patient DB, for example, perceived radiating lines, grids, shimmers and waves. He spoke of “a quick movement,” “a sharp movement,” or a “corner-shaped wave.” These are reminiscent of synesthetes’ descriptions. Like many patients with synesthesia, peduncular hallucinations, and phantom vision, the movement DB detected was felt outside of himself:

... they all appeared to stand out in front of the screen. I felt I could push them back ... there was a definite movement. Something seemed to pop out a couple of inches ... I felt as something was coming up to me (my emphasis).

Barbur & colleagues (1993) extended Weiskrantz’s observations by showing that awareness of motion in the blind visual field was accompanied by peristriate activation that encompassed V5, the motion area. Also, intact volunteers who perceived a vaguely located illusory motion had their V5 activated without engagement of V1 (Zeki 1993). The purported V5 homolog in humans lies at the occipitotemporal junction (Rees, Friston, & Koch 2000; Rizzo, Nawrot, & Zihl 1995). This is the area damaged in Zihl’s remarkable case of akinetopsia (§5.5).

Pertinent to the poor localization of synesthetic photisms, Zeki (1993) noted that transcranial magnetic simulation of V4 produces colored photisms whose spatial register calls to mind the topographic organization of V4 in the macaque. Inasmuch as the human V4 complex is a putative color center, the vague spatial localization of colored synesthetic photisms must therefore depend on engagement of brain areas that have a looser representation of the visual field than either V1 or V4. Recall that recent work has revealed two subdivisions of the human color center: the posterior one, V4, is retinotopically organized, whereas the anterior one, V4a, is not (Bartels & Zeki 2000; Zeki & Bartels 1999).

Table 6.7 reminds us that the posterior-inferior temporal cortex (PIT) activated in word-color synesthesia (Paulesu et al. 1995). PIT is understood to integrate color with shape (Corbetta et al. 1991) as does V4a.
It is definitely a visual association area (Van Essen 1985) and well connected to V4. The spatial topography of PIT, however, is more degraded than that of V4 (Komatsu et al. 1992). MW attended to the shape, texture, movement, and location of his tactile synesthetic percepts. His left PIT activated during synesthesia whereas the left angular and supramarginal gyri deactivated.

In considering why the V4 color center did not activate during perception of synesthetic photisms, we should remember that a perceived attribute evoked through unconventional channels should not be expected to activate the same member of that attribute’s distributed system as conventional stimulation does (Martin et al. 1995). This is in keeping with my comment above that some of the observed PET activations may actually represent modulating inhibition. This brings to mind an earlier study of mine regarding rCBF in auditory eidetic recall (Cytowic 1985). That study showed almost perfect correlation in the right hemisphere between the landscape obtained while actually hearing music and that obtained during the “eidetic” memory of it (figure 6.13). In both hemispheres, flows to regions involved in processing sound decreased when the physiologic stimulus was removed; this may have to do with selective attention that requires a “shutting down” of areas involved in interpretation of sound when one tries to recollect what had been previously heard. Such a shutting down of the left S1 was observed during MW’s synesthesia when it was enhanced by the amyl nitrite adjuvant.

6.6 A TRANSMODAL BINDING MODEL OF SYNESTHESIA

In the first edition of this book, I singled out the hippocampus as the most likely structure to participate in the expression of synesthesia and its emotional and hypermnestic qualia. One reason I did so is that there are persons with hippocampal epileptogenic foci who have synesthetic experiences relatable to a seizure, but who are not synesthetic otherwise (Anderson 1886; Gloor et al. 1982; Gowers 1901; Horrax 1923; Ionaescu 1960; Jacome & Gumnit 1979; Kennedy 1911; Mulder & Daly 1952; Penfield & Jasper 1954; Penfield & Perot 1963; Spiers et al. 1985; Weiser 1983). Conversely, TX is a woman with lifelong tactile-auditory-visual synesthesia who, in adolescence, developed complex partial seizures with a left temporal focus. Imaging demonstrates no macroscopic structural lesion. She feels that carbamazepine, prescribed for her seizures, has made her synesthesia less vivid. Her situation suggests that although synesthetic expression might depend on limbic structures, her idiopathic synesthesia is not due to the epileptic spike itself. This is congruent with the examples of epileptic synesthesia given in §4.6.1. This situation is also analogous to the behavioral features observed in temporal lobe seizures (i.e., hypergraphia, hyper-
Figure 6.13 Regional cerebral blood flow values while listening to music (top) and during its eidetic recall (bottom). See text for further details.
Another reason I highlighted the hippocampus was strongly anatomical. There are few places in the brain where it is possible to bring signals together from functionally different and geographically independent areas. As I pointed out in the beginning of this chapter, the brain as a network is vastly underconnected. There is a certain kind of togetherness in the thalamus, the lateral frontal cortices, the insula, and the claustrum. But the most important togetherness that connects every sense as well as the internal milieu happens in those limbic entities housed in the anterior temporal lobe. Information can be fed both stepwise and by direct long relays into the temporal lobe where it converges on the entorhinal cortex, which is the primary gateway to the hippocampus lying underneath. Through its outputs to entorhinal cortex and fornix, the hippocampus can feed back to every entity that originally fed into it. In short, my earlier viewpoint embraced a fully convergent synthesis, taking advantage of the fact that modality-specific attributes of a stimulus succumb to cross-modal contamination during a process of convergence (Goldman-Rakic 1988; McClelland 1994).

My final reason had to do with Paul MacLean who, upon handing me a reprint of his classic 1949 paper just over two decades ago, pointed out the hippocampus as a possible neuroanatomical mechanism for synesthesia:

Here [in hippocampal formation] the possibility exists for correlating not only olfactory, gustatory, and other visceral sensations, but auditory, visual, somesthetic and, perhaps, sexual sensations as well . . . It is important to stress that there is an overlapping of the three main fiber systems into the subiculum of the hippocampal gyrus. There are also longitudinal fibers associating the hippocampal formation throughout its entire length. In light of these observations, there is a possible neuroanatomic mechanism to explain some of the seemingly paradoxical overlapping (or synesthesia) of the various qualities contributing to emotional experience. (MacLean 1949, p 347)

A dozen years later my thinking has changed given recent data from various sources. I now feel that the sundry observations regarding synesthesia are better explained by the binding via transmodal entities of diverse qualia. Perusing figure 6.9, for example, the question naturally arises, Could not synesthesia be explained by existing transmodal structures beyond the fourth synaptic level? Could not a gene mutation together with experience strengthen projections between modalities in the transmodal bridge? This would have the advantage of not having to require wholly new cross-wiring between modalities and could also explain the heightened affect—both pleasant and vile—that accompanies synesthetic percepts.
Paulesu & colleagues see association cortex as the key to spoken word-color synesthesia. They suggest “unusual anatomical connectivity between language and visual areas” that occurs at the “boundary” between them. Ramachandran & Hubbard (2001) take a similar tack with respect to color and graphemes. I am circumspect when the former generalize their findings and propose that the link in “specific forms of synesthesia is likely to occur where the two sensory dimensions implicated have a greater anatomical opportunity to be integrated, namely at their boundaries.” First, we already know that nonsynesthetes have integrative projections between auditory language and vision, as figure 6.9 clearly shows. Second, their generalization breaks down in situations where more than two senses combine, and says nothing to explain synesthesia’s affective state, genetics, and so forth. Third, inferring anatomical connections by virtue of proximity is always a shaky assumption in brain science.

Conventional anatomy cannot support polymodal integration taking place in association isocortex given that projections from various specialized areas remain segregated and have little if any spatial overlap (Goldman-Rakic 1984; Zeki & Shipp 1988). Therefore, integration must occur either elsewhere or in the electrophysiologic process that binds diverse modes together. If not, we then need to address the how and why of retained perinatal connections (a form of neoteny) and whether such posited connections occur focally or diffusely throughout the brain. That is, if horizontal connections exist between color and graphemes than why not elsewhere, anywhere, throughout the brain where they would be expected to produce observable symptoms?

The proposed retained perinatal connections would have to be nonlimbic-to-nonlimbic by definition—precisely the kind that underlie language. But I have already quoted Geschwind’s analysis regarding these type of connections and subsequently demonstrated how linguistic meaning does not underlie synesthesia (see §§3.5, 3.5.1 and 7.3.2). Indeed, synesthesia is anterior to language. It is, rather, meaningful relations that characterize synesthesia, and we know that ascribing meaning to objects requires the participation of transmodal entities.

All of us make cross-modal associations constantly thanks to the transmodal entities in our brains, and we are never confused perceptually because sensory fidelity is preserved though at least the first four synaptic levels of sensory-fugal processing, as figure 6.9 shows. On the contrary, perceptual confusion would likely ensue in the presence of direct connections between different unimodal areas precisely because sensory fidelity would be lost. The phenotypic heterogeneity of synesthesia may parallel a heterogeneity of genetic expression. If so, retained connections among unimodal areas would result in disabling perceptual confusion (as experienced by a few individuals described in this book) whereas hyperconnectivity in transmodal areas would result in
typical idiopathic synesthesia, which is usually pleasurable and not confusing perceptually.

Ramachandran & Hubbard (2001), for example, are taken with the fact that the color area and the number-grapheme area both lie in the fusiform gyrus, especially in the left hemisphere (Tarkiainen et al. 1999). Speculating that a single gene mutation causes an excess of cross-connections or defective pruning of connections between diverse brain areas, they propose that the activation of neurons representing numbers causes a concomitant activation of neurons subserving color.

Instead of local cross-activation, however, a gene mutation could result in anomalous dominance, thus explaining all features of synesthesia including the mild neuropsychological deficits. Top-down feedback by transmodal to unimodal areas nicely explains both the hypermnesis and the effect of synesthesia if one of the transmodal binding nodes is the hippocampal-entorhinal complex that underlies explicit memory. “In implicit memory, the information remains in the form of isolated fragments, mostly within unimodal and heteromodal association areas; in explicit memory it becomes incorporated into a coherent context through the binding function of limbic nodes” (Mesulam 1998, p 1027). The amygdala participates in attention, affect, and memory. With respect to memory, it encodes both implicit and explicit emotional correlates of experience, a function complementary to that of the hippocampal formation, but emphasizing the association of sensory experiences to emotional valence (Cahill et al. 1995).

Transmodal nodes not only support convergent synthesis, but also—predominantly—create directories (maps, look-up tables) for binding distributed modality-specific fragments into coherent experiences, memories, and thoughts. Mesulam gives the analogy of producing green by superimposing blue and yellow lenses, which can still be separated to yield the original, uncontaminated colors. Transmodal areas are not centers wherein convergent knowledge resides, but critical gateways for accessing the relevant distributed information (Mesulam 1994). Accordingly, if one were forced to say “where” synesthesia takes place the answer would have to be, In unimodal association cortex and downstream areas. The binding of distributed information, however, is effected by transmodal entities.

The Hebbian rule of covariance (Cruikshank & Weinberger 1996) and the existence of reciprocal projections between unimodal and transmodal areas are the two essential features underlying the process whereby directories for multimodal binding are constructed within transmodal areas. Once a record of synchronous activity in two unrelated unimodal areas is recorded in the transmodal node, future activation of one reacti-ES

The proposal that transmodal rather than local connections are operative in synesthesia is consistent with Lovelace & Grossenbacher’s
Ramachandran & Hubbard (2001) demonstrated that rapidly alternating graphemes were followed by their respective colors up to a rate of 5 Hz, beyond which the colors disappeared even though the graphemes were clearly discernable. The loss of perceived color for graphemes alternating past a given frequency even though the numbers themselves could be clearly discerned, is consistent with a hyperbinding or feedback hypothesis inasmuch as both require a finite time for a graphic stimulus to traverse the synaptic hierarchy and backpropagate to coactivate the color map.

Parenthetically, to speak of “centers” or “areas” is misleading because the anatomical distribution of stimulus-induced activation is a probabilistic function determined by the goal of the task rather than the nature of the stimulus. Selectively distributed processing dictates that faces, for example, activate not only the face area but also other visual areas to a lesser extent, much like a contour map shows a principal peak surrounded by lesser peaks and valleys. Color perception, word recognition, or shape discrimination are not the final products of a hierarchical assembly line but a complex surface of peaks and valleys spread over the cerebrum. Functional imaging emphasizes the peaks and therefore gives the impression of sharper localization.

It may be that the overwhelmingly most common manifestation of synesthesia, color-graphemic and color-phonemic, is a special exception. The cortical areas for color and graphemes have just been functionally identified in humans, though we do not yet know their topographic level anatomically. Because there is no macaque analog of the grapheme area, anatomical mapping in humans will be necessary. I understand how tempting it is to posit extraordinary projections between the color and grapheme regions given that they lie adjacent on the fusiform gyrus. But I am uncomfortable with the idea of horizontal connections because I do not like to violate basic principles and prefer to explain synesthesia via pathways that already exist rather than by recourse to extraordinary ones. Besides, horizontal connections remain overwhelmingly local, within a millimeter or so of their origins, and cortical columns largely project to nearby columns, not distant regions.

Another general principle is the profound vertical organization of the brain, and it is via vertical projections to deeper structures that adjacent topologic areas connect. As an analogy, the Red Line of Washington’s Metro forms a U–shape. You cannot travel east to west from Silver Spring to Bethesda because there are no horizontal connections; you must go by way of downtown. So vertical binding of diverse qualia would be intellectually more agreeable than horizontal cross-talk, but I could be wrong. Time and further data will tell.
To me, the question boils down to whether intersensory binding is local—say restricted within the fusiform or angular gyrus—or removed, requiring a trip downtown for binding via existing reciprocal transmodal pathways. It is possible, too, that a single explanation is inadequate if it turns out that “strong” and “weak” forms of synesthesia do exist (Martino & Marks 2000). Weak forms such as color-graphemic and color-phonemic synesthesia would presumably result from local anomalies within the fusiform gyrus whereas more robust and polymodal forms would result from more widespread anomalies involving heteromodal structures such as the angular gyrus or inferior parietal lobule as well as other transmodal entities such as the insula, claustrum, or hippocampus. If two such classes of synesthetes do exist, their psychophysical performance would differ on experimental tasks. Given the heterogeneity of phenotype, however, it seems far more likely that gene expression is mixed rather than strictly bimodal.

Further support for transmodal binding comes from epileptic synesthesia. At first glance, kindling (induced hyperconnectivity) in TLE patients might explain the high incidence of synesthesia in this population. Epileptic synesthesiae include hearing, vision, taste, pain, touch, visceral sensations and autonomic symptoms. However, given that the usual sites of seizure foci in TLE are perisylvian, amygdalear, and hippocampal, any hyperconnectivity induced by kindling is not, by definition, between areas of unimodal association isocortex. Rather, it entails transmodal entities. Therefore, if kindling of transmodal entities that are already polymodal produces synesthesia, it suggests that heightened binding by existing transmodal entities is the normal synesthetic bridge rather than wholly new cortico-cortical connections between unimodal areas.

We need a model that explains all types of synesthesia as well as the feeling state that accompanies it. Isocortex alone will not do. The insula is an entity to watch inasmuch as it receives projections from all sense modalities. Also, there is a correspondence between the architecture of insula sectors and the areas with which they connect in various modalities (Mesulam & Mufson 1982). The limbic role of salience may be seen in fMRI studies of Stroop color-word interference tasks wherein the insula activates along with anterior cingulate, premotor, and inferior frontal regions (Leung et al. 2000). The insula-claustrum activates in PET studies of tactile-visual cross-modal transfer (Hadjikhani & Roland 1998). The claustrum, a deep subcortical structure, receives and gives rise to multimodal cortical projections just as the insula does.

It seems more likely to me, however, that as yet unspecified transmodal entities serve as a bridge to bind diverse isocortical areas, affect, and memory, and that the genetically induced cerebral reorganization that allows them to do so in a manner different from nonsynesthetes also comes at the cost of mild neuropsychological deficits. Although
synesthetic brains are hardwired to make exceptional cross-modal associations, learning must be involved, just as it is with language. Just as grammar and syntax become stable so too color-grapheme combinations become inflexible once learned. Continuing research will clarify this point.

It is further likely that any two or more cognitive domains—not just sensory ones—can be bridged. This much is already understood with the participation of language elements and movement in synesthesia. But the additional observations of synesthetic gender and personality, projected emotional states (e.g., “nervous peaches”), and orgasm need to be explored (§8.1.4). Transmodal binding could explain heterogeneous experiences such as these. It will certainly be exciting to watch as new research sorts out of which of these alternatives is valid.
This chapter builds upon the previous one in using developmental neuroanatomy to address a number of unsettled issues. These include neonatal synesthesia, cross-modal similarity and metaphor, the conundrum of phoneme-based versus grapheme-based synesthesia, and meaning, affect, and plasticity in synesthesia.

7.1 NEONATAL SYNESTHESIA

William James (1890) called the infant’s perceptual world a “blooming, buzzing confusion.” Contemporary data suggest that his description was right.

We have long known that very young children can form cross-modal associations per se by demonstrating, for example, their ability to recognize as identical an object seen alone and then palpated in the dark (Ettlinger & Blakemore 1969). We have further known that the capacities to form metaphoric and cross-modal associations remain neurologically separate during the age range of 3 to 8 years: whereas the formation of metaphoric associations remains inferior to the formation of cross-modal ones at all ages, even 3-year-olds can relate specific differences in physical stimuli across sense modalities (Sepehr et al. 1988).

It was initially quite surprising that newborns less than a month old might be able to detect intersensory equivalence (Lewkowicz 1992). The best-known study of cross-modal effects in the first month of life is that by Meltzoff & Borton (1979) with smooth and nubby pacifiers: in both the original study and in some replications, most babies looked longer at the pacifier shaped like the one they had just sucked. The initial cross-modal transfer hypothesis argued that infants could recognize objects in more than one modality by virtue of being able to represent objects abstractly. However, Maurer (1993) questioned this interpretation after failing to replicate the Meltzoff-Borton protocol. She criticized it for not including controls for side bias and stimulus preference (Maurer, Stager, & Mondloch 1999) and argued that neonates resemble synesthetic adults in that they experience a sensory confusion rather
than a differentiation as originally proposed by Meltzoff. Maurer observed the paradoxical presence of cross-modal matching during the first month of life as well as the apparent emergence of cross-modal perception only later during the first year (Maurer & Mondlach 1996; Rose & Ruff 1987).

Infants show a U-shaped developmental curve for cross-modal transfer from vision to touch and proprioception, as well as from hearing to vision. That is, they show significant effects during early and late infancy with random performance in between as infants shift from a synesthetic style to one in which they base their cross-modal associations on more differentiated sense modalities. Matches at an early age may not be precise, given that neonates do not seem surprised or distressed when they reach for an object and find only empty space (Field 1977). Likewise, early imitation of facial gestures that oblige transfer from vision to touch and proprioception is imprecise and fades at about 2 months of age only to reemerge later in the first year. A similar pattern exists for auditory localization and delayed visual recognition; as the proto-cortex becomes more differentiated, these responses become harder to elicit, only to reappear later on, better controlled, and more precise (de Schonen & Mancini 1998; Maurer & Maurer 1988). Maurer therefore hypothesizes that newborn perception is synesthetic, and that certain, widely observed developmental patterns make sense if the infant changes from apparent cross-modal transfer based on synesthetic confusion to cross-modal transfer based on associations among differentiated sensory modalities.

The weak form of her hypothesis is that infants do not differentiate stimuli from different modalities but rather respond to the total energy summed across modalities to detect nonveridical intermodal correspondences based on the pattern of energy flux such as interval, periodicity, consonance, or symmetry. That is, the newborn perceives changes over time and space in the quality of energy, not the sense in which it arose. From Maurer’s perspective, Meltzoff & Borton did not discover cross-modal transfer between the feel and the sight of a nubby or smooth pacifier. Instead, they documented 1-month-olds’ confusion between oral and visual stimulation:

The babies sensed smoothness or nubbiness—continuity or discontinuity of energy—through the mouth and through the eyes. Since most one-month-olds cannot form complete schemas for shapes in 90 seconds [the duration of stimulus exposure], babies attended to the familiar pattern of energy, unaware that it was now coming from a new modality. (Maurer 1993)

The strong form of Maurer’s hypothesis states that synesthetic perceptions result from a largely undifferentiated and poorly functioning cerebral cortex that is influenced by transient but functional connections between diverse sensory cortical areas, between cortical areas and
limbic entities, or both. “In the strongest form of the hypothesis, the baby is unable to discriminate real from induced percepts (a green object from a green-inducing tone).” Whereas synesthetic adults can make such discriminations “there is no a priori reason to assume that newborns can” (Maurer & Mondloch 1996). As the cortex becomes more differentiated, the crude cross-modal matches will diminish with time and differentiated intersensory relations will surface.

7.1.1 Evidence for Neonatal Synesthesia

The evidence in favor of the neonatal synesthesia hypothesis is diverse. I reviewed in §6.3.1 how the brain forms from the inside out and how the process called physiologic necrosis shapes and prunes human brains when superfluous neurons fail to establish synaptic connections. This molding, which is determined partly by genetics and partly by environment, actually continues into the second decade of life, although the sculpting in later years has more to do with myelination, whereas neuronal death is the dominant force in early life. For example, synaptogenesis in striate cortex is most rapid between 2 and 4 months of age, whereas a synaptic elimination of 40% occurs between 8 months and 11 years of age (Huttenlocher & de Courten 1987).

Maurer first recapitulates evidence from psychophysical probes and functional imaging during synesthesia to show that (1) olfactory, reading, and spoken-word stimuli evoke massive redistributions of cerebral metabolism compared to controls, (2) that activations and deactivations alike occur in association areas typically unrelated to the precipitating stimulus, and (3) that conventional cortical depressants and stimulants affect the intensity and quality of synesthetic experience. In accepting a limbic element as a plausible bridging entity among sense modalities, Maurer relies on both animal and human data. In the monkey, for example, limbic elements mediate veridical cross-modal interactions as measured by delayed matching-to-sample; lesions of the amygdala, but not the hippocampus, impair matching between vision and touch while leaving unscathed matching within either modality (Murray & Mishkin 1985). Maurer thus argues that limbic elements (1) might be obligate for veridical cross-modal interactions, and (2) they might mediate synesthetic perception in an unstimulated modality when cortical activity is depressed. This is consonant with concepts introduced in chapter 4.

The human cortex is hardly functioning at birth (M. Johnson 1997). There is little dendritic arborization (Huttenlocher 1994) and little metabolic activity outside of the well-differentiated idiotypic S1 and M1 areas (Chugani 1994). By contrast, the limbic system develops quite early in both monkeys (Bachevalier, Hagger & Mishkin 1991) and humans (Benes 1994). It is most likely functional at birth in humans; unlike adult amnesiacs with temporal-limbic lesions (McKee & Squire
1993), newborns can recognize a face even after a delay (Pascalis & de Schonen 1994). Facial recognition is a visually triggered episodic memory, the recognition of an example within a class, and the veridical representation of a part (an object that decomposes no further).

The transient connections that exist between diverse neural structures in various neonatal mammals suggest a plausible anatomical basis for human neonatal synesthesia. The neonatal hamster has transient connections between the retina and the main somatosensory and auditory thalamic nuclei, whereas the kitten has similar transient connections between visual, auditory, somatosensory, and motor cortices (H. Kennedy et al. 1997). At birth, the monkey has transient connections from auditory cortex to V4, transient feedback projections from supragranular cortical layers to V1 and V4, and transient projections from inferior temporal cortex to several limbic entities (Webster, Bachevalier, & Ungerleider 1995). These projections undergo considerable revision as the monkey ages. The human cortex shows the same pattern of robust connections that are subsequently pruned (Huttenlocher & Dabholkar 1997).

Finally, claims for overall phylogenetic differences specific to cross-modal performance cannot be sustained from the data for humans, apes, monkeys, and nonprimates. Using 2-deoxyglucose to query whether cross-modal performance is mediated by representations localized in areas of polysensory neural convergence has not yielded convincing evidence either (Ettlinger & Wilson 1990). Using 2-deoxyglucose during cross-modal recognition and tactile discrimination performance in monkeys, Horster & colleagues (1989) found that left hemispheric structures were more strongly labeled than right hemispheric ones, and that the amygdala never gave rise to significant outcomes, whereas paralimbic (insula) and subcortical entities (claustrum, pulvinar) reliably did show activations during these tasks.

Diverse lines of evidence suggest that the transient connections observed in early development are functional. For example, in human newborns, but not in adults, white noise affects the somatosensory potential amplitude evoked by electrical stimulation of the wrist (Wolff et al. 1974). Only during early infancy does spoken language evoke responses in visual cortex (Neville 1995); similarly, viewing faces compared to moving lights activates Broca’s area in newborns (de Schonen et al. 1996). Such transient connections persist and remain functional in later life if the infant is deprived of a given sensory input or if the usual pattern of synaptogenesis and elimination is disrupted by an infantile lesion. For example, in adults blind since birth, striate and extra-striate visual cortices activate during tactile discriminations (Sadato et al. 1996), whereas in congenitally deaf persons, the auditory cortex responds to visual stimuli (Neville 1995). Naturally, some of the cursive projections I have enumerated may be inhibitory.
Thus, Maurer concludes, perception in the newborn might be influenced by transient connections between sensory association areas that result in undifferentiated cortical activations and deactivations, as well as undifferentiated limbic input.

7.1.2 Assessing Neonatal Synesthesia

Aside from being unable to replicate Meltzoff & Borton’s smooth-nubby pacifier experiment, Maurer also maintained that preferential looking on the infant’s part was not the most reliable way to measure either purported cross-modal associations or neonatal synesthesia. Rather, she recalled Marks’s demonstration regarding common sensory matching along the dimensions of perceived pitch, size, and brightness (Marks 1974). That is, both synesthetes and non-synesthetes agree that higher-pitched sounds “go together” with smaller, brighter visual photisms, whereas lower-frequency sounds appropriately “go together” with larger, less luminant visual targets.

Non-synesthetic children as young as 3½ years old agree with similar pitch-size-brightness correspondences. If all neonates indeed perceive synesthetically, and if the neural basis of adult synesthesia is the persistence of linkages among the sense modalities, then conventional pitch-size and pitch-brightness associations should be measurable in neonates. Maurer has begun to do precisely this in 30- to 36-month-olds by showing them videotapes of two bouncing balls—one smaller and white, the other larger and gray—bouncing in synchrony with each other and with a tone presented as the balls reverse trajectory at the bottom of the screen. On alternating trials the tone frequency was either 512 Hz or 256 Hz. Eleven out of twelve children matched in the predicted direction, saying that the smaller, white ball made the higher-pitched sound.

If these results could be replicated in newborns, then the strong form of Maurer’s hypothesis is proved. The strong hypothesis predicts that presentation of the higher-frequency sound will cause infants to look longer at the smaller, more luminous ball because, accordingly, they are experiencing smaller, brighter percepts. Maurer & colleagues are currently testing these predictions by using (1) visual preference, (2) conditioning, and (3) recovery from habituation. The neonatal synesthesia theory predicts that synesthetic effects should decrease with age and that older infants should readily dishabituate to a change of modality (or a reversal of what was once a synesthetic correspondence) and likewise should cease to show intermodal potentiation and inhibition.

7.2 SYNESTHESIA, SIMILARITY, AND METAPHOR

Similarity is a fundamental cognitive attribute. We describe one thing as being like another. We also develop dichotomies, such as good
versus evil, to clarify our thoughts. It is probably impossible to under-
stand anything without forging such polarities. Some polarities ap-
ppear obvious because they have a physical basis, such as positive and
negative. Others are elusive and resolved only by perseverance. When
we eventually fathom a linkage, we call it insight.

Insight, of course, is emotional, just as synesthesia is, and what I am
hopefully essaying toward is some clarification of why or how synes-
thetic percepts are attached to an overt emotional state. Because the
anatomy of emotion is also partly in the anatomy of memory (another
notable attribute of synesthetic percepts), increased clarity comes from
the capacity to remember and ponder our previous actions and deci-
sions. Discerning dichotomies and similarities is a natural part of this
process, and might be compared to the physicist’s duality principle,
which states that light is simultaneously a wave and a particle and that
any experiment designed to demonstrate one property makes it impos-
sible to observe the complementary one. Our metaphoric concepts (see
below) do likewise: in emphasizing one aspect of an object, they hide
others.

Before probing the relation between synesthesia and metaphor, let us
first turn to sensory similarities, both synesthetic and conventionally
cross-modal ones.

7.2.1 Sensory Similarities

Three properties of synesthetic perception suggest how it is possibly a
universal trait that may even have an inborn basis (Marks 1975, 1978).
First of all, synesthesia has been reported to be much more common in
children than in adults (Marks 1975; Hall 1883; Galton 1907; Werner
1940; Révész 1923; English 1923; Lenzberg 1923; Riggs & Karwoski
1934), and most synesthetic adults report having had the experience as
far back in childhood as they can remember.

Second, synesthesia consists largely (though not exclusively) of reg-
ular congruences between specific aspects of experience in different
modalities. That is, synesthetes show systematic relations among
dimensions of given modalities. Most important, synesthetes concur
widely about which dimensions correspond. For example, soft, low-
pitched sounds are dim or dark in color; as sounds get louder or higher
in pitch, the colors brighten. Low-pitched sounds are associated with
large, rounded forms that are darkly colored, whereas high-pitched
sounds appear as smaller, sharper in contour, and brighter. The con-
nections between pitch and brightness, between loudness and bright-
ness, and between pitch and size exemplify the general rule that
correspondences between dimensions characterize synesthetic percep-
tions (Marks 1974).
Third, some non-synesthetes may experience synesthesia under the influence of psychotropics such as LSD or mescaline. When they do so, they report experiences similar to those of idiopathic synesthetes (Strassman 1984; Delay, Gérard, & Recamier 1951; Simpson & McKellar 1955).

What led Marks to suspect that the cross-modal correspondences underlying synesthesia may be universal was his observation that “many of the very same rules that govern the perception of the synesthetic minority also govern perceptual and verbal behavior of the non-synesthetic majority.” This line of reasoning suggests that synesthesia rests on a shared core of cross-modal similarities—similarities that may well be innate in early life.

Figure 7.1 illustrates Marks’s experiment addressing similarity of pitch and size in color names. He found a striking ordering of five color names with respect to pitch (N = 500, p < .001). These results compare favorably with those of the study matching pitch and color in 995 children in grades 3 to 6 (age 8 to 12 years) (Simpson, Quinn, & Ausubel 1956) (figure 7.2).

Marks & colleagues (1987) showed that children as young as 4 years old recognize perceptual similarities between hearing and vision, in that they can match pitch to brightness and loudness to brightness. Not until about age 11, however, can children recognize similarity between pitch and size. Perhaps the pitch-size correspondence must be learned, perhaps by associating size with acoustic resonance. It is noteworthy that the reliable recognition of the “warm” and “cool” colors emerges only at about the same age of 11 years (Morgan, Goodson, & Jones 1975).

Even 4-year-olds show at least some capacity to translate meanings metaphorically from one modality to another (such as rating “low-pitched” as dim and “high-pitched” as bright). Improvements with age
in making metaphoric translations of synesthetic expressions parallel both the children’s increasing differentiation of meanings along literal dimensions, and their increasing capacity to integrate component meanings in compound expressions. Marks & colleagues postulated that “perceptual knowledge about objects and events is represented in terms of locations in a multidimensional space; cross-modal similarities imply that the space is also multimodal.” Only with increasing age does language later gain access to this graded sensory knowledge, thus permitting the interpretation of synesthetic metaphors according to the neurophysiology of cross-modal perception.

The perceptual similarities described above derive from fundamental similarities in phenomenal experience itself. These in turn become available to the more abstract system of knowledge embodied in language. In summary, Marks (1989) concluded that perceptual experiences in meanings are multidimensional, and that verbal (semantic) knowledge taps earlier perceptual knowledge. This conclusion was later echoed by Day (1996) who noted that colored sounds are the most common expression of physiologic synesthesia, whereas metaphoric elaborations of tactile sound are most common in (English) literary synesthesia. It appears likely that human thought itself is largely metaphoric. Hearing is the sense most frequently expanded by both sensory synesthesia and synesthetic metaphors. Day also concluded that synesthetic visual hearing, which antedates language, has probably influenced language development.

Figure 7.2 Percentages of subjects choosing each of six colors with a designated sound stimulation. (A) “high-pitched” colors; (B) “middle-pitched” colors; (C) “low-pitched” colors. (From Simpson, Quinn, & Ausubel [1956], with permission.)
7.2.2 The Physical Basis of Metaphor

Upon learning of synesthesia, nonsynesthetes most often ask, “Is it real?” My response to this reflexive query is, “Real to whom? To you or to the person who has it?” The question asks for a third-person account of a first-person experience and exposes our most commonly constructed dichotomy, that of subjective versus objective, or experiential versus reasoned. The insistence on a third-person, often technological, explanation shows how intensely we value the rational and the external over direct experience.

We try to make sense of the world by creating dichotomies and by thinking in categories. We split our existence into objective and subjective parts that respectively compartmentalize external demands and inner concerns. But reality is not the same as our thoughts about it, and we often fail to ponder what an imposition intellectual categories are in diminishing direct experience. This is evident in stock phrases such as, “Sorry, I wasn’t thinking.” No one ever says, “Sorry, I wasn’t feeling.”

The flaw in stressing objectivity is that it is possible to have an objective view of anything, but only from your own subjective point of view. You cannot have a subjective evaluation of a species other than yourself, for instance. Hence, you cannot know what it is like to be a bat, a whale, or anything other than yourself (Nagel 1986). Every subjective experience is connected with a single point of view—namely, yours. The error of persons who place reason and objectivity above all else is in trying to develop a view from nowhere, detached from other values. Perhaps we can imaging a view sitting isolated out in space, but the more we think about it the more we see that it is impossible to have a view from nowhere without beginning with a view from somewhere. That somewhere is yourself. It is difficult to imagine what the objective character of an experience would be like. In his famous paper, “What Is It Like to Be a Bat?”, philosopher Thomas Nagel (1974) asks, “After all, what would be left of what it was like to be a bat if one removed the viewpoint of the bat?”

Because metaphor joins reason and imagination, the conceptual system on which reality is based is in part imaginative. Likewise, creative ideas are partly rational in nature, as is emotion (de Sousa 1983). Objectivity fails to see that the human system of concepts is metaphorical, involving an imaginative understanding of one thing in terms of another. Subjectivity fails to see that even the most imaginative flights occur in the context of objective experience gained by living in a physical and cultural world. The elaboration of metaphors, for example, is an imaginative form of rational thinking.

I want to present the case that everyday language and actions are permeated with metaphoric concepts based in physical experience rather than abstractions (Leary 1990; Lakoff & Johnson 1980). The commonly
held premise that metaphor is merely language (something like rhetoric or poetry) perpetuates the view that the world is dispassionately objective, meaning free from human concepts of it. However, concepts are not defined by fixed properties but rather in terms of how we physically interact with objects.

Consider the premise that metaphor is experiential (thus subjective) and visceral (thus emotional), an a-rational transfer of connotations from one thing to another. Metaphor physically encapsulates our relations with the world and though it is a means of discerning the similar in the dissimilar, it is emphatically not a product of reasoned analysis. The objective person claims to comprehend something in terms of its inherent properties, some disembodied ideal. To suggest that this is utterly false, consider a most subjective example, namely love. Dictionary writers allude to affection, sexual allure, and the like. Metaphoric comprehension sees love as a journey, madness, or a battle—things grasped in the course of experiencing it directly. Consider these examples (from Lakoff & Johnson 1980, passim):

**LOVE IS A JOURNEY**
Look at how far we’ve come only to go our separate ways. It’s been a long, bumpy road and this relationship isn’t going anywhere. It’s on the rocks.

**LOVE IS MADNESS**
I’m crazy about you and insanely jealous. You drive me wild and make me go out of my mind.

**LOVE IS A BATTLE**
She is besieged by suitors who pursue her relentlessly, causing her to flee their advances and fend them off. The tactics they use in fighting over her are unbelievable.

Trying to pen an objective definition of love reveals the concept to be entirely metaphoric. A metaphor is defined as experiencing one thing in terms of another, as the metaphoric knowledge of love illustrates. Metaphoric understanding is the ability to perceive similarity among seemingly dissimilar objects. As Aristotle put it, “It is from metaphor that we can best get hold of something fresh” (Rhetoric, 1410b).

The easiest metaphors to understand are those based on simple spatial directions such as up. We change our physical orientation during activities such as standing, sleeping, climbing, or diving. Given that a physical orientation is central to having a body, Euclidean orientation is central to our conceptual system. That is, the structure of our spatial concepts emerges from our direct physical experience.

**CONSCIOUS IS UP; UNCONSCIOUS IS DOWN**
Wake up. I’m up already. I’m an early riser. I dropped off and fell asleep. The patient went under anesthesia, sank into a coma, then dropped dead.
CONTROLLING IS UP; BEING CONTROLLED IS DOWN

He’s on top of the situation, in high command, and at the height of power in having so many people under him. His influence started to decline, until he fell from power and landed as low man on the totem pole, back at the bottom of the heap.

GOOD IS UP; BAD IS DOWN

High-quality work made this a peak year and put us over the top. Things were looking up when the market bottomed out and hit an all-time low. It’s been downhill ever since.

RATIONAL IS UP; EMOTIONAL IS DOWN

My heart sank and I was in the depth of despair, unable to rise above my emotions. I pulled myself up from this sorry state and had a high-level discussion with my therapist, a high-minded, lofty individual.

The physical grounds for these metaphors is that most mammals sleep lying down and stand up when awake. Well-being, control, and things characterized as good are all up. Because we control our physical environment, animals, and sometimes even other people, and because our ability to reason is assumed to bestow this control, control is up implies human is up and therefore rational is up.

Spatial orientations such as up-down, front-back, and center-periphery are the most common ones in our system of concepts but, given the variety of ways we interact with the world, others exist. We make inside-out distinctions between reason and emotion, for example, and generally characterize rationality as up, light, and active, while the emotions are down, deep, and murky—passive, irrational passions over which we have little control. Cognitive functions of the brain are called “higher” while emotions and habits are labeled “low.”

Anthropologists tell us that the major orientations of up-down, in-out, center-periphery, and active-passive exist in all cultures. But which concepts are most valued varies from place to place. Some cultures prize balance, whereas America seems taken with the extremes of up or down orientations.

Forming metaphoric concepts is like culling tidbits of experience and then treating them like autonomous entities that we can arrange. Our interactions in space yield orientational metaphors. Other experiences give rise to what are called ontological metaphors, ways of treating events, actions, emotions, and ideas as reified, self-contained objects. Cultural influence elaborates ontological metaphors. We can elaborate the mind is an entity into either the mind is a machine or the mind is a brittle object to get the following:

THE MIND IS A MACHINE

We are cranking out a lot of paperwork. You could see his wheels turning. Their proposal just ran out of steam.
Compare this with the results of a different elaboration:

**THE MIND IS A BRITTLE OBJECT**

He *cracked* under pressure. It was a *shattering* experience. You *bruised* his ego.

Metaphors emphasize some facets of an object but hide others. The *machine* metaphor paints the mind as having a source of power, an expected level of efficiency, an optimal production capacity, and an on-off state. However, it hides the vagaries of thought, its ability to deal with fragmentary information, and other results stemming from its subjective properties.

By switching metaphors, we alter how we comprehend something and thus alter reality. Words do not change reality, but changing our concepts does alter what we perceive and how we act on those perceptions. Ontological metaphors are so pervasive that they seem natural and self-evident descriptions of mental life. It never dawns on us that they are metaphors. Ponder the experience implicit in the following:

**UNDERSTANDING IS SEEING; IDEAS ARE LIGHT**

I *see* what you are saying. It was a *brilliant* remark and a *clear* discussion. Your point of *view* gave me the *whole picture*. Their proposal is *murky*, the ideas *opaque*, and their premise is *transparent*.

**EMOTION IS PHYSICAL CONTACT**

The verdict *bowled him over*. I was *struck* by his generosity. His donation *made an impression* on me. That model is a *knockout*. I was *touched* by their kindness.

It is evident that different metaphors produce different flavors of a given concept. The intuitive appeal of a concept rests on how well its metaphors agree with actual experience. One factor contributing to the irrationality of the human mind is the conflict among metaphors that arises from real differences in their physical foundations. For example, “That’s up in the air,” and “The matter is settled” are each physically consistent with “I grasp your meaning.” If you can grasp something you can examine and understand it, and things are easier to grasp if they are down rather than flying up in the air. Thus, ***unknown is up*** and ***known is down*** are coherent with ***understanding is grasping***. However, ***unknown is up*** is inconsistent with the orientational metaphors ***good is up*** or ***finished is up*** (e.g., “Finish up this last piece of pie”). Logic demands that ***finished*** be yoked with ***known***, and ***unfinished*** yoked with ***unknown***. But our experience disagrees. We do not consider the unknown to be good, and the physical experience leading to ***unknown is up*** is entirely different from that on which the two incongruent metaphors are based. This shows how the ability to be at odds with ourselves or the ability to hold conflicting beliefs simultaneously is based on physical experience rather than reason.
This new line of thinking is dramatically different from conventional thoughts about metaphor. We used to think that only metaphor could make our abstractions concrete. We thought of it as something highly conceptual like poetry or rhetoric, and that it shared the rarefied realm wherein such devices as synecdoche, synchoresis, paradiastole, concision, and antanaclasis reside. Now, metaphor is increasingly viewed as an emergent property of mind that is rooted in the body. Because it organizes physical sensation—especially affect—cognitively, metaphor is more and more viewed as a developmentally early cognitive function related to synesthesia (Modell 1997).

7.2.3 Physiologic Substrates of Synesthetic Metaphors

The evidence from newborns and young children suggests that a handful of cross-modal connections are inherent in the human nervous system. Current physiologic models support this. For brightness and loudness, for example, an equivalent neural response corresponds directly to perceived intensity. That is, the discharge rate of neurons is the temporal code for sensory intensity. Auditory afferents, for example, employ time to encode both loudness and pitch (Buser & Imbert 1992). It is for this reason that auditory pitch as well as loudness should resemble visual brightness, and both do. Temporal coding accounts nicely for perceptual parallelism between the senses. In this example, the brightness of one modality aligns itself synesthetically with more than one dimension in another modality—in this case loudness and pitch. Other sensory equivalences based on physiology are the similarities, first noted by Békésy (1959), between hearing and skin sensation.

The physiology of opponent-process cells is well understood. Because they provide both continuous (graded) and categorical (discreet) information, they suggest themselves as one possible entity at a brainstem-to-intermediate level of the nervous system to consider as a synesthetic link. Numerous sensory dichotomies exist such as green versus red, dim versus bright, soft versus loud, high versus low, and so forth. Opponent circuitry might provide a physiologic code for distinctive features whose positive-negative contrasts serve as labels that are rendered equivalent in perceptual metaphors. If some semantic features are stored in memory as positive and negative poles of opponent processes, then sensory terms with corresponding polar values (e.g., positive values for high pitch, loud, and bright) would be semantically as well as perceptually equivalent. I leave it to the reader to couple this idea with the spatial extension of auditory scene analysis explicated earlier in §5.2.

Multimodal cells and heteromodal isocortex are additional entities that could subserve cross-modal similarity (see §4.5; see also Stein & Meredith 1993). You will recall that some neurons respond to more
than one modality, whereas some neurons in heteromodal isocortex are themselves multimodal (though largely the region is mostly a mixture of neurons that prefer different modalities). Damage here results in cross-modal deficits. In sum, there are several types of physiologic entities that could subserve cross-modal similarity, and we may be innately wired to do so given that neonates and young infants can match across modalities in the absence of experience. With increasing age, perceptual knowledge makes itself available to the abstract structures of language. This perceptual knowledge reveals itself in innate synesthetic metaphors.

7.2.3.1 Synesthesia as a Model for Metaphor  We return full circle to neonatal synesthesia because synesthetic equivalences provide a starting point for transforming the neonate into the mature, metaphoric adult as perceptual equivalences make themselves available to language. Once children understand that they can map one sensory pole to a different modality, they can presumably extend the process to nonsensory categories, rendering that new experience bipolar. The same sort of neurophysiology that subserves sensory dichotomies can now also mediate more abstract semantic features to which the properties of order, gradation, and polarity may also apply. Polarity has special importance because a nonsensory feature can now be represented by two opponent processes with reversed polarities. This leads to the orientational metaphors discussed above, such as those based on polarities of up or down.

I have focused on sensory similarities because they commonly rely on directly given perceptual equivalences rather than on conceptualized or constructed verbal analogies (Marks & Bornstein 1987). Because we and the world are in constant flux, perceiving similarity in the dissimilar allows us to reduce variation and increase order. Similarity enhances memory by facilitating recognition of new information.

Some sensory similarities manifest in early life and appear to be innate, such as brightness-loudness; these produce synesthetic metaphors. Other similarities such as color-temperature or pitch-size manifest much later, near adolescence, and appear to be based in experience; these produce synesthetic metonymies (a metonymy is a relationship based on association rather than equivalence, and most are learned). Both contribute to elaborating more complex ontological metaphors. Perceptual synesthesia and linguistic synesthesia may both emanate from phenomenological similarity of sensory experiences in different modalities.

7.3 SYNESTHESIA AND LANGUAGE  

Synesthesia is a cross-modal manifestation of meaning in its purely sensory, perhaps purest, form. Three components of evaluation, potency,
and activity lie within semantic differentiation (Osgood et al. 1957). One dimension of intersensory correspondence that derives from the basic structure of individual nervous systems is affect, and it is affect that resides within evaluation.

From what I have presented in preceding sections, synesthesia is not lost in the cognitive transition from infant to adult but becomes subsumed by verbal devices as cross-modal matches shift from purely sensory, to sensory-verbal, to perhaps a singularly verbal realm. The flexibility of metaphoric correspondences exacts a price, however, given that symbolic manipulations are several steps removed from the sense impressions that initially engendered them, thereby losing the immediacy and richness of sensory synesthesia. As Marks (1975) pointed out, “Baudelaire (1860) the hashish smoker could perceive, as Baudelaire (1857) the poet cognized how ‘Les parfums, les couleurs et les sons se répondent.’”

I cited references (§7.2.1) that synesthesia appeared to be more common in children than in adults. Based on those nineteenth- and early twentieth-century reports, children are roughly three times more likely than adults to be synesthetic. Do some children lose their synesthesia as they grow up? Perhaps ontologically, synesthesia is too general, imprecise, and inflexible a form of cognition compared to language and the later-developing meanings possible in the verbal realm. This is what Jerome Bruner (1964) called transition from iconic to symbolic modes of representation. More recently, conceptual reorganization has been established in several areas of cognitive development (Karmiloff-Smith 1992). Whatever they may be, the changes observed in synesthesia during the infant-to-adult transition raise important developmental issues.

### 7.3.1 Colored Language

Color synesthesia based on elements of language contains several subsets: word-based (as a gestalt), graphemic (how it is written), phonemic (how it sounds), or numeric (pertaining to the integers). Following the convention of citing the synesthetic sense first yields the terms chromatic-lexical (Gk. lexikos = of words), chromatic-graphemic, chromatic-phonemic, and chromatic-numeric synesthesia.

Based on the total synesthesia opus, everyone agrees that the trait is innate. No one has ever learned synesthesia nor is it volitionally manipulatable aside, perhaps, from the experience of accomplished meditators (Walsh, in press; see also §4.5.2). Indeed, synesthesia’s automaticity is clinical diagnostic criteria No. 1 (§3.2). But wait—synesthetes typically report being able to slow down and browse whatever part of the percept interests them (e.g., subject JM) or to go to it in space (e.g., subject MP). So some degree of voluntary manipulation is possible.
Suppose the letter m is red. There must be something about m-ness, the quality of being “m,” that is red. This must therefore be a learned attribute despite synesthetes’ claim that they have always had their trait as far back as they can remember. Yet we commonly acknowledge that childhood memory only reaches back to around the time of language acquisition. Also note that numerals are almost always separately colored independent of the letters that constitute the numeral’s name, indicating that color is linked to specific language symbols. The same holds for punctuation: the ampersand, virgule, and other operators (subject MT).

If synesthesia were absolutely innate, it would then be plausible to expect that language-based synesthesia always be phonemic, given that phoneme perception is present since birth (Eimas et al. 1977; Aslin, Pisoni, & Jusczyk 1983). Yet all nine of Baron-Cohen & colleagues’ subjects (1993) had chromatic-graphemic synesthesia, as do many other subjects. Indeed, phoneme-based synesthesia appears infrequently. Grapheme perception is present only from about age 3 to 4 years (Frith 1985). It is possible that chromatic-graphemic synesthesia begins as chromatic-phonemic synesthesia and then undergoes a conceptual reorganization with phoneme-to-grapheme conversion rules and the acquisition of literacy. There is no a priori reason why young synesthetic brains should not face the same developmental reorganizing pressures as everyone else. Prospective testing of synesthetic children would be necessary to prove such a conversion hypothesis, however. This is a difficult thing to do.

Another quirk is observed in Paulesu & colleagues’ six spoken word–color synesthetes. I mentioned that within the category of language-based synesthesia, they represented a “pure,” albeit small subset. It is odd that these individuals experienced synesthesia only upon hearing words rather than reading them, because skilled readers automatically connect the sound of the word with its visual appearance. That is, seeing words automatically activates the visual orthographic lexicon (Patterson & Morton 1985).

To answer the question, What is it exactly that determines the color? in language-based synesthesia, Baron-Cohen & colleagues (1987, 1993), concocted a number of internested tests. For example, man, male, masculine, and so on were all very different colors, indicating that semantically related words were not related in terms of their evoked color. Likewise, phonologically related terms such as man, moon, moan, and mean were also not related by color. They used homophone pairs to disentangle graphemic from phonemic synesthesia. Thus, using homophones such as bear/bare and where/wear, only chromatic-phonemic (but not chromatic-graphemic or chromatic-lexical) synesthesia should yield the same colors for both members of the pair. Using word pairs whose initial phonemes differed in their first letter, such
as rice/writer or fish/photo, only chromatic-phonemic (but not chromatic-graphemic or chromatic-lexical) synesthesia should give the same color for each pair. In all nine of their chromatic-graphemic synesthetes, it was the initial letter that determined the word’s overall color. Similar results obtained for my subject JM, among others. By contrast, their subject EP, who had chromatic-lexical synesthesia, was not influenced by either the first letter or the component letters of colored words. This was demonstrated by using nonsense words (Hilgard 1951) such as huk, liir, polt, and tweal, wherein the evoked color turned out to be a composite of the individual letter colors. For example, huk was dark red (h), yellow (u), and purple (k). This result contrasted to the outcome for real words, whose colors were not related to the colors of component letters but resulted from the words’ meaning.

7.3.2 Meaning, Synesthesia, and Language

So, we again come back to meaning. Marks’s early papers left no doubt that synesthesia is perceptual, and that these percepts are meaningful. Neither he nor I have ever accepted the view that synesthesia is linguistically mediated. In fact, we have both provided evidence that synesthesia antedates language. Osgood (1952/1990), inventor of the semantic differential, wrote that “meaningful reactions may be just as involuntary as perceptions—try to observe a familiar word and avoid its meaning!” Likewise, “you can no more fail to understand a sentence in your native language than you can fail to see a horse in front of you” (Smith 1989). Perhaps we can further explore this root property of meaning by comparing synesthesia with the linguistic quality of syndesis.

Childs (1999) used the term syndesis (from Greek roots that mean “binding together”) for the “subjective experience of employing language in interpersonal situations.” It operates in all modes of language use: listening, speaking, reading, and writing. “The subjective feeling of syndesis is rarely noticed by monolinguals because it seems simply to be part of consciousness.” Table 7.1 compares and contrasts synesthesia with syndesis according to my five diagnostic criteria. Little need be said about criteria nos. 1 and 2 except to point out that hearing and reading, often misconstrued to be passive, may elicit autonomic-hypothalamic affective responses such as changes in breathing, pulse rate, sweating, intestinal motility, and galvanic skin resistance.

The consistency of percepts (criterion no. 3) distinguishes synesthesia from syndesis in two respects: first, whereas synesthetic associations are fixed, language vocabulary is learned and updated throughout a person’s lifetime, and second, learning to syndesize in a second language has no counterpart in synesthesia. However, synesthetes must be
able to incorporate new experiences into their repertoire. Though the new associations are not deliberately made, they are made nonetheless. Recall subject MP whose “memory maps” were discussed in §5.7. When her grandmother asked her, then age 4, how to spell tea she recalls that the letter “t” was in the dark part of the alphabet that she could not yet see. The alphabet was only just beginning to take shape and was still clouded in darkness until she learned to read at age 5. Here is a synesthetic percept in the act of forming, wherein the shape, spatial configuration, brightness, and color antedate language—that is, her concept of the letters themselves. As Childs pointed out, “for all synesthetes, percepts must have formed at some time, but the starkness and simplicity of percepts is consistent with their having been formed before recoverable memories began.” If true, then synesthetic percepts are not so wholly different from the percepts of a first language, which everyone learns early and well—so well that after about age 7 we can never learn another language without an accent (Scovel 1988). Although syndetic percepts come in great variety, once fixed they are relatively stable.

Regarding criterion no. 4, memorability, the implicit comparison is between those with syndesis alone and individuals with both syndesis and synesthesia. “Syndesis makes an experience memorable, but synesthesia may make it unforgettable” by adding an extra modality to what nonsynesthetes ordinarily experience. Childs (1999) suggested that the vividness not available to nonsynesthetes accounts for synesthetes’ superior memories.

<table>
<thead>
<tr>
<th>Cytowic’s five diagnostic criteria</th>
<th>Synesthesia</th>
<th>Syndesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Involuntary (automatic)</td>
<td>mostly</td>
<td>partly</td>
</tr>
<tr>
<td>2. Spatially extended</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>3. Consistent and discrete</td>
<td>fixed once</td>
<td>fixed once; modifiable</td>
</tr>
<tr>
<td>4. Memorable</td>
<td>enhanced memory</td>
<td>ordinary memory</td>
</tr>
<tr>
<td>5. Emotional feeling of validity</td>
<td>yes</td>
<td>yes, but with more complexity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Additional considerations</th>
<th>Synesthesia</th>
<th>Syndesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>6. Simultaneous processing ability is destined from birth, cannot be learned or forgotten</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>7. Discrete sets of percepts (languages) can be activated one at a time</td>
<td>no</td>
<td>yes</td>
</tr>
<tr>
<td>8. Different modalities are aspects of a single process</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

From Childs (1999).
Criterion no. 5 addresses emotional validity. The existence of expressions concerning the inability to “put something in words” indicates that syndesis promotes a feeling of validity, yet the existence of humor, irony, and lying indicates that language leaves the question of validity open and offers more dimensions of emotional resonance than synesthesia does.

Perhaps the greatest difference between syndesis and synesthesia is that polyglots can syndesize in more than one language and enter a mental state specific to it. They get deeply into the “speech-feeling” (Leopold 1949) of a language and are budged from it only with effort (Martinet 1953). No such change of mental state occurs with idiopathic synesthesia. Automaticity and vividness are hallmarks of synesthesia, but also characteristics of one’s first language. But it is precisely the inability to form these vivid and automatic associations that frustrate the adult language learner. Learning to syndesize is possible, but it must be done by learning to experience it, and to experience it is to partake of its meaning. Though you can learn several languages, you can activate only one at a time. Compared to synesthesia, then, language is more restricted—greater flexibility comes at a price of a narrower bandwidth.

To put to rest the idea that language is requisite for cross-modal associations, I note that Norman Geschwind (1965a) was explicit in discrediting the idea that “verbal mediation” is the means by which humans achieve cross-modal transfers.

As I have noted earlier, it cannot be argued that the ability to form cross-modal associations depends on already having speech; rather we must say that the ability to acquire speech has as a prerequisite the ability to form cross-modal associations. (p. 275)

Geschwind (1964) earlier laid out the distinction between limbic and nonlimbic entities in forming both speech and cross-modal associations:

The ability to acquire speech has as a prerequisite the ability to form cross-modal associations. In sub-human forms, the only readily established sensory-sensory associations are those between a non-limbic (i.e., visual, tactile, or auditory) stimulus and a limbic stimulus. It is only in man that associations between two non-limbic stimuli are readily formed and it is this ability which underlies the learning of names of objects. (p. 155)

Although this is true, limbic entities obviously participate in language. MacLean (1990) cast the limbic system as such a coprocessor:

There is no evidence that the limbic structures of the temporal lobe are capable of comprehending speech. [Nevertheless] without a co-functioning limbic system, the neocortex lacks not only the requisite neural substrate for a sense of self, of reality, and the memory of ongoing experience, but also a feeling of conviction as to what is true or false. (p. 578)
The neurological systems that serve synesthesia and syndesis may turn out to be more similar than we thought, especially if a left hemispheric localization of synesthesia holds up over time. Compared to language, we can regard synesthesia as a more immediate and concrete system of meaningful relations.

### 7.4 AFFECT AND SYNESTHESIA

We can now answer the question why synesthetic percepts are attached to an overt affective state. From the foregoing, the reason should be clear: *synesthetic percepts are foremost meaningful, and affect inheres in the meaningful evaluative component of the semantic differential*. Compared to syndesis, the affect of synesthesia is one of certitude, recognition, and overall satisfaction of apprehending a connection. As SdeM says, “I know it’s 2 because it’s white.” With the later appearance of language, affect can be further elaborated along various dimensions.

There is also a relationship between affect and spatial extension that has to do with salience. Figure 7.3 illustrates a network for spatially distributed attention that contains three different representations of extrapersonal space. The reticular formation, thalamus, and striatum sustain an *attentional matrix*, whereas three cortical entities provide the *vector of force* that focuses attention on appropriate targets. Within the limbic system’s cingulate cortex and projections through the cingulum bundle resides motivational valence, which encompasses the body schema, extrapersonal space, and intrapsychic representations.

The foregoing explications of meaning and affect in synesthesia should make it clear why these are inherent properties. It is not enough to focus on whatever two senses are involved in a given instance. Any general theory of synesthesia must explain its basic properties of meaning, mnesis, affect, and spatial extension in addition to the diverse sensory modalities involved.

### 7.5 PLASTICITY IN YOUNG SYNESTHETES

Throughout the voluminous and uneven literature on synesthesia, case reports appear of child synesthetes whose percepts change somewhat over time. These appear exclusively in instances of color-language synesthesia and, given their context of case reports illustrating the constancy of synesthetic associations over time, it does seem paradoxical that this potential for change is either dismissed or overlooked.

Cases among children have received little notice in spite of the fact that synesthesia has its origin during childhood. It is also reported in the older literature to be more prevalent during childhood. Riggs & Karwoski (1934) suggested that synesthetic manifestations among
children are more vague and ephemeral than those of adults, but this remains speculation. They also noted that the affective valence of a stimulus is often a factor in making connections. For example, a very pleasing color is likely to be applied to persons well liked in the case of color personality or colored letters. “The affective factor is seldom present in isolation but is operative in almost all types of connections.”

Jordan (1917), himself synesthetic, described the colored letters of his 8-year-old son. Five years later, at age 13, and without mention of the matter during intervening years, the father had the boy repeat his color list. The father dismissed changes in his son’s color selections as indicating “vagueness of color.” However, 11 of 26 or 42% of the boy’s color-letter associations had changed (table 7.2), a number I find hard to dismiss.

Riggs & Karwoski (1934) presented the cases of four children whose color associations changed over time. All of the children showed the common cross-modal associations of low sounds with large, dark photisms and high sounds with small, brighter photisms.
Table 7.2 Change in letter-color associations with age

<table>
<thead>
<tr>
<th></th>
<th>8 years old</th>
<th>13 years old</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>red</td>
<td>red bright</td>
</tr>
<tr>
<td>B</td>
<td>bluish</td>
<td>gray</td>
</tr>
<tr>
<td>C</td>
<td>white</td>
<td>white</td>
</tr>
<tr>
<td>D</td>
<td>bluish</td>
<td>gray</td>
</tr>
<tr>
<td>E</td>
<td>pale green</td>
<td>yellow</td>
</tr>
<tr>
<td>F</td>
<td>red-brown</td>
<td>brown</td>
</tr>
<tr>
<td>G</td>
<td>pale brown</td>
<td>yellow</td>
</tr>
<tr>
<td>H</td>
<td>green</td>
<td>yellow</td>
</tr>
<tr>
<td>I</td>
<td>black</td>
<td>black</td>
</tr>
<tr>
<td>J</td>
<td>dark blue</td>
<td>greenish</td>
</tr>
<tr>
<td>K</td>
<td>brown</td>
<td>brown</td>
</tr>
<tr>
<td>L</td>
<td>pale green</td>
<td>green</td>
</tr>
<tr>
<td>M</td>
<td>red</td>
<td>brown</td>
</tr>
<tr>
<td>N</td>
<td>pale greenish</td>
<td>light brown</td>
</tr>
<tr>
<td>O</td>
<td>light blue</td>
<td>black</td>
</tr>
<tr>
<td>P</td>
<td>yellow</td>
<td>yellow</td>
</tr>
<tr>
<td>Q</td>
<td>pale red</td>
<td>red-brown</td>
</tr>
<tr>
<td>R</td>
<td>dark green</td>
<td>dark red</td>
</tr>
<tr>
<td>S</td>
<td>silvery gold</td>
<td>silver</td>
</tr>
<tr>
<td>T</td>
<td>white</td>
<td>silver</td>
</tr>
<tr>
<td>U</td>
<td>yellow</td>
<td>yellow-brown</td>
</tr>
<tr>
<td>V</td>
<td>silver</td>
<td>white</td>
</tr>
<tr>
<td>W</td>
<td>red-brown</td>
<td>brown</td>
</tr>
<tr>
<td>X</td>
<td>silver</td>
<td>silver</td>
</tr>
<tr>
<td>Y</td>
<td>silver</td>
<td>white</td>
</tr>
<tr>
<td>Z</td>
<td>reddish</td>
<td>dark brown</td>
</tr>
</tbody>
</table>

Italicized pairs indicate change over time. Forty-two percent of this child’s letter-color associations changed over 5 years.
From Jordan (1917).

1. An 8-year-old boy with colored letters. When tested 5 years later “some changes were made, but on the whole the two sets of color responses were quite similar.”

2. A 6-year-old girl with colored numbers. At age 9 she was questioned again, “and it was found that some of her colors had changed while others remained constant.”

3. A 7-year-old boy with colored letters and numerals. The color associations for the digits remained constant, while those for his letters were variable.
4. A 7-year-old girl with colored music and colored personalities. Her performance is very similar to that of VE (§3.6.1 and 3.6.2) in that she showed large context effects. The investigators played ten musical scales (major, minor, and chromatic). Middle A, for example, was reported as being yellow, gray, yellow, blue, orange, purple, red, blue, orange, and green on the different trials. When the task was repeated 2 months later, “there was practically no correspondence with the original results.”

Riggs & Karwoski commented that “frequently, synesthesia disappears in adolescence …” a phenomenon of which I am personally familiar in less than a handful of cases. In each, the loss was around onset of puberty. Maurer’s data from neonates and my discussion of developmental issues are congruent with Riggs & Karwoski’s statement, as is the implicit and dynamic hierarchy in the theoretical progression of chromatic-phonemic → chromatic-graphemic → chromatic-lexical word synesthesia. We need to be open to the idea that synesthesia in youngsters might be in a state of flux. And, indeed, why should it not be given that young brains are constantly reorganizing themselves in response to the numerous factors I have explicated?

Thus far, we have evidence only anecdotally that the change can go either way. I have a male subject with a synesthetic brother who recalls his own childhood synesthesia, but states, “by the time of my bar mitzvah it was gone.” Two women with colored hearing insist that the trait was not present before age 13 years. Hinderk Emrich has also noted some instances where synesthesia either vanished or was intensified at puberty.

Various issues I have outlined here suggest themselves as subjects for further study.
At the very end of *The Mind of a Mnemonist*, Luria (1968) devoted a few pages to S’s personality and posed the following:

Is it reasonable to think that the existence of an extraordinarily developed figurative memory, of synesthesia, has no effect on an individual’s personality structure? Can a person who “sees” everything; who cannot understand a thing unless an impression of it “leaks” through all his sense organs; who must feel a telephone number on the tip of his tongue before he can remember it—can he possibly develop as others do? … Indeed one would be hard put to say which was more real for him: The world of imagination in which he lived or the world of reality in which he was but a temporary guest. (pp. 150, 159)

What seems surprising, especially to those who encounter synesthesia for the first time, is how synesthetes appear to be such ordinary persons from all walks of life. As their histories suggest and the evidence supports, most are of normal or superior intelligence. They have superior memories and claim to be highly organized because of their synesthesiae. Yet their cognitive skills are uneven. They have gaps in their intellects and quirks in their personalities. The most common findings are poor mathematical aptitude despite a good memory for numbers; a poor sense of direction; and a tendency toward concreteness.

Almost all synesthetes have suffered ridicule or derision because of their parallel senses. As children, they were accused of overactive imaginations, taunted by their classmates, and sometimes doubted by their own parents. Unlike the stresses of expectation that befall child prodigies, foreigners in a strange culture, or the sickly child, synesthetes shoulder those of the freak. What is the effect of having a “sixth sense” on personality, memory, learning, organizational skills, and interpersonal relationships? How does synesthesia affect childhood development, imagination, and creativity?

You cannot assume that synesthetes represent a homogeneous population any more than other groups that are clinically defined. Clinical criteria define a symptom complex by setting inclusion and exclusion restrictions. However, they do nothing more and do not guarantee uniformity of brains or behavior.
8.1 PSYCHOLOGICAL PARAMETERS OF SYNESTHETES

8.1.1 Psychometrics

Eight synesthetes were given the MMPI. The results were unimpressive, and none had significant elevations of the clinical scales. On clinical interview, none were judged to have current or historical evidence of psychopathology.

The Wechsler Memory Scale (Revised) confirmed that synesthetes do have excellent memories. The acalculia and other elements of Gerstmann’s syndrome found in some subjects were also explicated in chapter 4. Thus far, only a small number of synesthetes are frankly acalculic; the bulk tested show subtle arithmetical deficits such as letter-to-digit transcoding, but few overall have been tested formally with such sophisticated probes. A smattering of reported individuals have had Stroop-type tests performed. Stroop interference demonstrates synesthesia’s automaticity; it cannot say whether synesthesia is perceptual or conceptual given that Stroop interference can occur anywhere in the sensory-fugal flow (MacLeod 1991).

In addition to Stroop-type tests, comparison of homonyms, synonyms, and the like are additional probes that may answer some questions and raise others. For example a woman and her father both taste words. “Your name, Richard, tastes like a chocolate bar,” the woman writes, “warm and melting on my tongue.” “Some words are a complete ‘experience’ in that they have flavor, texture, temperature, and are sensed in a certain place in my mouth, i.e., back of throat, tip of tongue, etc. Often, the spelling affects the taste. ‘Lori’ tastes like a pencil eraser, but ‘Laurie’ tastes lemony. Go figure.” In such a case, one might first verify whether the spelling or meaning determines the synesthesia. Another concern is that there are innumerably more words than smells, so what eventually happens (a similar case holds for those in whom sound rather than spelling determines colors)? Do tastes occur only for nouns, or concrete nouns? What about verbs, adjectives, and grammatical functors? What does the word “eraser” taste like? The questions go on.

We can summarize here the favorable influence of synesthesia on organization, creativity, and memory. There is a tendency to prefer order, neatness, symmetry, and balance. Work cannot be done unless the desk is arranged just so, or everything is put away in the kitchen in its proper place. This preference for order extends to other people’s homes and offices as well. Synesthetes resort to mentally redecorating the environmental spaces in which they find themselves.
8.1.2 Personality of Letters and Numbers

Although MT’s personality seemed normal by both clinical examination and the MMPI, it came as a surprise that her letters, numbers, and punctuation marks not only have color but also gender and personality. As with her colors, these characteristics are durable over time, her lists showing no variation over 5 months nor again at 2 years. I have since encountered both male and female synesthetes for whom letters and integers have gender and personality. These individuals came to my attention via the online synesthesia list.

Table 8.1 gives the colors, gender, and personalities of MT’s letters, numbers, and punctuation marks. When asked to recite them, she names these characters without the slightest hesitation. Her descriptions are articulate and given with conviction. She says that her color list is as accurate as she can describe. The colors are at once very specific, yet difficult to define. It is interesting to note that the letters of her initials, M (“my favorite color for ‘my’ letter”) and T, are both masculine.

Multiple-digit numbers and groups of letters forming words contain the colors of their constituent elements. Numbers 11 to 19 retain the gender of the final digit, but there is a blending of the personality characteristics of the composite digits. Beginning with 20, however, the genders are determined by the first digit alone. For example, 20 is male whereas 40 is female. The 40s, 400s, 4000s, and so forth are all female. Similarly, words take on the gender of the initial letter, but not the color or any other attribute.

The binding of categorical and conceptual attributes is further argument for a role of transmodal entities in synesthetic binding.

8.1.3 Geographical Knowledge and Pathfinding

Decades ago when I began collecting cases of synesthesia, several subjects commented on their profoundly poor sense of direction. I found this surprising inasmuch as excellent memory seemed to be emerging as a characteristic of synesthesia. As I continued to gather cases I began to inquire systematically into aptitude for geographical knowledge and pathfinding, and decided to pursue the hypothesis that, as with their mild mathematical difficulty, synesthetes might have a relative deficiency in geographical relations and navigation.

Thirty-one percent (13 of 42) reported a good geographical memory and sense of direction, whereas 69% (29 of 42) claimed it was poor. The latter went to unusual lengths to get around. Generally, subjects relied more on network than on vector maps (Byrne 1982), even in their hometowns. This was particularly surprising in those cities laid out on a grid system, such as New York or Washington, DC.
<table>
<thead>
<tr>
<th>Alphabet</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Bright-to-medium yellow; female; very feminine (always in dresses)</td>
</tr>
<tr>
<td>B</td>
<td>Orangey-beiges, medium tonality; female; sturdy in character</td>
</tr>
<tr>
<td>C</td>
<td>Sky blue or slightly deeper; male, a touch impetuous, but generally dependable</td>
</tr>
<tr>
<td>D</td>
<td>Deep charcoal, nearly black; male; dashing, a bit of a joker</td>
</tr>
<tr>
<td>E</td>
<td>Light lavender; male; a soft-spoken type</td>
</tr>
<tr>
<td>F</td>
<td>Brownish-woody–colored, medium tonality; male; perpetually youthful, easygoing, casual dresser</td>
</tr>
<tr>
<td>G</td>
<td>Slightly lighter than medium purple; male; rugged good looks, and credible</td>
</tr>
<tr>
<td>H</td>
<td>Orange but toned down, (lighter than B); female; of a more formidable figure than A, but just as feminine</td>
</tr>
<tr>
<td>I</td>
<td>White; with “dirty edges”; male; a bit of a worrier at times, although easygoing, sincere</td>
</tr>
<tr>
<td>J</td>
<td>Violet–red-violet (purple with reddish cast); male; appearing jocular, but with strength of character</td>
</tr>
<tr>
<td>K</td>
<td>Yellowy-beige (more to beige than to yellow); female; quiet, responsible</td>
</tr>
<tr>
<td>L</td>
<td>Beige/tan/khaki: a specific shade; male; handsome, easygoing, adult without a thickened figure</td>
</tr>
<tr>
<td>M</td>
<td>Blue-violet (my favorite color for “my” letter); male; secretive, powerful, handsome</td>
</tr>
<tr>
<td>N</td>
<td>Medium-to-deep green, but the lightest of the green characters (which include T, Z, and 2); male; youthful, handsome, mediator type</td>
</tr>
<tr>
<td>O</td>
<td>Clear; the color of (clean) water; female; quiet, warm, reliable, of balanced character</td>
</tr>
<tr>
<td>P</td>
<td>Orangey, browner than B; female; busy, fun, sisterly</td>
</tr>
<tr>
<td>Q</td>
<td>Cranberry; female; elegant, nontalkative, more earthy than the playing-card depiction of Q (as “queen”)</td>
</tr>
<tr>
<td>R</td>
<td>Red; female; all-American woman, outgoing, active</td>
</tr>
<tr>
<td>S</td>
<td>Pastel yellow (lighter and less yellow than A); female; independent but good at partnering; mature</td>
</tr>
<tr>
<td>T</td>
<td>Forest green; male; quite masculine, and quiet, gentle, mature, responsible, slim build, handsome, good in relationships</td>
</tr>
<tr>
<td>U</td>
<td>Soft pink; rosy but not “pinky-pink”; female; of rounded, not slim, figure; sweet, hard-working, quiet</td>
</tr>
<tr>
<td>V</td>
<td>Yellowy beige but subdued (more beige than A; deeper than S; more yellow than L or K); female; very feminine, un flauntingly sexy; sophisticated</td>
</tr>
<tr>
<td>W</td>
<td>Medium gray; “clean” gray; male; open-minded, seeming older than other characters; good-looking, friendly</td>
</tr>
<tr>
<td>X</td>
<td>Cheddar cheese color but deeper; androgynous; easygoing and fun-loving; of balanced character; sometimes cheerful, sometimes worried</td>
</tr>
<tr>
<td>Y</td>
<td>Medium-to-deep gray; male, effeminate, attractive, responsible</td>
</tr>
<tr>
<td>Z</td>
<td>Deep forest green; male; dashing and very handsome because of it; mature but still playful; reliable</td>
</tr>
</tbody>
</table>
Table 8.1 (continued)

<table>
<thead>
<tr>
<th>Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
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<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>10</td>
</tr>
<tr>
<td>11–19</td>
</tr>
</tbody>
</table>

Punctuation marks

| ? | Cranberry-purple; masculine; respectable, serious, mannerly |
| , | Dark-gray; male; a bit irreverent |
| : and ! | Blackish, charcoal gray; masculine |
| ” | Beige; masculine |
| ' | Black |
| + | Yellowish; female; subdued character |
| # | Beige; male, hard-working |

Groups of similar colors

| A, S, V, 4, @, $, + | I, 1 |
| B, H, P, 8 | J, Q, ? |
| C, 5 | K, X, #, + |
| D, (W), Y, 7 | N, T, Z, 2 |
| E, 3 | O, 0 |
| F, L, ” | (R, 10) |
| G, M | U, 6 |
Below are three examples of the distress caused by poor sense of direction.

**RB**  I have no sense of direction, which causes me distress. I cannot visualize where one location is in relation to another, even though they are very familiar places to me.

I can’t tell you how relieved I felt when you told me this was common with synesthesia. My husband says I’m the only person who tried to go through a turnstile in the wrong direction. If I’m driving and come to a dead-end street I can’t get back to a parallel street and get terribly lost. I worked in the same office building for 10 years and still have trouble finding friends’ offices. (5/6/87) (Note her spelling and grammatical errors.)

**MN**  I have no sense of direction. I cannot read a map. In driving to a new location (which has been murder for me this Summer looking for a new job and going to several interviews a week [in various new locations]) I must have very specific directions. Most of the time, I have to “practice” a day in advance before going some place new. Then I must write it down, very specifically in my own words and descriptive phrases. Most people think I am an idiot because I cannot read a map. (7/7/85)

On visiting my hotel for an interview, SdeM had to twice get instructions on how to find the elevators. Yet their location was obvious. She claims to be only slightly better at network maps than vector maps

… but I have to have a map of every place I go to. I have absolutely no sense of direction, even in cities I live in. Coming up out of the subway, I have to stop to figure out what side of the street I’m on. I’m always getting turned around. I’ve lived in Boston for eight years now and I still get lost. No one in my family has this problem. They don’t need maps. (10/3/85)

Several issues appear to be involved. The first is that a “good memory” does not apply to all aspects of memory, such as place finding. In the face of boasting that they could easily recount conversations long since past, interview others without benefit of note taking, or recall the location of reference material even down to the specific page of a book, the prospect that synesthetes suffer poor spatial memory is provocative. It seems paradoxical to have a spatial impairment when synesthesias are so often intertwined with number forms and other spatial concepts.

Geographical knowledge is presumed to be an example of spatial aptitude that depends on the right parietal region. When we ambulate through our own homes, give directions to a stranger, mentally envision which shops we can visit during our lunch break and what the most efficient sequence would be, we are said to be using topographical knowledge or a cognitive map.

The terms of navigation are largely unfamiliar in neuropsychology. “Map” refers to a large-scale spatial representation. “Placekeeping” is any method of knowing one’s current position and orientation on a map. This can be accomplished either by using a “landmark” (identify-
ing a location predicted by the map) or by “reckoning” (monitoring movements to deduce changes in position and direction; hence the term “ded reckoning,” now usually misspelled “dead reckoning”). A “compass” orients a navigator with respect to a fixed frame of external reference. Although an accurate map and either careful ded reckoning or landmark recognition are the only obligate tools for navigation, a compass does permit one to follow a steady heading. A compass requires the additional tools of a “sextant” and a “clock”; however, neither is thought to be meaningfully operative in humans. A talent for distance and angular estimations has been described in humans (Benton, Levin, & Van Allen 1974), but how this fits in the larger picture is unclear.

We know little of the possible neural counterparts of the above navigational entities. Almost nothing is known about mental placekeeping and how we maintain our orientation relative to Euclidean space. The Puluwat islanders use a colorfully abstract and imaginative system during their protracted canoe voyages (Gladwin 1970), but this does little to explain how the rest of us make it from home to the office every day. There is also no firm evidence that humans possess a mental compass, though we know that many birds can detect and use the earth’s magnetic field, as well as skylight polarization (Waldvogel 1990).

The properties of cognitive maps should not be misunderstood to resemble those of cartographic maps. They are not read and memorized, but are learned by engaging the Euclidean world. Whereas visual knowledge or perception has a single viewpoint, cognitive maps are acquired by personal experience gained from multiple viewpoints. Two different representations of large-scale space are (1) vector maps and (2) network maps (Byrne 1982). Vector maps code horizontal distances, whereas network maps encode only topological relations. A network map represents nodes along a string, each node marking a physical location and sometimes containing instructions for a directional turn. Underground railway maps such as those of the Paris metro or the London tube are good visual examples of network maps (although anyone who has used one to guide walking on the streets above knows that although the topology is accurate, the vector distance is not).

Network maps are far more common than vector maps, the skill and development of which appear to emerge later. The skills required for each are clearly distinct. To test network maps you might ask, “Tell me all the turns, and whether they are left or right ones, that you would make to get from here to the park.” A typical probe for vector map integrity would be, “Point toward the cathedral,” or “Is it farther as the crow flies from here to the train station or from here to the park?” When viewed from above, vector maps are isomorphic to the real world.

Psychology has paid more attention to the static aspects of spatial knowledge as a repository of fact rather than to the dynamic aspects of
keeping one’s bearings. Until more is known of the dynamics of spatial knowledge, it is difficult to know what symptoms to look for. From the preceding information, however, we can predict that certain dissociations should occur in clinical settings.

At the simplest level, topographic knowledge dissociates from other visual skills requiring spatial knowledge, and vice versa. That is, one encounters patients who cannot follow and describe familiar routes or learn new ones, but who have no difficulty in other visuospatial realms. Failures of object recognition, visual memory, and imagery, for example, dissociate from an inability to navigate and should be apparent in everyday performance. Persons with retained networking might describe the steps taken to reach their destination, yet have no idea about the vector of the starting direction (the congenitally blind person approximates this shortcoming). Conversely, those with retained vector mapping can accurately relate the distance and direction of the starting point but will be unable to retrace their steps or describe how they reached their destination.

Topographic ability is sharply distinct from purely perceptual abilities such as pointing, line bisection, or depth judgment. Patients with defective spatial localization rarely get lost or lose their topographic knowledge, and the two are seldom impaired together. Hemianopic patients never get lost either, because they scan effectively with their intact hemifield. Another dissociation concerns constructional apraxia: those with constructional apraxia usually have no topographic disability, whereas patients who get lost usually do fail at constructions. Constructional apraxia and unilateral neglect often are asymmetrically associated with deficiencies of topographic knowledge.

What evidence there is suggests a double dissociation between network and vector maps. There is some clinical support for the premise that those spatial neighborhoods that we cannot see from a single viewpoint, but that we learn instead by locomoting through them, can be treated as a unitary concept distinct from verbally acquired geographical knowledge. Gender differences also exist that persist throughout the life span. Normative experiments (Beatty & Tröster 1987; Beatty 1989) indicate that males more accurately locate places on maps than do females, and that males perform more accurately on measures of egocentric and allocentric spatial orientation. However, both males and females learn locations of unfamiliar places at a similar rate, whether such learning is intentional or incidental. Age, education, and gender are stable and noninteracting factors in geographical knowledge, though age is the most potent because of the experience gained in living in a landscape. Geographical knowledge does not decay with age.

There are also potential confounds in assessing topographic knowledge. Patients with posterior right hemispheric lesions have defective
judgment for direction and distance. Yet where the lesion is for localizing points in space depends on whether the task is wholly visual and whether stimuli are to be localized within “grasping distance” of the limb axis, require a verbal judgment, or whether the coordinates are relative to the patient’s body or to Euclidean reference points. Some failures of topographic knowledge are actually shortcomings of either memory or representation. Sometimes, derelictions in following familiar routes or in learning new ones are problems with perception or attention. Once past these confounds, we can talk about true topographic knowledge.

8.1.3.1 Cognitive Maps in Synesthetes To summarize, geographical knowledge is presumed to be an example of spatial aptitude dependent on the right parietal region. Since various data suggest that synesthesia localizes to the language hemisphere, a right posterior lesion would appear at first to be incongruous in the scheme of understanding synesthesia. To the extent you agree with Geschwind’s thoughts on laterality and dominance, however, you could speculate that some event in embryonic neuronal migration in these predominantly female synesthetes might have an effect in the opposite right hemisphere. If so, the clinical manifestations could be one of selective spatial difficulty (Geschwind & Galaburda 1985a, 1985b, 1985c).

This idea was explored in a number of synesthetes with the Fargo Map Test and the New Map Learning Test (Beatty & Tröster 1987). The Fargo Map Test is a standardized means of assessing remote memory for spatial knowledge. The subjects first report all the places in which they have lived for at least 1 year throughout their lifetime and the age range during which they lived at each location. The subjects then locate as accurately as possible target items such as cities, mountains, and rivers on a series of eighteen outline maps. Each map contains twelve to sixteen target items. The first map is of the continental United States and contains both items that require only gross localization of features (e.g., Atlantic Ocean, Canada) as well as items requiring finer discrimination (e.g., Chicago, New York City). The following seventeen regional maps contain outlines of the forty-eight contiguous states in groups of two to six states. In addition to locating the various targets, subjects are asked to identify the individual states. The New Map Learning Test consists of a study map of three contiguous fictitious states within which fifteen hypothetical towns are located. The towns have concrete and highly imaginative names (e.g., Emerald, Rifle, Cotton) and only one examplar of a particular semantic category appears as the name of the town on the map. The test map is an outline of the three fictitious states and twenty-five dots (fifteen towns and ten distractors). Four trials are given for learning.
The results of five subjects are as follows. Female synesthetes AC and JM claimed to have a good sense of direction, and in fact were almost 2 SD above the mean for North Dakota females of the same age and education in geographical knowledge and in learning new maps. DS, MT, an MW—who claimed “no sense of direction”—were also quite good at geography but mildly impaired at learning new maps.

### 8.1.4 Clairvoyance and Other Unusual Experiences

The experiences of synesthetes related below are quite distinct from the comments of oddballs and synesthesia wannabes. As a group, synesthetes seem more prone to “unusual experiences” than one might expect—17% of my original 1989 cohort, although if anyone knows what the general population baseline for unusual experiences is, I should like to know.

#### 8.1.4.1 Clairvoyance

Synesthetes HC, TP, MG, and MLL have all had clairvoyant experiences. MLL, for example, has given me numerous examples of clairvoyant dreams. They are not frightening but are always ominous, portentous, and about bad news. This calls to mind the amygdala and its participation in frightening experiences.

One is also reminded of the age-old association of psychic experience with ictal events. Experiential manifestations of temporal-limbic seizures may include a sense of portentousness or other affective state, feelings of unreality, out-of-body experiences (autoscopy), forced thinking, memory flashbacks, and illusions of familiarity or unfamiliarity, called déjà vu or déjà vécu (Gloor et al. 1982; Penfield & Jasper 1954). These latter terms mean “already seen” or “already experienced” and convey the sense that what the patient is experiencing at the moment has been witnessed or experienced previously. This often leads patients to believe that they are clairvoyant or prescient (“I must have known it was going to happen, because it was all familiar to me”) (Spiers et al. 1985). The opposite, jamais vu or jamais vécu (“never seen” or “never experienced”), may also occur, leading individuals to believe that events or people that are actually familiar are nonetheless alien.

#### 8.1.4.2 Projection of Animate Traits

Whereas the personality traits that MT projects onto her letters and punctuation marks are stable, a handful of synesthetes have revealed—cautiously—that inanimate objects possess, for no apparent reason, qualia that we normally ascribe to ourselves or to others. SM is aware of the incongruity of these episodes while still recounting that they have a feeling of certainty.

I know this sounds completely absurd, but the other week my husband and I were in the produce section of the market, when I grabbed his arm and said, “I don’t know why, but these peaches are extremely nervous.”
What this calls to mind is a psychic seizure wherein a temporal-limbic discharge induces an affective state. Here, however, the referent is discordant. SM has no history of epilepsy and no EEG was performed. I have not followed up this matter.

### 8.1.4.3 Psychokinesis

JB was quite frightened when things around her seemed to move.

At first, with movement of objects, I thought I was out of my mind, so I stopped talking about it. Lights would pop on. I would seem to affect electrical appliances. Plants would jump when I was near them. But I don’t think about it is much as I used to. I was very skeptical. I used to think, “This cannot be happening to me.” But it did. It did happen to me.

This sounds somewhat like episodic metamorphopsia or some other dysmorphopsia. Normally perception is not reflexively directed back on itself, but directed outward toward the world. Thus we can forget about ourselves during ordinary perception.

### 8.1.4.4 The Feeling of a Presence

PP experiences spontaneous blobs of color that “visit” her. Some blobs are “helping” and others just “visiting.” For example, a translucent but not transparent red blob covered the back of her writing hand while she was completing an examination of some difficulty; another time a blue light, warm, as if the sun were shining directly on it, hovered about her left arm and shoulder as she wrote a letter on an emotional subject. The “visiting colors” are of three types: (1) a purple 3\(^\times\)4-inch oval that appears daily, (2) a smaller blue light that often appears when she puts her baby to bed, and (3) assorted other colors with magenta and silvery white sparks that seem to be all around.

I thought of these as Angels but who knows what they are. I’ve mentioned some of my experiences—no one so far knows what I’m talking about, but I love them. I’m grateful for it. For the record, I guess I’m “normal” otherwise, whatever that is.

The feeling of a presence or the “visitor experience” is actually known to clinical neurology and correlates with lesions in mesiobasal (amygdaloid-hippocampal) portions of the temporal lobes (Persinger 1983, 1989). These areas of the brain are associated inter alia with the experience of meaningfulness, the sense of self and its relationship to space-time (with its religious or cosmic associations), dreamy states, feelings of movement, and smell. Accordingly, there are references to a sense of presence, feelings of moving or floating, dreamy states, and flashes or objects “just missed” in the corner of one’s eye (because the most peripheral part of the visual field projects to the lingula of the temporal lobe). Stimulation of deep temporal lobe structures, such as
the hippocampus and amygdala, evoke just these kinds of phenomenological qualia (Gloor 1972, 1986).

In regard to the affective component of synesthesia, a *widened affect* is typical of the phenomenon just described (Bear & Fedio 1977; Geschwind 1983).

### 8.2 SYNESTHESIA AND ART

In the first edition of this book, I wrote extensively about geometry, color, and form in regard to art as well as to religious symbolic painting, divine proportion, and dynamic symmetry. While not without intrinsic interest, I judge them to be of marginal importance to a neurological understanding of synesthesia. Interested readers are referred to chapter 8 of the 1989 edition.

Before considering color, let us reflect a moment on geometry and space. What is this inherent propensity for the human mind to find correctness and even pleasure in geometric proportions? The history of the ideal solids and divine proportion was not designed as an abstract philosophical construct and forced down everybody’s throat in the lyceum. It was developed because it appealed to the aesthetic sense. It appealed to the brain’s sense that such proportion and geometry was proper and correct. Jung applied the same ideas centuries later in his discussion of archetypal symbols. We have them, said Jung, because they appeal to a deeper level of ourselves, that part of our knowledge that does not reach consciousness, which is to say the majority of it. This is what we mean when we say that art speaks to the depths of our souls—it speaks to that greater formless part of ourselves of which we have no awareness.

Humans have a tendency to display an innate geometry. Although not as intense as the urge that children have to babble and acquire language, there also exists an inherent urge to draw. This visual urge is, I believe, universal. Children have a natural compulsion to scratch and scribble on the walls and elsewhere despite society telling them that they “shouldn’t” act upon these impulses. Society discourages this visual-manual geometry while encouraging linguistic murmurings.

#### 8.2.1 Color

All color in nature depends on an object’s surroundings. The sky that looks blue is composed of predominantly green and violet light. But if we look to the seemingly blue sky through yellow-green foliage, the color of the sky will appear to be purple with white. The same sky will look green seen through scarlet autumn foliage. This is known a simultaneous contrast. Colored shadows are an important example
of consensual illusions; we examine the neurophysiology of colored shadows in chapter 9 when discussing illusions and what is “real.” A telling anecdote about synesthetic painter, printmaker, photographer, and stage designer David Hockney is that in the spring of 1983 Hockney’s workshop was reproducing some photocollages for simultaneous exhibitions. He summoned his technician to complain that a particular print was inaccurate. “The color’s gone wrong here,” he said. “Can’t you make it darker?” The technician explained that the original prints had been incorrectly developed and that he was just trying to compensate “to make it look more like the true color.” Hockney scolded, “I don’t ever want to hear you say that to me again. There is no such thing as ‘true color.’ Duplicate the prints as they are in my original drawing. I’ve used their misprintings in building up the collage” (Hockney 1984).

We saw in chapter 6 that different components of vision are segregated into largely independent parallel pathways from the diencephalon onward. Different subdivisions of the visual system can be predicted by interactions of color, shape, depth, and movement in human perception. Cytochrome oxidase staining of area 18 (V2) shows alternating thin dark stripes, pale stripes, and thick dark stripes, each with distinctive physiologic properties. The thin dark stripes have high color opponency and are not orientation-selective; the thick dark stripes are selective for binocular disparity and orientation, suggesting that they are concerned with stereopsis (depth vision); and the pale stripes select for orientation, with more than half of them end-stopped. Furthermore, each of the three subdivisions receives a different input from area 17 (V1): the thin stripes from the blobs, the pale stripe from the interblobs, and the thick stripes from layer 4B (Livingstone 1987, 1988, 1990).

These neurophysiologic differences between subdivisions of the visual system predict that brightness contrast and color contrast contours should convey different types of information, and indeed artists have known this in their own terms. Vision is a multipartite process involving one system for shape perception, another for color perception, and still others for movement, location, and spatial orientation. They all differ in their contrast sensitivity, temporal resolution, and acuity. The color system has a three- to fourfold lower acuity than the form system does, for example. Therefore, colors can “bleed” off of shape boundaries, as often happens in watercolors, without interfering with the assignment of colors to objects in the image. This is, of course, the same thing that happens in hallucinations when color melts off object boundaries. Color can take on a life of its own, as we have seen over and over again in the various manifestations of synesthesia.

Color influences form, contour, and perspective—and vice versa. Edge detection, boundary, contrast, and depth are all modified by
color. We take many aspects of color perception for granted. Color illusions are quite easy to produce and should therefore disquiet us about what truly is “real.”

Borders, contours, and lines do more than just indicate the outline of objects: they can also determine how we perceive their three-dimensional shape, position, and movement. In this, the artist and scientist concur. Both the artist and scientist are aware, as the public or casual viewer is not, that although a contour formed by two vivid colors may be quite noticeable, it is remarkably ineffective in generating a sense of position, depth, or movement. A much stronger effect is achieved with two different shades of the same hue or even two shades of gray. In a common example, converging lines in a flat plane give a strong illusion of depth; stippling can give the impression of a three-dimensional object to a flat outline; and the apparent shape of the torso can be altered by lines in a garment that draw the eye along one direction. Although colored and colorless contours have a low and high ability, respectively, to generate a sense of three-dimensional shape, position, or movement, the identical contour can be more or less effective in generating these properties depending on what colors form the border. Margaret Livingstone has given demonstrations of this relationship (1987, 1988).

We see what our culture tells us to see. This gives rise to our many shared illusions, such as color constancy. Others are more culturally determined, and different cultures can literally perceive the world in different ways. The 1898 Cambridge anthropological expedition to Torres Strait found that the natives were not fooled by optical illusions that uniformly deceived Europeans. Our lives and behaviors are much more profoundly affected by the beliefs we hold unconsciously than by those we hold consciously, and processes of interpretation are also influenced by those beliefs. An example is the well-known experiment in which rapidly exposed playing cards with reversed suit colors are perceived as the subject normally expects them to be.

8.2.2 Olivier Messiaen (1908–1992)

Composers have been writing pictorial music for centuries, but no composer has, over such a long period of time or in such exhaustive detail, filled his music with passages specifically arising out of a study of nature’s colors and birds as has Messiaen:

Colors are very important to me because I have a gift—it’s not my fault, it’s just how I am—whenever I hear music or even if I read music, I see colors. (Hume 1979; italics added)

A trip to Utah came about when Messiaen accepted a commission to write a work in honor of the United States. Aux canyons des etoiles
was inspired by Bryce Canyon, “the most beautiful thing in the United States. The piece I composed about Bryce Canyon is red and orange,” says Messiaen, “the color of the cliffs.” That Messiaen’s synesthesia is bidirectional is evidenced from similar comments about his compositions wherein he speaks of translating colored landscapes into music (Samuel 1976 p. 93).

Olivier Messiaen was a brilliant organist for more than 47 years, professor of music at the Paris Conservatory, and considerably influenced twentieth-century music. Six decades ago he invented an original compositional tool, the “modes of limited transposition.” His works are so stylistically original as to be instantly recognized. Messiaen’s music consistently uses a polymodal form based on our chromatic system of 12 tempered sounds. He works with readily classifiable categories of sound. The harmonic logic behind his modes is consistent and it is “mathematically impossible to find other modes that follow the structural laws inherent in these” (Messiaen 1944).

The modes draw their special coloration from the fact that their harmonics are limited to a certain number of transpositions (hence the name). Through this device that determines the vertical spacing of notes, Messiaen succeeds in “putting wheels of color in opposition, and to intervening rainbows, finding complementary colors in music.” In chapter 1 of Technique of My Musical Language (1944), Messiaen explains some of the mathematics behind his rhythmic and harmonic structures in a section entitled, “The Charm of Impossibilities and the Relation of the Different Subject Matters.”

It is a glistening music we seek, giving to the aural sense voluptuously refined pleasures. This charm, at once voluptuous and contemplative, resides particularly in certain mathematical impossibilities of the modal and rhythmic domains. Modes which cannot be transposed beyond a certain number of transpositions, because one always falls again into the same notes; rhythms which cannot be used in retrograde, because in such a case one finds the same order of values again—these are two striking impossibilities … Immediately one notices the analogy of these two impossibilities and how they complement one another, the rhythms realizing in the horizontal direction (retrogradation) what the modes realize in the vertical direction (transposition).

In the nonretrogradable rhythms of the modes is found a highly detailed and self-contained mathematics. These modes cannot be transposed because they contain in themselves small transpositions; these rhythms cannot be retrograded because they contain in themselves small retrogradations. Finally, the last note of each group is always common with the first of the following group; and groups of these rhythms frame the central value common to each group. “The analogy is now complete … The impossibility to transpose the modes makes their strange charm. They are at once in the atmosphere of several tonalities, without polytonality. Their series is closed. It is mathematically
impossible to find others of them, at least in our tempered system of 12 semitones.”

Speaking of his listener, Messiaen says that to be charmed will be his only desire. That is precisely what will happen; in spite of himself [trying to inspect the nontranspositions and the nonretrogradation] he will submit to a strange charm of impossibilities; a certain effect on tonal ubiquity in the nontransposition, a certain unity of movement where the beginning and end are confused (because they are identical) in the nonretrogradation, all things which will lead him progressively to that sort of theological rainbow which the musical language, of which we seek edification in theory, attempts to be. (Messiaen 1944, chapter 5)

Messiaen’s synesthesia is bidirectional: music is color and color is music. He is absolutely convinced that his experience is valid. Indeed, he invented the modes precisely to convey music in color terms. Mode 2, for example, is a certain shade of violet, blue, and violet-purple, whereas mode 3 is orange with red and green pigments, spots of gold, and a milky white with iridescent reflections like an opal. Consequently he can speak of “color chords,” and a melody that has associated harmonies can be said to be “colored” by these harmonies rather than “harmonized” in the classic sense.

Movement 7 of his symphony Aux canyons des etoiles is titled “Bryce Canyon and the Orange Red Rocks.” That is, the music paints the color of the cliffs. As a Steller’s jay flies over the canyon,

his belly, wings and long tail are blue; the blue of his flight and the red of the rocks takes on the splendor of Gothic stained-glass windows. The music of this composition attempts to reproduce all these colors.

For the Steller’s jay, chords with “contracted resonance” (red and orange) … Chords with “transposed inversions” (yellow, mauve, red, white, and black) render the colors of the rocks … Next, polymodality superimposing the three 4-mode (orange-colored with red stripes) to the six 2-mode (brown, reddish, orange-colored, purple) bring to a fortissimo conclusion the sapphire blue and orange red rocks. (Messiaen, 1977)

When one understands that this is not metaphoric speech, not artistic license, but what he actually sees, then one can only marvel at what is going on in his mind. The modes are not harmonies in the usual sense of the word, nor are they even recognized chords. “They sound like colors.” To speak of an exact correspondence between a key or a conventional chord and a color is not possible because his colors are complex—he often speaks in terms of stained-glass windows—and they are linked to equally complex sounds.

It is also probably not possible to understand Messiaen’s music without acknowledging the intense influences of Catholicism and natural mysticism. Given the long history of color in religious symbolic painting, it is not surprising that Messiaen finds a “natural” mystic
symbolism in color. For example, his favorite color, violet, is complex “because it blends blue, an extremely cold color, with red, an extremely warm color. But violet is capable of many nuances.” The violet in which red dominates is called purple, and at the other end of the scale is a violet containing more blue than red called hyacinth blue. These two violets hold meaning: in the symbolism of Middle Age stained glass, according to Messiaen, the one represented Love of Truth and the other the Truth of Love. “This reversal of terms is certainly not just a play on words but corresponds without doubt very closely to these nuances of violet.”

Some think that Messiaen’s mysticism is expressed in his use of unusual instruments with prolonged resonance, such as gongs, tam-tams, the ondes martenot (an electronic instrument with a metallic timbre), the percussion instruments of the Balinese gamelan, and bells with their harmonic halos and overtones “which bring us close to some of the enormous and strange noises in nature like waterfalls and mountain torrents.” Such sounds capture the power and mystery of nature that so fascinate Messiaen. What sounds complicated in his music actually stems from a few ideas crystallized around his synesthesia and its intellectual refinement.

8.2.2.1 Predictive Musicological Analysis Musicologist Jonathan Bernard (1986) has demonstrated the correspondence between color and sound structure in Messiaen’s work through conventional musicological analysis. Color arises from the vertical spacing of notes. That is, chords formed by modal transpositions have characteristic spacing, and two different spacings of the same modal set correspond to two different colors.

To Messiaen, there is no such thing as a single note. He is always aware of the overtones and harmonics, especially in natural sounds such as wind, waterfalls, and birdsong that so often populate his compositions. Where you or I might hear one sound, Messiaen hears many within it. For example, what we hear as a single chord of pitch-class notation 2,2,2,7,8,6,4, Messiaen hears as many sounds. Conversely, inasmuch as his synesthesia is bidirectional, we see one color whereas Messiaen sees all the nuances so typical of synesthetes describing their colors “just so.”

Messiaen’s first public mention of synesthesia was a passing reference to “the gentle cascade of blue-orange chords” (Messiaen 1944, vol 1, p 51), even though he had been composing with the modes before age 20. Though his idiosyncratic color experience remains outside our ken, just as it does with any synesthete, the music to which his colors are attached is accessible. Messiaen’s associations are involuntary and constant, “suggesting that the relevant sonic characteristics are not
dependent upon the particular attributes of individual performances” (Bernard 1986). This fact requires the participation of transmodal tissue in synesthetic binding.

What separates Messiaen from ordinary persons with color-music hearing is that he has found particular sound-interval combinations that invoke a variegated range of colors, allowing him to “paint the visible world in sound.” Messiaen sees three types of colored sounds. The first is monochromatic, labeled simply “green” or “red,” for example. The second sound type is a bichromatic mixture described in hyphenated names such as blue-orange. The third is a more complex mixture of pairs (“gray and gold”), triplets (“orange, gold, and milky white”), or a dominant color that is “flecked, striped, studded, or hemmed” with one or more other colors.

The primary sources for these associations come from biographers (Samuel 1976; Goléa 1960), from copious notes that Messiaen wrote about his compositions, and from color notations written on the published scores themselves.

8.2.3 David Hockney (DH)

The British painter David Hockney (born 1937) (DH in table 2.2) was personally examined. He has synesthetic associations among sound, color, and shape. It was not, of course, evident in the paintings that made him famous, as these are “silent” works. Costume and stage sets for the Ballet de Marseille and Glynbourne and Metropolitan Operas revealed a new element in Hockney’s work due, in my opinion, to his synesthesia, given that he explicitly conceived his designs to the music. Certain comments by the artist made me suspect that he was synesthetic, a suspicion that was confirmed by later examination (September 11–12, 1981).

I find that visual equivalents for music reveal themselves. In Ravel, certain passages seem to me all blue and green, and certain shapes begin to suggest themselves almost naturally. It’s the music that attracts me to doing the set designs rather than the plot.

Unable to read music, he plays it over and over. “I’ll listen to the specific music constantly while I’m working,” says Hockney. The kinetic movement of his arm is guided by the music. In painting Ravel’s L’Entant et les sortilèges for the Metropolitan Opera in 1981, the “musical description of the tree in the garden has actual weight, like a tree has. I drew the form of the tree to the music. I painted the sets to Rossignol the same way—to the music.”

Like Messiaen, Hockney is an example of an innate talent within synesthesia that is modified by personal intellect and creativity. One finds in Hockney an extremely intelligent man who is a master of his
craft, has a firm sense of its history, and is above all else articulate enough to convey to the rest of us a sense of the process that permits him to translate his private synesthetic visions into moving public artwork.

8.2.3.1 His Synesthesia

Dear Dr. Cytowic:

I know it seems a long time to take to answer your interesting letter, but I have carried it out with me for a few months sometimes thinking of replying and then putting it off, then thinking I put it off for a good reason. Would it tell me anything—or do I really want to know, etc.

I must admit my first reaction to it was that you were trying to describe academically something I’d always thought and explained away as “poetic.” I’d never heard of synesthesia.

Anyway here I am replying to your note. Curiosity has got the better of me and so perhaps we could arrange a meeting. (8/10/81)

Hockney was not exposed to music as a child and he has no musical talent. “It wasn’t until I was forced to do something about it in 1974 with The Rake’s Progress.” Apprehensive about having to conceive a visual piece to accompany the opera score, he gave up trying to analyze the music only to realize he was experiencing something else. “But then it was largely involuntary and I do ‘get it,’ something clicks and all of the sudden you hear and feel more of the music.” In the Ravel, the tree music (of L’Enfant et les sortilèges) dictated its volume and weight. By this, Hockney means an expanse, a volume and visual area that corresponded to the physical shape of the music. He would actually paint with a long 3-foot brush, articulating at the shoulder rather than the wrist, while he listened, the music dictating his arm motions—the lines, curves, dots, and blots, as well as the color and overall dimensions. “In all operas I’ve done, the music gives me the set—the color and shape. In the [Stravinsky’s] Oedipus Rex there was not much color but lines and sharp things that suggested cross hatchings.” Note his reference to elementary configurations.

A pilot study was performed in Hockney’s home. This confirmed the existence of absolute and relative effects in a sound-color matching task similar to the one described in chapter 3. This forced-choice test used 120 trials for each stimulus. In the study with Hockney, however, actual Munsell color chips were used instead of verbal labels. In addition to the effect of single tones on color matching I examined melody by using major and minor arpeggios and triad cords. Cords are more like tones than they are like arpeggios; arpeggios are ascending tones strung together. Tones that were perceived as high tended to evoke reds, pinks, and yellows whereas the minor arpeggios showed a very restricted response and evoked blues and purples. For Hockney, the thing that most predicts a restricted response is melody. Thus, the pilot
studies seemed to confirm what the artist himself acknowledged, that the music itself, its melody, dictates shape, color, configuration, and movement.

8.2.3.2 Color and Space Once Hockney’s attention became focused on these issues as a result of painting stage sets to music, he became preoccupied with color and space in a new way. What Hockney wants is space in which one can walk around corners as distinct from the regimented single-point perspective that Canaletto, for one, relied on. The manipulation of space is possible through the use not only of color, which creates space for Hockney, but also of colored lights. Over the years, Hockney has experimented with increasingly complicated colored lighting systems. The best way to reveal Hockney’s thoughts on color, light, and form is to let the conversation speak for itself.

REC: You’ve taken some joking for your “light box,” which is actually a scale model of the Metropolitan Opera stage, complete with a colored lighting control system. You actually alter your design sketches while viewing them in the light box. Can you explain its importance?

DH: Not many people use color—real color—in the theater. If you’re going to use color then you have to have colored lights, otherwise you’ll never know what color to paint. You have to test it. I had that box made in London when we were doing the Ravel because of what happened when we were doing [Satie’s] Parade. When I finished the drops for Parade last year, John Dexter said “That’s nice, we’ll just put white lights on them.” I said “No. You put red and blue lights on them because that’s what will make it magic. That’s what will make it sing.” It took them some time to realize that I was right. In London, five months before we staged it, I lit it crudely, and then slowly we devised that machine so that I could time the color changes to fit the musical changes.

REC: Do you always work with the lights on your sketches?

DH: Constantly. I keep fiddling. Looking, listening, and playing with the lights and it simply takes you a long time because you keep hearing more and more in the music.

REC: During the matching task we did yesterday, you said that the “correct” color stood out when the music was played. How so?

DH: There’s a shimmer so that one of the colors stands out at the moment that the music is on. When the sound is coming, there’s an extra vibrancy to the color.

REC: A eureka feeling?

DH: Yes, an intuition that says “This is it!”

REC: Is this something that happens or are you deciding this?
DH: Well, it only happens when you look at this chart [the Munsell color chips]. It would be somewhat easier if these colors were bigger. If each color chip were a few inches big there would be a lot more of it and you could feel it more. It’s a special characteristic of color, that the more you see it the more there is.

REC: You’re the only one I’ve ever heard say that.

DH: I think it’s common knowledge. To make blue bluer you simply add more space to it.

REC: This chip is red to me whether it’s this big or this big. Its physical size doesn’t change the color of it.

DH: If you make it bigger you make it redder. I know there’s more of it, but it makes it seem redder. Light and dark is a factor, too. If it’s bigger, then you know it’s not dark. It becomes something else. Look at this color, which is much darker in tone than this one here. But if it was bigger, it wouldn’t be dark because there would be more of it and it expands it a bit and it’s not the same thing.

REC: So color can be used to control the sense of space?

DH: Blue has this quality to being spatial, which other colors do not. The more of it there is, the more you feel of it. I did the same thing with light and dark in Oedipus Rex.

At the end of the opera, Hockney projects gold light out onto the proscenium and the front of the house to incorporate the audience into the opera. Hockney’s hand outlines a cross in the air as the speaks.

DH: The music is like this—horizontal and vertical, very geometric. I projected the gold onto the side of the proscenium to give it incredible weight and to make it big. Boom, boom. The first quality of Rossignol that caught my ear was of transparency. I listened first. I don’t look at the score because I can’t read music. When I first heard it it doesn’t occur to you that it’s Chinese. What one hears is a transparency. It’s about transparent things, night, moonlight, water.

REC: Your set for Rossignol is also all blue, it’s monochromatic.

DH: But there are a lot of different blues in it. It’s not just all one blue.

(This infinite variety of a single color, the exactness of shade, is a typical synesthetic comment. The viewer does not notice the myriad nuances and merely perceives the design as blue.)

REC: How does the blueness fit in with the finished work of art?

DH: It’s the blueness and this sense of transparency that’s in the music that made me think of the very refined beautiful china of the 17th century. Not the overdone 19th century stuff with dragons, but much simpler, purer versions. I went to the Victoria and Albert Museum in London and in just two cases of pottery I took about 150 photographs.
and that's where the trees, mountains and people come from in the set. Since the three Stravinsky operas are all in some way ritualistic, each piece is united by a circle motif. John Dexter wanted a disc on the floor but I wanted a transparent blue circle. So I made it a blue china plate.

REC: What about revisions? How much of the color and shape comes to you from just hearing the music and how much do you bring to it by “intellectualizing” or intentionally revising?

DH: It’s like the shimmer with the color chips. I know visually when the color or the lines fit the music. We made about 10 palace drops for Rossignol and I thought “It doesn’t fit the music.” The lines weren’t right. Each time you listen, though, you hear more and more in the music. It’s very complex. In the end, it looks like Chinese Cubism to me, but it fits the music. It looks three dimensional, too, because I’ve painted it on black velvet. But actually it’s completely flat. Black has an enormous space to it. Once you grasp the illusion of three dimensions, you don’t scrutinize it.

We went through 27 versions of The Rite of Spring sets before they fit the music too. Most of the problem there, however, was getting the color right.

REC: You say that you actually paint while the music is playing.

DH: It’s very hard to describe because it’s ineffable. With Ravel’s tree music, for example, I remember drawing the lines of the tree to the music because it had a weight. You know how a tree has a volume and weight. I drew it during the music.

For Rossignol and the others it was the same. When I’m working on it I will play the music constantly. Normally when I work I do not work to music. I don’t like it as background because you find you either listen or you don’t. It could be trashy music—a little ballet or something, Swan Lake—where you wouldn’t be too distracted. But I couldn’t possibly work and listen to a Beethoven quartet. I couldn’t, because I would lose the lines of what I was drawing at the moment.

REC: Do you think it’s hopeless for you to give an example of hearing something and then saying “This is what I’ve drawn to that specifically”?

DH: The problem is, the first thing I draw would not be quite right. Although lot of times they are. I put this down to the fact that music reveals a bit more to you when you hear it over and over. There’s simply more there than you’ve thought at first.

See, you’re asking me to describe verbally feelings, which in art you sometimes don’t have to bother. You feel it. Verbalizing them is often impossible and unnecessary, of course. I’m not sure I would have thought about this at all except for the fact that you’re going to do this in the theater. You begin to think in ways you wouldn’t quite always
think about the music. Maybe a musician would always think this way, but I wouldn’t.

REC: Does the actual performance, the singing and musicians, influence the way your set looks to you?

DH: Yes, it works both ways. One has to be flexible, too, although I’m quite insistent on some points, particularly the color. There are many things to consider. You work with a director, and people have to move in your sets. John Dexter [the director] tends to make diagrams, that’s his style. I said “Ok, but I’ll make pictures of them since I like pictorial stuff.” Then you’re told that the chorus has to be there in the middle—36 of them—or they have to be in from the beginning. Well, that’s ruined my picture, I think. Then I think, well there’s no need to if you stick them in the middle right from the start, then you’ll forget about them. They’ll disappear. Then the musical people tell you there must be something behind the people otherwise you won’t hear the sound, and you know if it doesn’t sound right, it’s going to look hideous. And so there’s no point arguing. It’s very complicated.

REC: Let’s go back to your comment about Cubism. That Cubism is more real than reality and not just an intellectual idea.

DH: One-point perspective, like any photograph, is a view of the world from one exact point. It’s a Renaissance machine, a little hole that you look through—an unnatural way to look at things. We really don’t do that at all. You suddenly see that when you being to look at things—this table, for instance. Sometimes you see surfaces, the grain of the wood, the shine of your tape recorder, the blackness, it gets closer to the way you actually see things. It’s a jumble all at first.

When you draw, you tend to look at relationships—and this is what’s so difficult about drawing. You have to isolate a bit. A line of the table there, but while you’re doing that that’s all you’re looking at and you didn’t get the shape of everything else that’s in the peripheral vision. So what you finish up with in the end is not quite real. You sight in bits that weld into one, but the Cubist way is to look one place but you might be painting what something in the peripheral visual field looks like.

I’ve just begun to try to examine this. When you look, what is it you really see? If you draw quickly it forces you to look. I have many methods of drawing, it’s fascinating. I might be doing an academic drawing of a head. Well the moment you look into the eyes, the rest of the face goes away. Whereas when you draw quickly, you tend to be looking at the whole thing all the time. Of course it’s harder to draw quickly. It’s also harder to draw loosely, which is why people who can’t draw very well draw very tight, always. If you draw slowly, all the time it’s analysis. Whereas when you’re drawing quickly, you’re not really responding in an analytic way. You’re not quite sure what it
is you’re doing. Your hand and mind are responding to whatever ... It’s hard to say. Usually when you draw quickly a lot is hit and miss.

Line drawing is the hardest. I have to concentrate, it’s the most tense work. A few lines have to represent weight, texture, flesh, many things, usually without chiaroscuro. It’s quite tense, I love the exercise. You never discover how to do it. Every drawing is just as hard. When you’re doing line drawing you’re not consciously thinking how to do it, you’re thinking “What is it,” trying to find out what’s there—there’s so much there—you’re trying to throw away an awful lot. All drawing is throwing away, isn’t it? You’re always drawing much less than what is there. It’s hard to find essences. Good drawing is knowing what to throw away.

For Hockney, not only does color create space but sound does as well. Even one’s own hearing gives a sense of personal space (see §5.2) and perhaps his gradual loss of hearing in recent years has triggered his preoccupation with creating new types and visual space in his photographic collages (Hockney 1984). His art has shifted from painting to assembling large “cubist”-style pictures made from collages of smaller snapshots. Hockney distrusts photography’s claim of greater reality and authenticity. He believes photographs are extremely untrue. It is not just that lines bend in ways that they never do when one looks at the world. Rather, the eye never sees so much in one glance. Photography’s panorama is not true to life. One can paint with a camera, however, and this is what Hockney does in using small single-point perspective photographs to create a larger image with multiple focal points.

Ordinary photography is obsessed with subject matter, whereas his photocollages are about the way items catch the eye. Ordinary photographs present a world from which details can be elicited. Hockney suggests that this is the opposite of how we actually see the world. The general perspective is built up from hundreds of microperspectives. Vision is a continuous accumulation of details perceived across time and synthesized into a larger, continuously metamorphosing whole.

His photocollages explore the creation of deep space out of bits of pictures containing shallow space. A Mohave Desert landscape, for example, telescopes 900 yards of road, cacti, litter, and street signs into an image that seems everywhere in focus in front of the viewer. “In that picture, there was only one photograph that actually depicts space. Every other picture was made holding the camera close to the surface, almost parallel to it. And yet it looks like a landscape full of space. There’s something happening that’s a bit weird.”

The urge to depict and the longing to see depictions is very strong and deep within us. It’s a 5,000-year-long longing—we see it all the way back to the cave paintings—this need to render the real world. Art is about correspondences—making connections of the world and with each other.
The refinement of Hockney synesthesia by his intellect and skill had led him to see and develop such connections.

8.3 DELIBERATE CONTRIVANCES

One supposes that an aesthetic based on synesthesia can be only marginally meaningful to a general audience. Literally caught off the artist’s personal vision, we can appreciate such works sympathetically but without fully understanding their inspiration. This hardly means that the artworks are unable to move us, for they certainly do, and music, perhaps more than any of the arts, easily transports us to that transitory and mystical change in self-awareness that is known as ecstasy. Ecstasy is simply any passion by which the thoughts are absorbed and in which the mind is for a time lost. In *The Varieties of Religious Experience* (1901), William James spoke of its four qualities of ineffability, passivity, noesis, and transience. We should note that these are also qualities of synesthesia.

Whereas some color-music compositions stem from true synesthetic experience (Critchley 1977; Wood 1936; Messiaen 1944), others are wholly made up or deliberately contrived (Jewanski 1999). These latter include compositions by Alexander Scriabin (*Prometheus* [1911] and the never completed *Mysterium*), Sir Arthur Bliss (*Color Symphony* [1922]), and Kandinsky & De Hartmann (*Der gelbe Klang* [1912]). Though colored music is not without intrinsic interest, the notion that color and music can be translated into each other rests on the fallacy that a universal translation algorithm among sensory modes exists. Moreover, mixed media is not a modern invention. Odorama, smellavision, son et lumière, and laser light shows all have their historical place.

Just as there are deliberately contrived sound-color compositions, so too have painters been inspired by music. *Music—Pink and Blue II* (1919), by Georgia O’Keefe, is such an example. O’Keefe created a series of pictures inspired by music, yet they are inspired rather than synesthetically dictated, and the distinction needs emphasizing. O’Keefe was influenced by Wassily Kandinsky’s *On the Spiritual and Art*. Without knowing the directness of synesthesia, she discovered by a more circuitous route that colors could convey psychological and emotional states of mind. Her convictions about the expressive power of abstract art are clearly stated in a letter from 1930.

I know I cannot paint a flower. I cannot paint the sun on the desert on a bright Summer morning but maybe in terms of paint color I convey to you my experience of the flower or the experience that makes the flower of significance to me at that particular time. (O’Keefe 1987)

Both synesthesia and the artistic experience are ineffable, and both indescribable by language.
A discussion of sound symbolism and synesthetic metaphor in poetry is beyond the scope of this chapter. Such a discussion can be found in Marks (1978, chapters 7 and 8), and general discussions of literary synesthesia can be found in Adler (2001). In the Orient, synesthesia is understood exclusively as a literary trope, the perceptual phenomenon being entirely unknown. Japan’s most celebrated haiku poet, Matsuo Bashō (1644–1694), repeatedly employed synesthesia to merge diverse sense qualities. It is an effective device for presenting an experience in its totality compared to the scientific method, which breaks the whole into its component parts. In part due to cultural forces, literary synesthesia in Japan presumes an attitude that accepts the ultimate interrelatedness of all things (Ueda 1967). The following haiku merges three sensory modes:

*Kane kiete*  
As the bell tone fades

*Hana no ka wa tsku*  
Blossom scents take up the ringing

*Yube kana*  
Evening shade

Here, Bashō describes the reverberating sound of a fading bell as it merges with the fragrant perfume of flower blossoms, which in turn blends with the shadowy darkness of evening shade. The Japanese verb *tsuku*, meaning “to strike” or “to ring,” is juxtaposed with the phrase *hana no ka*, or “scent of blossoms,” in such a way that the cherry blossoms are said to “ring their scent” (Odin 1986). This treble fusion calls to mind Baudelaire’s statement in “Correspondences,” that *Les parfums, les couleurs et les sons se répondent*.

The idea of contrived synesthesia is found in the invention of Zoltán Kodály (1882–1967), the Hungarian composer and educator, even though Kodály himself had colored hearing. Kodály invented a method of teaching music to deaf students by the use of hand signs, each hand position representing a note value. Popularly, this auditory-manual yoking surfaced in the film *Close Encounters of the Third Kind*, in which an alien spaceship visits Earth. The alien message is a melody coupled with colored lights that emanate from the ship. The earthlings respond by parroting the melody and colors even though they have no idea what they are “saying.” At last, a wise scientist uses Kodály’s formula for sound and hand motions, and deciphers the message as a gesture of greeting and a handshake.
We do not recognize the “color” of certain wavelengths that stimulate the eye, as is so often said. If we did, an object’s color would change continually as the illumination changed (this is the puzzle of color constancy). Rather, we perceive the permanent properties of colored surfaces under varying illumination: what remains constant under shifting lighting is an object’s lightness compared to everything else in the spatial surround. An object’s lightness does not depend on the flux of energy reaching the eye. Edwin Land (inventor of Polaroid) elegantly demonstrated that constant color depends on a comparison of an object’s three relative lightnesses in short-wave, medium-wave, and long-wave radiation; because they are constant, color is constant whatever the illumination.

The nervous system therefore constructs one stable aspect—the reflectance—from a constantly varying aspect—the total flux of electromagnetic energy reaching the eye. The result of these operations is the construction of a colored surface from the spatial surround. Color turns out to be a property of brains, not a physical property of the world.

9.1 SEEING AND REALITY

The reality of seeing; the seeing of reality. Both are topics that come readily to mind on considering the overlaps among synesthesia, hallucinations, illusions, and imagery. Though such conditions often display a common cognitive structure, what the various overlaps show is that the function of seeing is not limited to vision.

Astute humanists have commented on this, an example being Aldous Huxley’s *The Art of Seeing* (1942), a book that describes Huxley’s blindness following punctate keratitis at age 16. It chronicles Huxley’s developing awareness of the ancillary nonoptic aspects of vision, particularly in his chapters, “The Mental Side of Seeing,” “Memory and Imagination,” and “The Variability of Bodily and Mental Functioning.” He appropriately chastised the ophthalmologists who gave him spectacles and wrote him off as permanently blind. The book illustrates
how dogma squelches the very creativity that is often the basis of much scientific discovery.

Those who still claim that the subjectivity of experiential phenomena is somehow “unscientific” should note that the array of objective physiologic changes that accompany perception include galvanic skin resistance; pupillary adjustment; variation in temperature, pulse, and respiration; and electromyographic bursts. The bulk of these are evidently efferent manifestations of the autonomic nervous system. EEG, rCBF, PET, fMRI, and so forth have measured objective change during experiential states.

There are no such things as sensory data. Although the term “sense data” suggests immediacy, perception is the outcome of a most elaborate interaction between a stimulus and the apparatus of the brain. A visual experience is hardly a perfect replica of the retinal image: immense series of interactions begin there and continue through stages, building in complexity such that hypercomplex cells—feature detection neurons—respond only to certain geometric shapes, line orientations, or other highly specific attributes of a stimulus. However, this does not reach consciousness as far as we understand vision; besides, the scientific enthralment with feature detection neurons gave way to an equal excitement over binding, then 40-Hz oscillations as the basis for perception. This, too, will surely give way to some newer discovery. We really do not understand how all these details come together. Perhaps we keep forgetting that the majority of data or knowledge that we have does not reach consciousness (Kihlstrom 1987; Rizzo & Hurtig 1987). The neuron is a storyteller that accentuates some features, completely ignores others, and is our fragile link to the physical world.

We begin our essay into reality and unreality by looking at two illusions so common that only painters can avoid taking them for granted. We next examine the retinex theory of color vision, which shows that the identical flux of radiant energy reaching the eye can be perceived as different colors. Phantom vision and blindsight remind us that visual perception does not require striate cortex or even photoreceptors, and that the system can “go on its own.” A review of optic imagery is followed by a discussion of microgenetics, a grand theory that is able to unite much of this material.

9.2 COLORED ILLUSIONS: COLOR CONSTANCY AND COLORED SHADOWS

People commonly believe that color is determined by a physical cause, namely, the spectrum of the light falling on the retina. The mistaken belief is that the eye, like a color television camera, senses the redness, greenness, and blueness at every point by measuring how much energy there is of long wavelengths, medium wavelengths, and short wave-
lengths, respectively. Laboratory demonstrations wherein observers see one color when in fact they “ought” to see another are usually taken as proof that the eye does not work as well as it should based on the construction of its photoreceptors.

The correct explanation for color illusions, therefore, is that conventional theories are wrong if they are violated so easily and consistently. The color of objects does not depend on the spectral color of light reflected from them. Once we understand that color can be dissociated from the visual means by which we see an object and determine its shape, we can then see how color can exist separately in synesthesia and be attached to nonvisual objects with which it is not normally associated. In other words, color is quite independent of object vision.

9.2.1 Color Constancy

The most common perceptual illusion is the apparently constant color of objects in daylight. This helps put the notion of reality into perspective. Reality is relative. The constant appearance of objects under widely varying conditions of illumination, intensity, and wavelength distribution is a well-known psychophysical issue, has an abundant literature, and is a central theme in understanding how we see (Hunt 1967; Katz 1935; Helmholtz 1866/1967; Bartels & Zeki 2000).

Daylight is not fixed. It changes in brightness from dawn, to its apex at noon when the sun is directly overhead, to dusk. The full moon (0.3 lux) is $3 \times 10^{-6}$ as bright as the midday sun, yet the nervous system can adjust its sensitivity so that we see effectively in either condition. We can detect, in fact, the flash of a single photon (Abell 1969). Few people seem to notice that daylight also varies considerably in its spectrum. It shifts 200 nm depending on the angular distance of the sun from the horizon ($0^\circ$) or the zenith ($90^\circ$) (figure 9.1) (Henderson 1977; Judd, MacAdam, & Wyszecki 1964).

The morning light is reddish, the afternoon sun distinctly yellow-orange. The indirect northern light favored by painters peaks in the blue part of the spectrum. In the springtime woods when there is new leafy growth, the light is bright yellow-green; later in the summer when the leavens darken, the light shifts to the green part of the spectrum; in a coniferous glen it appears more blue. Added to these fundamental changes in intensity and spectral shifts are the sun, the sky, moisture, and particulate matter—all sources that make defining daylight a problem. At any one point it is a mixture. Light is scattered, refracted, and reflected. In spite of this dynamic quality of daylight, a piece of paper always looks white, an apple red, and a banana yellow. This is called color constancy.

I mentioned that artists seem to be the only earthlings who observe this daily dynamic. Artists know that color constancy is an illusion; the
Daylight from sunrise to sunset varies considerably in both brightness and spectrum. Consequently, objects viewed at midday reflect more blue light than when seen in the evening, when they should appear redder. The four curves chart the spectrum at four times of day, when the sun is at various angular distances between the horizon (0°) and the zenith (90°). The 8° curve was measured half an hour before sunset: its peak at 660 nm is deep in the red part of the spectrum. Hours earlier, when the sun is high in the sky at 70°, the light’s peak is some 200 nm shorter, well into the blue part of the spectrum. Although the colors of illuminated objects vary throughout the day, most people perceive them as the same at all times. (From Henderson [1977], with permission.)
public does not. For example, Claude Monet labored during the impressionist movement, which professed scientific interest in how light refracts, reflects, and impinges on the eye. One of his exercises was to paint the cathedral of Notre Dame at different hours of the day to show how the color of the façade and the entire ambiance changed. Even today, many people respond as Monet’s public did, thinking that he was depicting his emotional response to the cathedral at different times and not understanding that he was simply trying to paint it the way it looked. This insensitivity to color change is not a recent phenomenon that accompanied the advent of electric light. Color theory is hardly taught in formal art training any longer or discussed in current texts on vision. Brou & colleagues (1986) suggest a reason why we overlook the phenomenon. Living most of our modern life under artificial illumination,

we have become inured to the experience that faces and cosmetics, for example, change color between incandescent and fluorescent lighting. The constancy is so reliable that one routinely compares by memory the face color and lip color of someone who now stands under one form of daylight with the color seen an hour ago, a day ago, a week ago, and under another form of daylight, and thus detects changes due to blushing or paling or signifying disease such as jaundice (which turns the skin yellow) or anoxia (which turns it blue). Such changes are much smaller than possible changes in daylight color. It is as if, in the words of the 19th century physiologist Hermann von Helmholtz, we “discount the illuminant” when we perceive color.

We of course cannot discount the illuminant since we cannot know what light illuminates a surface; the eye receives only reflected light. We are only aware of the consequences of many processes applied to the flux of energy that reaches the brain. This is one reason why the analogy of the eye as a television camera is poor. Once we have a different understanding of the psychophysical basis of color perception we can appreciate how the perception of color can be detached from object shape and exist independently or, as we might say in synesthesia, incongruously with other objects.

Consider the problem of visually distinguishing objects in your environment. Imagine yourself in a natural setting such as the woods or a rock-strewn canyon. The objects are randomly distributed and reflect light according to their material composition and surface textures. The task for detection is to distinguish one boundary from another because two or more common regions bound a region of interest in the image, and it would be helpful for the change in light across one boundary to predict a property across other boundary segments. This is the problem of perceiving shape and configuration.

Color vision operates under dynamically changing daylight, varied reflectance, and diverse boundary arrangements. Color vision helps us
tell surfaces apart by supporting many more distinctions than monochromatic vision could. Because variable distinctions are a meaningless signal equivalent to noise, fidelity and uniqueness increase through color constancy. If boundaries changed simply because the illumination changed, we would be much less able to distinguish one thing from another. Our ability to distinguish shape would also be impaired, given the strong link between color and shape perception. In the everyday world, color constancy operates almost perfectly (Hurlbert 1999; Foster, Amano, & Nascimento 2001).

Reflectance is a quality both intrinsic to a surface and independent of the variables that cause the dynamic variations of daylight. It is the ratio of incident light to reflected light. Unfortunately, the eye receives only the latter and, if one adheres to the old-school dogma that color depends on the light reflected from that surface alone, then reflectance is useless in determining color. If surfaces are similarly illuminated, comparisons of adjacent surfaces will therefore be independent of incident light. This comparison is equivalent to comparing adjacent reflectances, which are individually unknowable. Brou et al. (1986) have devised computer color displays to illustrate this.

In sum, what color constancy shows is this: surrounded by boundaries that are ordered chromatically, identical colors will appear different. Exchanging one boundary for a small area that has marked spectral dissimilarity will induce the perception of color constancy.

9.2.2 Colored Shadows

The phenomenon of colored shadows may be thought of as the opposite of color constancy. If we think of them at all, we think that shadows are gray or black, whereas in reality they are always colored, taking on the complementary color of the lighted side. For example, if a colored light illuminates an object’s left side and a white light illuminates the right side, the shadow cast by the object blocking the colored beam will not be colorless, even though it contains only white light. The shadow’s color will be the complementary color of the colored light. The effect is striking.

If you photographed this experiment using colored lights from various parts of the spectrum and then compared the photos, the shadows would appear different, as expected. However, by masking the shadows’ surround (which consists of colored light), you would be surprised that the shadows now look identical. This indicates that boundary and color perception are intimately related, suggesting that if you were to perceive a boundary, then an experience of color might follow, as in synesthesia (recall figure 4.3).

In both color constancy and colored shadows, the color you attribute to a light is different from what you know it “really is.” It is different
from what the physical properties of the light lead you to expect and to predict. In color constancy, different spectral distributions have the same color; in colored shadows, identical spectral distributions have different colors. To rephrase this, the same stimulus looks different (colored shadows) or different stimuli look the same (color constancy).

You could sit on your patio and talk about the lawn furniture. "Yes, I can see that the dawn’s early light is rosy and quite different from the golden glow of teatime, but my chaise longue is still yellow. It doesn’t change with the color of the daylight because its yellowness is a physical property of the petrochemicals that make it up. You can change the light all you want, even put a pink spotlight on it at night, and it won’t change the fact that I know in my mind that it’s yellow. It is a real solid physical object and real objects don’t change."

This insistence, in which the mind refuses to acknowledge what the senses inform it, shows how firmly ingrained is the illusion of color constancy.

It is easy to insist that any apparent color change in the chaise is "just an illusion," which is precisely what Monet’s audience thought of his paintings of Notre Dame cathedral. Everybody knows that the stones of the cathedral, being "real objects," cannot change their color. It is difficult to grasp that the color is in our brains instead of being an untransmutable property of the bricks and mortar.

These examples show that daily experience is a fluid challenge of color constancy and colored shadows, illusions so firmly ingrained that most people fail to accept the illusory quality even when confronted with the facts. Only the artist seems undisturbed at the endless variation of color and takes the physical world at face value. Paradoxically, it is the artist rather than the staunch objectivist who views the world as it "really is."

In sum, boundaries determine color or a change in chroma. We know since the nineteenth century that if the eye is immobilized so that the image cast on the retina does not move, then the subject is unable to see within about 2 seconds, the maximum time for retinal adaptation. A fundamental principle of neurophysiology is that neurons signal change rather than a steady state. Normally, the eyes are in constant movement (called ocular jitter) and the photoreceptors thus constantly detect boundary changes. In mammalian vision, the retinal cones are very early elements in a series of neural apparatus that builds in complexity. Exploration of the retinex theory will add to evidence already given that color and shape are dissociable and subserved by different neural mechanisms.

9.3 RETINEX THEORY OF COLOR VISION

Those who do not believe their senses may feel better about the "objective reality" of scientific measurement. For such individuals, the
numerical values of the retinex experiments should be more disturbing than were the visual examples of color constancy.

Spectrophotometers cannot categorize color; only brains can do that. When viewing experiments that illustrate the principles of color constancy and colored shadows, one is tempted to ask. What color is it really? as if the eye were being fooled. The eye is not being fooled but is functioning, as Land puts it, “exactly as it must with involuntary reliability to see constant colors in a world illuminated by shifting and unpredictable fluxes of radiant energy.”

Because we all agree about the colors of objects, even down to the ability to match Munsell chips whose colors differ minutely, we assume there must be a stable physical property in a one-to-one correspondence that determines the color. This is not the case. It then seems a mystery how we can precisely agree on the colors we see when no obvious physical quantity exists at a given spatial point enabling us to specify an object’s color. Straightforward experiments make it abundantly clear that the stimulus from which the color of a point is calculated is not the radiant flux from that point. The psychophysical basis of color lies elsewhere. Once this is understood, the detachment of color (or shape, or any other sensory derivative) in synesthesia does not seem so bizarre.

9.3.1 History of the Study of Color

Newton (1730) stated, “Every body reflects the rays of its own color more copiously than the rest, and from their excess and predominance in the reflected light has its color.” Thomas Young (1802) suggested that there were three kinds of receptors with three different spectral sensitivities, and that their response at a point determines color at that point. His first idea was correct, but the second was not. Three kinds of receptors do exist, but they do not act together at a point, as is explained below.

The beauty of the physical world is fully matched by the beauty of the neural mechanisms that subserve vision and its derivative aspects. Land’s experiments in color vision (1959) and the retinex theory of color vision (Land 1974, 1977) are incontrovertible proof that the perception of color is not a property of what we usually call “the color” of light.

Newton separated sunlight into the spectrum with a prism in 1660. He even reversed this process by gathering the colored beams together with a second prism to reconstruct white light. This does not mean that color perception is a property of the spectrum of light. One of Newton’s experiments was to recombine only parts of the spectrum using a slit to cut off all but selected bands. When two such separate bands recombined on a screen, the color that appeared was one in between the
spectral bands that Newton was mixing. In 1959, Land re-created this classic experiment. When he placed slits just inside the ends of the yellow bands of the spectrum, the yellowish beams combined on the screen to produce, in agreement with Newton, yellow light.

Land then modified this demonstration by placing black-and-white photographic transparencies of a scene of various colored objects in front of the slits. The transparencies contained no color, of course, only lighter and darker areas formed by black silver grains on transparent celluloid. The two transparencies, however, were not identical. One was taken through a red filter and the other through a green filter. This caused some objects in the scene to be lighter or darker in one transparency compared to the second. All either transparency could do, however, is pass more or less of the light falling on its different regions.

When the yellow beams passed through these transparencies and fell on the screen, the result was not yellow, as in Newton's experiment. Instead, the original colored scene appeared with a full array of colors, including black and white. This straightforward experiment forces the counterintuitive conclusion that the rays themselves do not make the colors. At most, they can only carry information that the nervous system uses to perceive as colors of the various objects in the image. We can see that Aristotle was wrong about color being an absolute sense “peculiar to vision.” Color appears to be more like an Aristotelian common sense that can exist independent of vision, as it does in synesthesia.

Land found that the flux of radiant energy reaching the eye determines neither a colorless nor a colored image. The ability of the eye to discover lightness values independent of flux is convincingly demonstrated when only a single category of photoreceptors—the colorless rods—is operating. Whereas the initial electroretinogram signal is proportional to the light flux absorbed by the visual pigment, the final summated response is “lightness,” which bears little or no relation to the radiant flux absorbed. Inasmuch as processing flux to generate lightness could occur in the retina, the cortex, or partially in both, Land coined the term “retinex,” a combination of retina and cortex to describe the ensemble of biological processes that convert flux into a pattern of lightness.

The three retinal-cortical systems each form a separate image of the world. These images are not mixed, but are compared. Each system must discover independently, in spite of the variation and inability to know the illumination, the reflectance for each band of wavelengths to which that system responds. “A retinex employs as much of the structure and function of the retina and cortex as is necessary for producing an image in terms of the correlate of reflectance for a band of wavelengths, an image as nearly independent of flux as is biologically possible” (Land 1974, 1977). Land’s retinex algorithm is a model of human color constancy.
9.3.2 Research on Lightness

It is worth going into Land’s work in some detail. We have already looked at the common but erroneous belief that the spectral colors discovered by Newton are the colors of the world around us. Examining color constancy and colored shadows showed that objects in the world are unevenly illuminated. If the photoreceptors behaved like spectrophotometers (i.e., as intensity meters with peaks in three different parts of the spectrum) the color of objects would change dramatically from one part of the field to another, and they would also change in relation to one another as the illumination changed. The fact that colors remain constant indicates that photoreceptors do not operate this way. The redness so evident in daylight film that is exposed in tungsten light never bothers us when we step indoors to tungsten-lit rooms. Our nervous system does not perceive the extra red because it does not depend on the flux of radiant energy reaching it to perceive color.

Land discovered the constancy of lightness values by first examining images completely devoid of color. The rod cells respond to light $10^3$ times weaker than that required for cone reaction and can function in isolation upon donning neutral-density goggles that reduce the incident light by $3 \times 10^4$ (Hecht & Hsia 1945). After a half-hour dark adaptation, a colorless world emerges, with an effective illumination of $1/1500$th foot-candles. Objects exhibit a range of lightness from white to black and maintain this relative lightness as they are carried into regions of higher or lower flux. In fact, the illumination can be easily altered to yield more flux from a region that continues to look very dark than from a region that looks light, whether viewing real objects or a montage of light and dark papers. In such a collage of various lightnesses (whether colored, black, white, or gray papers), the lightness of any element is not appreciably modified by relocating it to a new surround. Thus, the rod system is unable to generate a colored image, but does yield one in terms of lightness.

McCann & Benton (1969) performed an experiment using two narrow-wave bands at 550 and 656 nm with levels adjusted so that only the rods and one of the cones (long-wave) received enough light to function. The result was similar to the multicolored images produced by Land’s duplex red-and-white system. McCann & Benton’s experiment showed that lightness information collected at two wavebands by separate receptor systems is not averaged point by point or area by area, but is kept separate and compared. Neither system alone (the rods nor the long-wave cones) can produce colors. The appearance of a variety of colors in this setup (mainly reds, browns, yellows, blue-greens, grays, and blacks) suggests a process operating somewhere in the visual pathway that compares the lightness of separate images provided by the two retinex systems. When three independent images constitut-
ing the lightnesses of the short-, middle-, and long-wave sets of receptors are compared region by region, the full spectrum of color emerges. According to Land, the reason that the color at any point in an image is essentially independent of the three fluxes on three wavebands is that the color depends only on the lightness of each waveband, and the lightness is independent of flux. The three lightnesses of an area determined by the three retinex systems is all that is necessary to characterize the color of any object in the field of view. For every trio of lightnesses there is a specific and unique color (some of which are not found in nature).

That this is so is shown by Land’s “color Mondrian” experiment. This experiment uses two boards 4.5 feet square identically covered with about 100 pieces of paper of various colors and sizes. These Mondrians, named after the Dutch painter Piet Mondrian, whose art the collage resembles, are arranged so that any piece of paper is surrounded by five or six papers of different color. (See figure 9.2 for further details of the setup and measurement of the triplets of energy fluxes reaching the eye.) A computer model of Land’s Mondrian retinex experiment has recently been created (Romaya 2000).

The point of the Mondrian experiment is this: for any two colors that can be viewed simultaneously, the setup can be arranged so that each color sends the identical triplets of energies to the eye. The Mondrian experiment demonstrates that color sensation is not related to energy (reflectance times illumination) even though that is the only information reaching the eye from the various areas of the Mondrians. The Mondrian experiment is an in-depth investigation of color constancy. Radiant flux that reaches the eye is irrelevant to the sensation of color. Instead, it is the quality of lightness, which is perceived differently at each of three wavelengths, that ultimately determines color perception. It therefore makes no sense to speak of “color” reaching the eye.

9.3.3 The Retinex Theory

Is there a physical correlate to the lightness of objects on three separate wavebands? The Mondrian experiment shows that each retinex system forms its own lightness image of the world. The images are not mixed but compared, and a comparison of lightnesses at each area gives rise to the range of sensations known as color. The physiologic embodiment of Land’s mathematical explanation could take various forms.

Imagine two light detectors positioned to measure the luminance at two different places on a sheet of white paper lighted strongly from one side. Given that the illumination is not uniform, the luminance measured by each detector will be different. As the detectors move toward each other, the luminance measures become equal and their ratio approaches 1. Now imagine any other hue next to the white. As the
two detectors bridge the boundary between the two areas that differ abruptly in reflectance, the ratio of the outputs of the two detectors approaches the ratio of the two reflectances. This single process of taking the ratio between two adjacent points both detects an edge and eliminates the effect of nonuniform illumination. (See figure 4.3 regarding edge detection based solely on nonuniform illumination.)

The entire visual field can be processed as ratios of luminance of closely adjacent points, generating dimensionless numbers that are independent of the illumination. Land constructed a computer program

Figure 9.2 (A) Equipment set up for Land’s “color Mondrian” experiment. The experiment employs two identical sheets of colored paper mounted on boards 4 1/2 feet square. The colored papers have a matte finish to minimize specular reflection. Each Mondrian is illuminated with its own set of projector illuminators equipped with bandpass filters and independent brightness controls so that the long-wave (red), middle-wave (green), and short-wave (blue) illumination can be mixed in any desired ratio. A telescopic photometer can be pointed at any area to measure the flux, one waveband at a time, coming to the eye from that area. The photometer reading is projected onto the scale above the two displays. In a typical experiment, the illuminators can be adjusted so that the white area in the Mondrian at the left and the green area (or some other area) in the Mondrian at the right are both sending the same triplets of radiant energies to the eye. The actual radiant energy fluxes cannot be re-created here in this black and white reproduction. Under actual viewing conditions, the white area continues to look white and the green area continues to look green, even though the eye is receiving the same flux triplets from both areas. (From Land [1977, p 111], with permission.)
to do just this and detect edges by calculating lightness (McCann, Land, & Tatnall 1970). The location of the biological counterpart is unknown but calls for an arithmetic that covers the entire visual field, does not depend on eye movement, and can be seen in pulses of light less than 0.1 second in duration (Land 1986).

Looking at actual retinex records, you would see large differences in lightnesses for most of the objects in the short-wave photograph and the photographs representing either of the other two systems. Yet, Land pointed out, it is the comparatively small differences between the long-wave and middle-wave lightnesses that produce the experience of vivid reds and greens. Perceived lightness changes little with enormous changes in flux. This responsiveness to small differences in lightness can also explain the color seen in highly unnatural situations: a spotlight in a void and Newton’s spectrum produced by a prism. Of interest is what color the light is when surrounded by an area devoid of light. It turns out that the narrow band of 600 nm will produce the sensation of reddish orange, a color not ordinarily perceived. Interestingly, Ramachandran & Hubbard’s (2001, in press) subject SS sees “weird” synesthetic “Martian colors” that are “extra-spectral.” That is, they don’t exist in the real world, only in response to graphemes and faces. The retinex theory explains the anomalous display of the spectrum as a series of three laterally displaced continuous gradients that share properties of both spots and areas. It is possible to predict colors of the spectrum from these properties, whereas the color Mondrian experiment demonstrated straightforwardly that it is impossible to assign a

Figure 9.2  (B) Physics of Land’s “color Mondrian” experiment. Identical energy fluxes at the eye provide different color sensations in the Mondrian experiments. In this example, with the illuminants from long-wave, middle-wave, and short-wave illuminators adjusted as indicated, an area that looks red continues to look red (left), an area that looks blue continues to look blue (middle), and an area that looks green continues to look green (right), even though all three are sending to the eye the same triplets of long-, middle-, and short-wave energies. The same triplets can be made to come from any other area: If the area is white, it remains white; if the area is gray, it remains gray; if it is yellow, it remains yellow; and so on. (From Land [1977, p 122], with permission.)
specific spectral composition to the radiance from a colored area in everyday life.

One might object that psychophysical evidence exists supporting an individual photoreceptor’s restricted spectra as well as its independent processing. For example, in the goldfish, long-wavelength light depolarizes horizontal cells whereas middle-wavelength light hyperpolarizes them (MacNichol, MacPherson, & Svaetichin 1958; Svaetichin 1956). Monkey lateral geniculate cells have receptive field center responses to one particular spectral region with antagonistic surround responses to a different spectral region. Color opponent cells also exist among ganglion cells (DeValois & Pease 1971; Wiesel & Hubel 1966). Lastly, goldfish ganglion cells and primate cortical cells contain complex double-opponent members (Daw 1972).

Such results may suggest that opponent processing, analogous to transmission of color television signals, operates in human color perception. A television camera uses three vidicon tubes, each responsive to one spectral region and each measuring the light intensity at every point of an image for each waveband. A color television receiver has three electron guns for each of the three color-emitting phosphors. However, what gets transmitted from the TV station to individual receivers are not three independent signals, but signals that are encoded by a system similar to the opponent processing first suggested by Hering (1964). Although the analogy is useful in illustrating how opponent processing can transmit signals over a distance, it is poor in that television detects, transmits, and reproduces an equivalent set of radiances on the face of a cathode ray tube. A color television does not reproduce color sensations; only a living visual system can sense color. The signal transmitted to the cortex correlates with an object’s reflectance, not the radiance that the photopigments absorb. Contrary to earlier research, the goldfish turned out to be a useful retinex model (Ingle 1985), and an analysis of opponent-color mechanisms is useful to understanding color constancy (Nieves, Garcia-Beltran, & Romero 2000).

The retinex theory originally suggested that reflectance calculations could take place in either the retina or the cortex. Subsequent research, largely in brain-damaged patients, has addressed the location of the retinex system and other details of its neural basis. Two facts are clear at the outset: that the retinex theory explains color constancy, and that computations for color perception occur across large distances in the visual field. Exploring binocular color interactions across the corpus callosum, Land & colleagues (1983) determined that the cortex was a necessary element for long-range color computations. Patients with unilateral parietotemporal lesions on either side showed that the neural circuitry mediating color constancy is independent of those for discriminating color and assigning color to objects (Ruttiger et al. 1999). Lastly, psychophysical and fMRI studies in a nearly blind person who retained
conscious perception of color determined that color constancy was severely defective and that color perception was wavelength-based. Cortical activations were restricted to V1 and V2 when the blind subject viewed and recognized colors. The authors concluded that, “A partly defective color system operating on its own in a severely damaged brain is able to mediate a conscious experience of color in the virtually total absence of other visual abilities” (Zeki et al. 1999).

These findings, coupled with previous physiologic, clinical, and imaging data, led to a proposal for three-stage cortical color processing in human brains (Zeki & Marini 1998). The first stage, based on V1 and possibly V2, is concerned with wavelength differencing and registering the presence and intensity of different wavelengths. The second stage, based on V4, is concerned with automatic color constancy operations without regard to context (i.e., memory, judgment, or learning). The third stage, based on inferior temporal and frontal cortices, is concerned with object color. This tripartite schema reconciles Land’s retinex theory, which operates without consideration of cognitive factors such as memory and learning, with the cognitive systems of Helmholtz and Hering, which do view such factors as necessary in determining color.

Lastly, a word about temporal disparities. The visual brain consists of many distributed processes acting in parallel. Psychophysical studies show that the activity in each parallel system reaches its perceptual endpoint at a different time, thus leading to a perceptual asynchrony in vision (Zeki & Bartels 1998b). In other words, processing systems are also perceptual systems that act autonomously. Activity in each can have a conscious correlate without involving activity in other visual systems. For example, color is perceived before motion by about 80 ms (Zeki & Moutoussis 1997) and form elements are first bound locally into shapes followed by a second stage wherein shapes are integrated with surface details (Humphries et al. 2000). Likewise, spatial and temporal imaging (ffytche et al. 2000) reveals that ipsilateral V5 is activated by signals from contralateral V5. An asymmetry of ipsilateral delay in normal persons and an asymmetrical loss of ipsilateral response following splenial section indicates that visual motion signals project from one V5 to another via two independent pathways. This allows for the possibilities of experiential dissociation and temporal desynchronization.

In relation to synesthesia, we see that the separate retinex systems usually work congruently and that binding of the consciousness generated by each parallel visual system results in an integrated image of the visual world. Inasmuch as various percepts are dissociable, either spatial or temporal dissociation might occur in one of the systems, giving rise to the perception of color where we do not normally expect it to occur. The analogy is with the desynchronization explanation for
déjà vu: the temporal desynchronization of the limbic component of perception leads us to believe that we have already experienced it.

9.4 OPTIC IMAGERY AND LIGHTNESS

Walter Boernstein, a student of von Hornbostel, comes from a school of psychology that approaches the relationship between perceiving and thinking from three biological perspectives: psychology, comparative physiology, and phylogenetics. The synthesis of phylogenetics with human psychology is a postulate going back over 100 years to Wilhelm Wundt.

Boernstein believed that perceiving and thinking are arranged hierarchically, and extend from archaic, purely somatic processes that are inaccessible to consciousness, to the most differentiated mental functions (Boernstein 1967, 1970). He also believed that the transition from low to high processes is demonstrable within a single individual as well as in the course of evolution. This hierarchical order can be traced in phylogenesis by encephalization and a close fusion of primitive functions with highly differentiated ones. The high-low fusion is better actualized in vision than in other human senses, and an example of a persistent primitive mechanism is the responsiveness of all living organisms to bright and dark stimuli.

Erich von Hornbostel (1931) demonstrated that nonvisual stimuli were perceived as “light” or “dark.” We just discussed lightness in the context of the retinex theory, and Marks demonstrated how the quality of brightness maps across intersensory dimensions. Von Hornbostel claimed that each percept is categorized by a specific sense quality and a nonspecific one. Specific qualities vary according to modality (color in vision, taste in gustation, pitch in hearing), whereas nonspecific ones are amodal (brightness, darkness, roughness). Note the similarity to Aristotle’s common sensibles. His concept of amodal sensory qualities, and specifically that brightness-darkness is a basic bipolar sensory quale, achieved recognition after von Hornbostel’s lifetime.

According to von Hornbostel, percepts in all modalities are characterized by the amodal qualities of bright and dark. Bright stimuli of nonoptic modalities influence seeing in the same direction as physical light, whereas dark nonoptic stimuli influence it in the same direction as physical darkness. This comes about by the amodal qualities acting on body tonus. Boernstein emphasized the role of structure (shape, configuration of parts, or gestalt) in perceiving and thinking. Perceiving high gestalten is not a pure sensory act, but requires integration of body tonus. Although the optic system is most highly correlated with body tonus and therefore the highest “spatial sense,” other senses such as olfaction, gustation, and temperature discrimination do have a dynamic spatial structure with little contour. Boernstein termed this
“pre-spatial.” Recall our discussions of spatial extension throughout chapter 5.

It is the high spatial structure of vision that makes it capable of “synopsis,” the perceiving “at one glance” a dynamic structure both in exteroception and in imagery. Both this spatial sense and that of lightness can dissociate. Boernstein showed the correlation between sensory and allied motor functions as a basis for the ability of the organism not only to sense bright and dark stimuli but also to experience accompanying emotions. Substantial support for this theory came from his experiments on induced optic imagery, that is, the additive effects of nonoptic stimuli on visual perception (Boernstein 1939). The relationship among seeing, feeling, and thinking is well expressed in Indo-European languages, where the root *vid* gives rise to *eidetic* and *vision* (both meanings), as well as *idea*, *idle*, *ideation*, and so forth.

How might such an analysis address the sensation of movement in synesthesia? The movement of simple photisms would not be so difficult, yet what about the tactile senses approaching and receding in MW, the movement of geometric shapes and lines in the various synesthetes with colored hearing, and the relative movement within spatial maps and number forms? The Gestaltists traced the phyletic evolution of thinking from intended movements. “What originally in fish is a combination of reflexes (‘taxis’) becomes an intended movement in the course of phylogensis; and, finally, in primates, including man, an internalized movement; i.e., a movement is first anticipated, and then carried out” (Boernstein 1970).

The principle of sense synergies states that within each sensory system, the specific sense modality is correlated with a tonic component on the same level of differentiation and, through it, with the body tonus as a whole. This correlation is particularly developed in vision, and the amodal nonoptic stimuli that increase body tonus can induce optic imagery, and vice versa. Boernstein cited Jaensch’s (1931) personality types—the integrated (i.e., those who have optic imaginative thinking) and the disintegrated—suggesting that there are persons prone to imagery and those who are not, just as there are those prone to synesthesia and those who are not. The disintegrated person does not integrate seeing and thinking, whereas in the integrated personality visual perception, imagery, and imagination constitute a dynamically integrated whole.

### 9.4.1 Is Synesthesia on a Continuum with Imagery?

Regarding synesthesia, we may ponder a possible continuum between synesthetes, who perceive additional and dynamic cross-modal qualities that the majority do not, compared to those who “think visually” but do not have spatially extended percepts or other defining criteria of
synesthesia. These two groups stand out from a third nonvisual group who find the entire topic incredulous. The analogy is with alexithymia, patients with emotional constriction (literally, “no words for feelings”) (Cytowic 1985; Lesser 1985).

Bright and dark nonoptic stimuli can induce light and dark visual images. Sounds, tastes, scents, and touches can be induced in dark-adapted subjects (Boernstein 1967). The induced optic images run the gamut from phosphenes to well-structured dream images that have a temporal sequence. Subjects “see things” that are distinct from imagery during dark adaptation (Boernstein, 1967, p. 166 ff.). Subjects react quite differently to the same process of dark adaptation with regard to the frequency, vividness, and elaboration of visual images. In some, an external nonvisual stimulus such as a slamming door causes a momentary increase in brightness; others experience spontaneous images before complete dark adaptation is achieved.

Boernstein could induce visual imagery via inhalation of “dark” and “bright” odorants. Of interest with regard to synesthesia, subjects saw discrete, generic patterns, except for a few “highly integrated subjects” whose images were more interpretive and metaphoric. Under appropriate conditions, stimulus agents inadequate for seeing do seem adequate to induce visual imagery precisely because they do not enter the brain through retinocortical pathways.

9.5 MICROGENESIS

The theory of microgenesis is rooted in the analysis of aphasic errors and in the perceptual errors called agnosias—but the theory is coherent across perceptual modalities, language, and action. Indeed, its global explanatory property is its chief attraction. Synesthesia is neither an aphasia nor an agnosia, of course, given that the “object” is neither substituted nor replaced; rather, the synesthetic object is perceived in addition to the evoking stimulus.

The dynamism of synesthetic percepts makes it of interest to microgenesis, which is fundamentally interested in dynamic errors. In language, for example, microgenesis can explain dynamic errors in a way that the Wernicke model cannot because one cannot map a dynamic psychology onto a rigid anatomy. As rCBF and PET studies demonstrated, synesthesia entails a stimulus-dependent change of focal cerebral metabolism—a metabolic lesion, if you will. Task-dependent elements in determining the size of metabolic lesions are well-known in PET scanning. For example, in linguistic-versus-tambour processing, the PET lesion is larger than the computed tomography lesion.

As seen in foregoing chapters, the parallel synesthetic sensation is not a fully developed object. It is generic and never elaborated. It never
assumes a pictorial or dreamlike quality, although it may possess movement and in this sense have a temporal sequence such as dreams do. The synesthetic percept is more like a moment of an incomplete object rather than the unfolding of a dreamlike narrative with subject-object relations. Synesthesia possesses color, form, space, and movement, which can dissociate from one another, just as form and meaning can dissociate in visual agnosia, or form, color, and location can dissociate in achromatopsia.

In this chapter we will develop further the topic of illusions. These were introduced in chapter 4 as one of the phenomena that are similar to synesthesia. Microgenetic theory is revealing in its analysis of hallucinations and visual illusions. This is particularly so in that microgenesis holds that objects unfold out of limbic structures and memory for their analysis in the external world, as they become externalized. Limbic-temporal structures serve as the fundamental layers of processing in microgenesis. It is possible with this theory to see how, during the unfolding from the transmodal level, an object in the process of externalizing could carry with it an attenuated object, such as shape or color, that we then call synesthesia.

### 9.5.1 Definitions Used in Microgenetics

#### 9.5.1.1 Phylogenesis and Ontogenesis

In ontogeny, you see development of the brain as a whole. In the cognition of the child or in a developing organism, cognition or behavior is grasped as an ontogenetic whole, expressing development of all systems at once. When looking at pathology in the adult, however, you look at a slice of the processing sequence in the cognitive structure.

The triune brain concept of Paul MacLean can help us think about vertical organization of brain function: a vertical, evolutionary, hierarchical point of view. These different levels of brain organization are not superimposed like a stack of coins, but are internested and merge stereodynamically over the entire neuraxis, being laid in parallel all the way down. MacLean derived many of his ideas from Paul Yakovlev (see Cytowic 1996 pp. 68–73).

#### 9.5.1.2 Symptom

In a microgenetic model, a symptom is a normal but preliminary behavior. It is a piece of the subsurface of the structural behavior that is prematurely displayed. Assume that a patient calls a table a chair. In the microgeny of word finding there is a zeroing in on the kind of word to a point where “table” and “chair” have a covalence and either one could come out. Finally, the word “table” pops out. If “chair” comes out by error, it is really normal in that stage of the unfolding of the word.
9.5.1.3 **Hallucination** Hallucinations are attenuated or truncated object perceptions. They reveal a normal stage that is embedded in a final object, a stage that is given up in the final object.

9.5.1.4 **Awareness** Another issue in microgenesis involves awareness of both actions and perceptions. Note that an intact perceptual system may allow you to be aware that your actions are erroneous. Patients with frontal lesions can be aware of their errors yet somehow be unable to correct them. They might verbalize the correct strategy on the Wisconsin Card Sorting Test but be unable to perform correctly.

Kornhüber’s readiness potential beautifully shows the illusive nature of awareness (figure 9.3) (Kornhüber 1974; Kornhüber & Deecke 1965). For those not familiar with this work, a subject is instructed to move a finger when he or she feels like it. Negative slow potentials build up bilaterally and then converge first on the supplementary motor area and then on the motor area contralateral to the finger movement. The readiness potential occurs 800 ms before the finger movement, far in excess of the time required for action potentials to traverse the known polysynaptic circuitry. In other words, the readiness potential far antedates the subject’s decision to make a movement. *We are deceived that we are a free agent in deciding to make a movement.* The decision is an interpretation we give to a behavior that has been initiated someplace else by another part of ourselves. Kornhüber’s work has been extended by Libet (1985, 1993).

9.5.2 **Object Perception**

The egocentric unfolding of primitive archaic space into the perception of an external object as represented by microgenetic theory explains nicely the perception of external objects in synesthesia.

Microgenetics relates the qualitative errors in fluent aphasia to visual object perception. For example, in the evocation of a word, a perceptual representation of the word “chair” goes through a series of levels in the mental representation of a word—from limbic to parietal to Wernicke’s area to auditory cortex. In this sequence, the unfolding travels from experiential or affective relations, to categorical ones, to a phonological representation. An analogous situation holds in both visual object perception and hallucination. In the unfolding of perception an object emerges from a collection of limbic structures and is selected out of a stream of experientially, symbolically, and affectively related objects toward a final stage of feature analysis.

This differs from the conventionally understood direction of visual perception wherein afferents enter visual cortex and project to inferior temporal cortex for matching to memory images or to the parietal lobe for spatial or configurational updating. That is, conventional wisdom
posits successive levels of shape construction. Whereas convention says that an object is constructed and then matched to memory, microgenesis says the reverse; an object unfolds out of memory toward its analysis in the external world. It unfolds from within the observer, from a primitive archaic space through a dreamlike system of experiential, symbolic stages toward a representation as a holistic object with object relations in a three-dimensional Euclidean space. It unfolds out of a volumetric or egocentric space within the body, a space of hallucination, out toward the space of the external world, where it finally detaches as an independent object "out there."

A perception goes through levels of space representation leading from a two-dimensional space map within the body organized around

Figure 9.3 Readiness potentials from various cortical regions in response to voluntary finger movements. Time zero is onset of finger movement. Graphs represent averages of 250 responses. (From Kornhuber [1974], with permission.)
a brainstem–tectal system. Thirty percent of the optic nerve fibers go to the brainstem, and certainly not all of them subserve pupillary response. An autonomous two-dimensional spatial map builds up in the brainstem, passes to the limbic system (to egocentric, volumetric, dreamlike space), to the parietal system (to a three-dimensional Euclidean object space, a peri-personal space that is still part of the body), and finally to a stage of feature analysis and selective focal attention—those features of an object that are independent, detached, and exist on their own.

Sensory input exists at each level. Heavy brainstem input modulates this early stage; limbic collaterals project with the optic radiations; a heavy parietal input goes through the pulvinar; and the geniculostriate system comprises the main input.

9.5.3 Hallucinations

The argument in microgenetics is that object representation is a self-contained system of cognitive representation; instead of building up objects from “sense data,” sensation constrains the process to model an object already out there. Autonomously developing object representation has successive levels of input and constraint. If you eliminate some levels of sensory input (constraint), the system runs by itself to produce a hallucination. A common experience would be hallucinating the telephone ringing or someone calling your name when surrounded by the white noise of the shower.

A hallucination is the development of an object that is not constrained to model anything in the real world that we think exists beyond our perceptions. This is the microgenetic approach. This model supposes that objects and images share the same neural basis and processes. This is a recent thrust of cognitive science in its study of imagery, but it is an old story in neuropsychology. For example, recall Klüver’s eidetic studies (§4.3 and 4.3.2). He noted pupillary constriction and dilation during visualizations of bright and dark eidetic images, respectively. The older literature contains examples of the relationship between hallucination and object perception.

For example, organic hallucinations tend to invade a defective visual field. In the older literature, when the fashion was to follow the evolution of a hemianopia, visual hallucinations occurred early in the development of the field defect and later in its recovery (Seguin 1886). In patients with scotoma, the hallucination occurs in the scotomatous part of the field (release hallucination). This is true not only in vision but also in hearing. Morel (1936) showed that schizophrenic patients had “scotomata”—gaps where they could not hear—in their audiograms during auditory hallucinations.
You might have a feeling that patients cannot attend to a hallucination and a perception at the same time, but in fact, they can have a visual perception and a hallucination side by side. It is not a problem of perceiving or attending to both. It is that one cannot hallucinate and perceive in the same locus at the same time because hallucinations replace the object. The hallucination replaces that part of the visual field where it occurs. It replaces the object rather than superimposing itself on perception because the hallucination is a preliminary object. Even hallucinations that seem real to the perceiver are not really object-like in their sense of realness. They are fluid and dynamic, like synesthesia. Colors melt off object boundaries and the space of hallucination is a tangible, almost viscous, space, not the empty space of object perceptions. In both hallucination and synesthesia, space itself is an object.

9.5.4 Visual Images

The hierarchy in image formation leads from a stage of brainstem-organized dreamless sleep through a stage of dreaming with increasing resolution and clarity to the point of a memory image. It then becomes a quite clear image, not just an image in the mind’s eye, like a memory image, but a pictorial image, like an eidetic one. It is almost, but not quite, like an object. At the next stage come afterimages (figure 9.4). This is the normal hierarchy of imagery. We know that there are transitions between these states. For example, waking up from a dream might leave you with a memory image of the dream. Older studies show that eidetic images fade over time to become more like memory images.

The microgenetic argument is that sensory input constrains successive levels of imagery so that the image substrate eventually models the object. If under the control of sensation, these images form like the substance of a perceived object. Suspension of sensory input releases successive levels of image formation at various levels of the neuraxis (see figure 9.4). At the brainstem level one has dreamless sleep; at the temporal level, dreamlike hallucinations wherein object meaning, experience, and symbolic relationships are important; at the parietal level, disruptions within an image causing illusory dysmorphopsia of seemingly external objects; and at the occipital level, elementary hallucinations and photisms that are similar to afterimages.

9.5.4.1 Neural Levels of Visual Image Formation

**Brainstem** Normally, we say that the upper brainstem mediates dreamless sleep because lesions there give either akinetic mutism or coma. However, disorders of object perception localized here are characterized by ballistic misreaching, neglect in the immediate limb space, and peduncular hallucinations.
Supranuclear palsy (Steele-Richardson-Olchewsky syndrome) involves the upper brainstem, basal ganglia, and cerebellum while sparing the cortex. Patients have a dementia with axial rigidity and severe spatial difficulties. They have ballistic misreaching and primitive space perception. Peduncular hallucinations, caused by lesions of the peduncles of the level of the colliculi and red nucleus, are full-field, polysensory, and tend to be crepuscular (i.e., occurring at twilight when visual input is reduced). Patients tend to be amused by their visions at first, but eventually develop a hallucinatory psychosis and become unable to tell if they are awake or dreaming. Images are close to the subject, as in synesthesia, and categorical rather than being elaborated with strong historical or developmental dreamlike qualities (Albessar 1934; DeMorsier 1938; Geller & Bellur 1987; Lhermitte, 1922a, 1922b; Schilder

Figure 9.4 Microgenetic hierarchy of action and imagery. Each level has an anatomical correlate. See text for further details. (Courtesy of Jason Brown, MD, New York.)
1953). The relation of self-concept to feeling, personal history, and the immediate past points to a limbic transition in the outward development of the mental state (Brown 1999).

Inversion phenomena wherein people appear to stand on their heads (Verkehrtssehen), or where right and left are suddenly transposed (Umgekehrtsehen), are associated with brainstem-limbic lesions, indicating that this so-called lower level of the neuraxis can profoundly alter cognition (Klopp 1951; Pichler 1957; Mouren & Tatossian 1963; Pöttzl 1943; Steiner, Shanin, & Melamed 1987). The majority of cases involve vertebral artery disease (Hicks, Leavitt, & Mckri 1994; Stracciari et al. 1993; Charles et al. 1992), with other cases reporting pathologic findings in the third ventricle (Pamir et al. 1990), in posterior white matter (Doğulu & Kansu 1997) or in bifrontal paralimbic tissue (Solms et al. 1988).

**Temporal Lobe** The kinds of experiences that one sees in synesthesia are most like the kinds of hallucinations and illusions one finds in temporal lesions. Here, common features occur in a group of agnosias and hallucinations (see figure 9.4).

Bilateral mesial temporal lesions produce agnosias for faces, objects, and routes. The association between route finding and face recognition disorders is strong, and both are similar to deficient object recognition. Shown a drinking glass, such an agnostic might call it a plate. The problem is with the object’s semantic category and not a problem in naming. Patients of this type of agnosia (who perceive form normally) have difficulty in selecting an instance from a class of overlearned objects. Thus, a bird watcher complains that all the birds look the same, a jockey can no longer individuate racehorses, a farmer cannot distinguish his cows, and a gardener cannot tell one plant from another (Farah 1990 pp. 73–74). As in synesthesia, generic qualities take over. In synesthesia, a stimulus causes a regression to earlier, more generic features of perception as well as those belonging to another mode. This can be interpreted as an arrested unfolding at the generic level.

Hallucinations and experiential responses dependent on the temporal lobe appeared in chapter 4. Psychiatric hallucinations tend to be large and scenic, progressing moment to moment with a dreamlike, historical quality. This kind of pictorial hallucination tends not to occur with brain tumors, which elicit more banal kinds of visual experience. The exception is a temporal lobe tumor wherein hallucinations are more dreamlike. The relationship among the above entities is as follows.

In a dream, one actually sees the object that is misidentified, whereas in agnosia we do not suppose the subject who calls a glass a plate actually sees a plate. We suppose he actually sees a glass but, in his mind, believes it to be a plate. The displaced image survives as the symptom of the agnosia. Cognition is arrested at a level at which the
semantic error is the symptom of the agnosia, whereas cognition in a hallucinating patient only reaches a certain point without unfolding further. The terminus of percept formation actualizes at this level as an object we call a hallucination. Whereas the hallucinating patient actually sees the object that he misconceives, the agnostic buries the hallucinatory symptom. Misrecognition is the price the agnostic pays to avoid hallucinating. Microgenesis sees agnosia and hallucination as two sides of the same coin.

**Parietal Lobe**  
Most parietal syndromes involve the space within one’s immediate grasp. Drawing, misreaching, body image, and neglect, for example, all relate to objects in the immediate surround.

Many bizarre visual experiences fall under the term *metamorphopsia*, the essential features of which are (1) deformation of shape, (2) change in size, (3) the illusion of movement, or (4) all three. I have listed this as a parietal syndrome although its locus is imprecise and vaguely occipitotemporoparietal (Cytowic 1996, pp. 215–247). Spatial distortions generally fall into the superordinate category of *dysmetropsia* and are illusions rather than true hallucinations because they involve real objects that undergo distortion.

Microgenesis interprets this as a stage giving rise to dreamlike images and the peculiar visual agnosias described above. The whole constellation in the microgeny of an object has come up one more level to resolve as a spatial image. It is a spatial image out there just within grasp *but not quite* independent because of its relation to limb action. Synesthesia shares this quality of being close up in the subject’s immediate personal space.

**Occipital Lobe**  
Occipital lesions pose problems with the analysis, discrimination, and fine segmentation of an object’s features wherein disconnected segments are rapidly organized into configurations (Kimchi 2000). Visual anosognosia, phantom vision, and categorical release hallucinations were discussed earlier. Palinopia is a visual perseveration, and polyopia signifies multiple images of the same object. Entomopia, or insect vision (from the Greek *entomon*, insect), connotes rows and columns of multiple images numbering in the hundreds, as might be experienced by looking through compound eyes (Lopez, Adornato, & Hoyt 1993).

In sum, there are a series of levels leading from dream to memory images, to eideticism, to afterimage, with a pathologic correlate at each level leading from a limbic-temporal, to a parietal, to an occipital stage. The evolution of the brain leads in this direction, not the other way around. The sequence of defects in visual imagery and a visual perception corresponds to the mode of the posterior aphasias. There
are deep-level problems of language perception related to experiential and word-meaning effects; surface-level problems involving categorical object-relational effects; and, finally, phonological effects linked to more recent levels of evolution. To perceive a word phonologically is similar to analyzing an object into its features, because one has an abstract lexical representation that comes in and up and has to be segmented.

So microgenesis suggests that many of these syndromes can be understood as moments in the process of object formation, the process of lexical realization linked to levels in the evolution of the brain. It is a theory that tries to be coherent across different cognitive domains: The model of action is the same as that for the anterior aphasias; a model of the posterior aphasias is a model of visual perception. Microgenesis is an attempt to explain the diversity of phenomena in terms of a unitary model in which diversity is captured through the concept of changes at successive levels rather than separate models or different local theories for every symptom that one encounters. That, after all, is what an evolutionary theory does. When Darwin saw the diversity of the world he tried to develop some principle to explain diversity. Microgenesis is an evolutionary-based model.

Jason Brown (1977, 1983, 1988, 1991, 1996) defined microgenetic theory as one that tries to explain diversity while maintaining consistency across different modes of perception. Microgenesis accounts for diversity in a unitary unfolding process via unfolding over levels and disruption of successive levels as it distributes itself over different sensory modalities or into action. Every symptom one sees is clinically explicable in terms of moments in normal processing with each different component of a unitary process.

9.5.5 A Microgenetic Explanation of Different Types of Synesthesia

The microgenetic notion of an arrested unfolding at the generic level can explain MW’s geometric taste, the audiomotor synesthesia of Devereaux (1966) in which nonsense verbal stimuli produce axial and ballistic movements, the many patients with colored hearing that involves shape, color, and space, and the other synesthetic combinations observed. However, what about more restricted forms such as colored letters and numbers?

The spectrum of synesthetic performance ranges from a vivid polysensory Gewebe to highly restricted forms between just two senses. The exemplar of colored letters or numbers (both of which can be either objects or categorical representations) concerns the level of graphemic or phonemic representation in digits and letters. When synesthetes hear letters and numbers, they say that they visualize them. When they are reading, a shape sits in front of them on the page (we know that skilled readers automatically activate the visual lexicon (Patterson & Morton
1985). When synesthetes spell, they form an image. For some, the phonemic sound determines a letter’s color. This suggests that morphic, lexical, phonemic, and chromatic attributes are all derivative elements of a deeper cognitive structure. In the case of colored letters, the morphology is that which belongs to the lexical representation of the letter, a morphic structure that is developed more as an external object than as a generic shape that arises if it is attenuated at an earlier level.

In considering the dissociation between form-based and meaning-based errors that microgeny explores, we see that form-based defects occur with occipital structures whereas meaning-based errors emanate from temporal-limbic ones. As we saw in chapter 7, synesthetic perceptions are meaningful but presemantic. Indeed, semantic vacuity is an evident feature of synesthesia; what survives is form.

What microgenesis lends to synesthesia is its explanation of object formation and hallucination. In microgenesis, object formation is an autonomous process arising from limbic and brainstem levels, constrained by sensory input operating at higher levels of isomodal and heteromodal cortex. It also seems that there is an analogy between the kinds of errors made in aphasia and the kind of generic perceptions found in synesthesia. Synesthetes, too, are aware of their “errors,” if you allow that the symptom of synesthesia is like any other symptom: part of a normal behavior that is displayed prematurely.

In this regard, synesthesia fits in nicely with the question, What is a symptom?, as answered by the microgenetic model. In this theory, a symptom is a normal but preliminary behavior, a piece of the substructure of an action, or a perception that is prematurely displayed. Just as in the microgeny of word finding there is a point at which “table” and “chair” have a covalence, and either could emerge in the task of naming a four-legged piece of furniture, so too in the normal unfolding of object perception the generic form may be inadequately constrained such that it carries additional information that detaches and externalizes as a perception in another mode, hence synesthesia.

This leads me to the TV analogy. We often think of the flow of neural impulses as linear, and emphasize its terminal locus—that is, we classically think of perception, an action, or an utterance as the terminal stage of some process. Instead of fixating on the terminal event, suppose we turned our attention to some earlier stage of neural transformation? When looking for relationships on any family tree, we find that members closer to the trunk resemble each other much more than members out on distal branches do. This is why family resemblances are more apparent in offspring when they are young children than when they are grown-up. For example, apes and humans are alike, although they hardly look it. Our brains are similar and our DNA differs by only 3%. But we need not go all the way back to DNA to grasp this similarity. Even in the case of different species, a human infant and
a chimp infant look strikingly alike whereas the adult members call attention to their disparity (see Cytowic 1998, p. 60 for an illustration). Regarding synesthesia, we conclude that all intervening transformations between the eye and the visual cortex are possible candidates for processes that are closer to the trunk of perception than a completed visual image is.

By analogy, the consensual image we see on the screen when watching television is the terminal stage of the broadcast. Someone able to intercept the transmission anywhere between the studio camera and the TV screen would be like a synesthete, sampling the transmission before it reached the screen, fully elaborated. Presumably, their experience would be different from those of us viewing the screen. We can similarly propose the concept of synesthesia as the premature display of a normal cognitive process.

The idea of any positive symptom being a premature display of a normal process was first articulated by Kurt Goldstein (1926).

Microgenesis is consistent across modalities. It usefully explains the various combinations of synesthesia. That is, the same kinds of relationships that underlie visual synesthesia can apply to synesthesia between and among other senses. Of course, microgenesis is just one way of looking at synesthesia. As I said with respect to changing metaphors, differing points of view stress some features and ignore others.
The pioneering work of Richard Cytowic on synesthesia is so important for neuropsychological research because it represents, for the first time, a comprehensive depiction of the enormously valuable bulk of evidence about the subjective experience of persons who, in my view, represent a normal variant of human perception and thus appear as subjective “singularities.”

Synesthesia may be regarded as an extremely fruitful type of “unusual normalcy” that apparently can teach us a lot about the constitution of the human mind, especially with respect to the crucial question of how the “unity of an intentional internal object” is generated, in the sense of E. Husserl. Synesthetes are people in whom additional types of internal unified “artificial sensory objects” are generated. Richard Cytowic took the great chance to explore this in two dimensions: the subjective-and-cognitive psychological perspective, as well as the neurobiological view using electrophysiological methods and functional imaging of the brain.

The enormous importance of Cytowic’s work, represented in the present excellent book, is demonstrated by the fact that, as synesthesia’s first researcher, he elaborated this above type of double-view in an extremely relevant borderline field in basic neuropsychological research about the human mind. He was also the first to qualitatively show that the relation between cortical and subcortical activations is shifted during synesthetic experience.

In terms of neuropsychological understanding as elaborated by my group within the last years, these results hint as to the possible central role of limbic structures and emotional components, so to speak, in the neuropsychology of binding, thus constituting a “unity of the senses” when an internal intentional object is constructed during perception. From this point of view, the current volume also touches fundamental aspects of philosophy of mind.

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Appendix

ON-LINE RESOURCES

Given how often uniform resource locators (URL) change, I have not listed them in print. Relevant and up-to-date links can be found at www.cytowic.net.

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