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DEPARTMENT OF PSYCHOLOGY

STUDY MATERIALS

18MPS11C-HISTORY OF PSYCHOLOGY

CONTENTS:

UNIT – II : SENSATOIN AND PERCEPTION

The perceptual problem – Sensation, Perception, Reason and Cognition – Physics and Visual perception – Physiology and perception – The science of illusion – The rise of behavioural laboratories – The psychophysicists and the correspondence problem – The Gestaltist's and the correspondence problem – The progress of perceptual research.

UNIT -II

SENSATION AND PERCEPTION

The study of sensation and perception is diverse. Partly this is the result of the length of time that perceptual problems have been studied. The Greek philosophers, the pre-Renaissance thinkers, the Arabic scholars, the Latin Scholastics, the early British empiricists, the German physicists, and the German physicians who founded both physiology and psychology considered issues in sensation and perception to be basic questions. When Alexander Bain wrote the first English textbook on psychology in 1855 it was entitled *The Senses and the Intellect,* with the most extensive coverage reserved for sensory and perceptual functions. During the first half of his career, the major portion of both the theorizing and the empirical work of Wilhelm Wundt (who is generally credited with the founding of experimental psychology) were oriented toward sensation and perception. The long history of sensory and perceptual research means that there is a huge database and that much information has accrued about the substantive issues concerning how the specific sensory systems operate and how we extract and interpret information from them. It would be possible to write a book just on the history of visual perception, or another on auditory perception, or yet another on the history of sensory and perceptual studies of the tactile, olfactory, or gustatory modalities. Even specific aspects of perception, such as the perception of pain, could generate its own full volume outlining the history of the major substantive findings and theoretical treatments of this single aspect of sensory experience.

In addition to the large empirical database that has resulted from the long history of research in this area, the study of perception has been affected by many“schools” of thought. Each has its own major theoretical viewpoint and its own particular set of methodological techniques. Thus, we encounter Psycho physicists, gestaltists, functionalists, structuralists, transactionalists, sensory-physiologists, analytic introspectionists, sensory-tonic theorists, “new look” psychologists, efferent theorists, cognitive theorists, information processors, artificial intelligence experts, and computational psychologists, to name but a few. There are even theorists (such as some behaviorists) who deny the existence of, or at least deny our ability to study, the conscious event we call perception. How, then, can a single chapter give any coherent treatment of the issues associated with this fundamental aspect of psychology? Fortunately, a broad overview shows that it is possible to see some unifying perspectives that have evolved through history. Common theoretical perspectives might be expected in this discipline, since most sensory and perception researchers are not exclusively bound to one sensory modality. Thus, we fifind Helmholtz and Hering studying both vision and audition, and George von Bekesy, who won the Nobel Prize for his work on hearing, also contributing to studies on vision and touch. Some researchers, such as Fechner, Stevens, Ames, Gibson, Wertheimer, Kofka, Helson, and others, have offered theoretical frameworks that are virtually modality independent and can be tested and explored using visual, auditory, or any other stimulus input. This is not to deny that there are issues that are important to a single sensory modality that do not generalize. One instance of a modality-specific issue might be the chain of events that leads from the absorption of a photon to a visual neural response and a conscious recognition of the stimulus. Instead, this is to suggest that there are global theoretical and methodological frameworks that encompass all sensory and perceptual research. To refer back to that very specific issue of visual detection, while the mechanism of how a photon is captured is specific to sight, all sensory modalities must deal with the ideas of detection and of sensory thresholds and their relationship to what the individual consciously perceives. It is also likely that the higher-level decisional processes, where the observer must decide if a stimulus is there or not, will be the same whether one is dealing with vision, audition, olfaction, or any other sensory system. Thus, we find that certain common issues and definitions cut across all sensory modalities. These methods, philosophical foundations, and psychological understandings have undergone a steady evolution during the history of this area of psychology.

This chapter will be written as an overview and will concentrate on some general themes rather than upon the data and findings from any one sensory modality. From this, hopefully, some idea of the context and scope of the study of perception and its relationship to other aspects of psychology and other sciences will emerge. Three global issues will reappear many times and in several guises during this history. The first deals with the *perceptual problem,* which is really the issue of the correspondence (or no correspondence) between our internal representation of the environment in consciousness and the objectively measured external physical situation. The second has to do with the borrowing of methods, viewpoints, and theoretical formulations from other sciences, such as physics and physiology. The third is the distinction between sensation and perception, which is really the distinction between stimulus-determined aspects of consciousness and interpretive or information-processing contributions to the conscious perceptual experience.

THE PERCEPTUAL PROBLEM

We must begin our discussion with some philosophical considerations. This is not merely because all of science began as philosophy, nor because only 50 years ago philosophy and psychology departments were often combined as the same academic entity in many universities. The reason that we begin with philosophy is that one must first understand that it takes a shift in philosophical viewpoint, away from our normal naive realistic faith in the ability of our senses to convey a picture of the world to us, for the very basic question of why we need a psychological discipline to study sensation and perception to become meaningful. To the proverbial “man on the street,” there is no perceptual problem. You open your eyes and the world is there. We perceive things the way we see them because that is the way they are. We see something as a triangular shape because it is triangular. We feel roughness through our sense of touch because the surface is rough. Thomas Reid summarized this idea in 1785 when he wrote By all the laws of all nations, in the most solemn judicial trials, wherein men’s fortunes and lives are at stake, the sentence passes according to the testimony of eye or ear, witnesses of good credit. An upright judge will give fair hearing to every objection that can be made to the integrity of a witness, and allow it to be possible that he may be corrupted; but no judge will ever suppose that witnesses may be imposed upon by trusting to their eyes and ears. And if a sceptical counsel should plead against the testimony of the witnesses, that they had no other evidence for what they declared than the testimony of their eyes and ears, and that we ought not to put so much faith in our senses as to deprive men of life or fortune upon their testimony, surely no upright judge would admit a plea of this kind. I believe no counsel, however sceptical, ever dared to offer such an argument; and if it were offered, it would be rejected with disdain.

Unfortunately, the man on the street and Reid are both wrong, since perception is an act, and like all behavioral acts, it will have its limitations and will sometimes be in error. One need only look at the many varieties of visual-geometric illusions that introductory psychology textbooks delight in presenting to verify this. In these simple figures, you can see lines whose length or shape are systematically distorted and various element sizes and locations that are misconstrued in consciousness because of the effects of other lines drawn in near proximity to them. Such distortions are not artifacts of art or drawing. Even in nature there are perceptual distortions, illusions, and instances of no correspondence between the reality and the conscious perception. Take the size of the moon. Everyone has at some time or another experienced the moon illusion, where the moon on the horizon looks much larger than it does when it is high in the sky. Surely no one thinks that the moon really changes in size as it rises in the sky. That this is an illusion has long been known. In fact, Ptolemy (127–145) (whose Latin name in full was Claudius Ptolemaeus), the ancient astronomer, geographer, and mathematician who lived in Alexandria, devoted over one third of Book II of his *Optics* to the topic of "illusions." He classified various systematic visual misperceptions under the headings

of size, shape, movement, position, and color and included the moon illusion as one of these topics. The issue of error and illusion will be a recurring theme, since only after the possibility of perceptual error is recognized can the *perceptual problem* be defined. At the first level, the perceptual problem is simply the issue of how "what is out there" gets "in here," or more formally, how do the objects, object properties, relationships between items, and the metric of space and time come to be represented in consciousness? At a second level, this problem may be extended to pose the *correspondence problem,* which asks, "How accurate are these perceptions?" and "How well do they represent the external reality?" This is a fundamental issue that has nothing to do with simple sensory limitations.

Obviously, in the absence of light we cannot expect the visual system to function, nor when the mechanical vibrations in the air are too weak do we expect the auditory system to register sounds. These situations, however, demonstrate *limitations*, which define the limits of the sensitivity of the sensory system and do not represent a failure of correspondence between perception and the external reality. However, once we allow for systematic distortions, where the perceived reality does not correspond to the physicist's measured reality, the argument for naive realism, that the eye merely "records" light and the ear simply "registers" sound, is no longer tenable. If illusion and distortion are possible, then the viewpoint that perception is a psychological act must be accepted.

SENSATION, PERCEPTION, REASON, AND COGNITION

The very first hurdle that had to be faced in the study of sensation and perception involved the definition of these processes and a determination of how they fit with other mental acts and processes. This is an issue that is fundamental; hence, it should not be surprising to find that long before data had been collected, at least well before empirical data in the form that we understand it today was available for analysis, philosophers were raising questions about the role that perception played in our mental life. During the era when Greece was the world's epicentre of intellectual activity, Greek writers and philosophers fell into two schools. One, characterized clearly by Plato (ca. 428–348 B.C.), argued that we should talk of perceiving objects *through* the senses but *with* the mind. The basic notion is that sensory inputs are variable and inaccurate, and at best provide only an imperfect copy of the objects and relationships in the world. We are saved by the mind, or more specifically Reason (yes, with a capitol *R*, since Reason is treated by the Greeks much like an individual in its own right, with special abilities, consciousness, and its own motivational system). Reason or intellect has the job of correcting the inaccuracies of the senses and providing us with a true and correct picture of the world. We are aided in this endeavor by the fact that we are born with a pre existing concept of space, intensity, and time from which we can derive the lesser qualities of size, distance, position, color, and so forth.

In the 1770s the German philosopher Immanuel Kant would restate this view. According to Kant, the intellect creates those phenomena that we perceive by applying a set of specifiable and innate rules. The intellect's task is made simple because it has available an innate concept of space and time and several innate organizing categories and procedures that define quality, quantity, relation, and mode. The sensory systems simply provide whatever limited information they can, and our conscious reality is then shaped by our intellectual activity. The intellect fifills in the holes and cleans up any minor discrepancies and inadequacies in the sensory representation. According to this view, the study of perception is simply part of the study of reason or cognition, and the study of senses, per se, would border on being a waste of valuable time and effort. Plato's views were not unchallenged even during his life.

At the very time when half of the cultivated population of Athens were flocking into the Grove of Hecatombs to listen to Plato's discourse on the rule of intellect, the other half of the population were going to the rival school of Aristippus (ca. 435–366 B.C.). This philosopher maintained that the senses are inherently accurate and thus responsible for our accurate view of the environment; hence, there should always be good correspondence between perception and reality. If there are any distortions, however, it is the mind or judgmental capacities that are limited and responsible for the discrepancies. This was not a new viewpoint. Protagoras (ca. 480–411 B.C.) captured the essence of this position when he said, "Man is nothing but a bundle of sensations." This doctrine, which would become known as Sensism, would owe its reincarnation to the philosopher Thomas Hobbes (1588–1679), who restated this view in 1651 when he wrote: "There is no conception in man's mind which hath not at first, totally or by parts, been begotten upon the organs of sense."

The height of the sensist doctrine can be found in the work of the associationist John Locke, who wrote more than 50 years after Hobbes about ideas. The very word "idea" is coined from the word *eidola,* which was supposed to be a copy of an object that was captured by the senses and sent to the mind. Eidolas were the basis of all sensory impressions and experience. An idea was a remembered or registered eidola, which could then be perceived by the mind, modified or associated with other ideas, and then laid down as a new idea or memory. Thus, in Locke's view of psychology, if we want to understand the mind, we must fifirst have an accurate knowledge of the senses and perceptual processes. The mind is simply a *tabula rasa,* a blank tablet or white paper, and sensory processes write on that paper. Thus, his view was that perceptual experiences create everything that we know or conceive of. Jean Piaget (1896–1980) would bring this same concept into the twentieth century when, in his 1969 book *Mechanisms of Perception,* he considered the hypothesis that there is no difference between perception and intelligence. Some attempts at compromise between these two extreme positions would be attempted. Perhaps one of the earliest came from Aristotle (384–322 B.C.). He began by arguing that there are some perceptual qualities that are immediately and accurately perceived by the senses. He noted that “Each sense has one kind of object which it discerns and never errs in reporting what is before it is color or sound (although it may err as to what it is that is colored or where it is, or what it is that is sounding or where it is).” There are, however, other qualities, such as movement, number, figural qualities, and magnitude, that are not the exclusive property of any one sense but are common to all. These qualities, according to Aristotelian doctrine, require intellectual meditation to assure accuracy of representation.

This compromise view would eventually lead to the separation of perceptual research into two domains, namely sensation and perception. Thomas Reid (1710–1796) is generally credited with making this distinction. A sensation is triggered by some impression on a sense organ that causes a change in experience. Thus, “I have a pain” is a statement that implies a sensation. It can have qualities such as a dull pain, burning pain, or sharp pain, and these are also indicative of a sensation. Perception, however, while depending on a sensation, is much more. It includes a conception of an object or a relationship that is being perceived, plus the immediate and irresistible conviction of the existence of objects or a spatial organization. Thus, “I have a pain in my toe because I stepped on a tack,” represents a percept and requires intervention of mind or reason. Reid’s dichotomy is still with us and is the accepted compromise view (even the title of this chapter is evidence of that); however, modern usage has introduced a bit of a conceptual drift. Hermann von Helmholtz (1821–1894), who left his mark on much of the theoretical foundation of the discipline, began to introduce the mechanism by which a sensation became a perception. Although much of his contribution to our understanding had to do with the physiological basis of sensory experience, he felt that something more was required to actually produce our perception of the world. In what may be the book that had the greatest impact of any ever written on vision, the *Treatise on Physiological Optics* (published in three separate volumes during the 1850s and 1860s), he proposed a process that he called *unconscious inference*. This is a mechanism by which individuals “derive” the objects in the environment using inferences made on the basis of their experience. Thus, perception is like problem solving, where the data used is the rather inadequate information furnished by the senses. Since most people share a common culture and environment, there will be a good level of agreement on the nature of objects and relationships in the world. Individual differences in personal histories, however, can potentially lead to quite different percepts among different people given the same stimulation. At the very minimum, the introduction of the factor of experience in shaping the final percept means that perception will have a developmental aspect and will certainly differ as a function of the age of the individual.

Helmholtz's view has a modern ring and uses terminology that psychologists are still comfortable with today. The general concept of an inductive process that shapes perception actually had a precursor in the writings of the ecclesiastic scholar St. Thomas Aquinas (1225–1274). In Aquinas's view all human knowledge is based upon the input of the senses. This sensory information, however, is believed to be the result of a simple transfer of an accurate picture of the external reality to an internal representation. However, this sensory input does not enter an empty, passive intellect. Rather, the sensory information is acted on by a second element, the *sensus communis,* or the center of common sense, which includes information from the individual's life history. This part of the mind actively organizes, mediates, and coordinates the sensory input. Thus, the senses provide an accurate picture of the world, and the higher perceptual or rational processes provide meaning, thus converting raw sensation into perceptual knowledge. The sensation–perception distinction would undergo at least one more major transition. The stimulus would come from Adelbert Ames Jr. during the 1940s and 1950s, who, much like Helmholtz, began with interests in sensory physiology but felt that more was required. Ames refused to accept the basic postulate of Aquinas, that the sensory input is an accurate representation of the external world. He felt that the correspondence problem was much larger than previously suggested. The example he began with was the observation that the retinal image is inherently ambiguous. A square pattern of light on the retina could be caused by any of an infinite number of different squares at an infifinite and indeterminate number of distances, and the same square image could be caused by one of an infinite number of squares of different sizes depending on their distance. This simple square image on the retina could also be caused by an infinite number of non-square objects, including an infinity of quadrilateral figures such as tilted trapezoids. Thus, shape, size, and distance, which are the basic elements we need to construct our conscious image of the external reality in visual perception, are not encoded in the sensory data in any manner readily accessible by the individual. How, then, do we construct our coherent perception out of our ambiguous sensory information?

According to Ames, we do this by inference based on our experience and any other information that happens to be available. In other words, perception is our "best guess" as to what is out there. This is an update on Helmholtz's view that "such objects are always imagined as being present in the field of vision as would have to be there in order to produce the same impression on the nervous system, the eyes being used under normal conditions."

What Ames did was to demonstrate how much experiential and non-sensory information goes into our final conscious perception. We have some basic concepts such as our presumption that rooms are square or that shadows provide information about shapes. Since our hypotheses about common object shapes and sizes and certain ideas about possible and impossible objects and conditions are built up by our history of transactions with the environment, this viewpoint came to be known as *transactional psychology*. Our perceptions always conform to our presumptions about the world, and we will distort our conscious picture of reality to fit those presumptions. Fortunately, most of our presumptions, since they are based upon experience, are accurate; hence, we are not generally bothered by failures in correspondence. However, situations can be set up that show perceptual distortions based on this inferential process. One such is Ames's well-known *trapezoidal room,* where to conform with our firmly believed notions that rooms are squared with vertical walls and horizontal floors and ceilings, we distort the size of people viewed in this oddly shaped room. This is the better perceptual guess, since people can come in all sizes while room construction is fairly standard. This clearly demonstrates an inferential and non-sensory contribution to conscious perception. The Ames and Helmholtz viewpoints would evolve into the "New Look" theories of perception (which permitted a broader spectrum of experiential and inferential contributions), then into information-processing theories (which focused on the deductive and analytic mechanisms used to form the percept), and finally to the modern conception of *cognition*. The name cognition, as used to label a very active field of inquiry in contemporary psychology, is itself quite old. It was first used by St. Thomas Aquinas when he divided the study of behavior into two broad divisions, *cognition,* meaning how we know the world, and *affect,* which was meant to encompass feelings and emotions. Today's definition of cognition is equally as broad as that of Aquinas. Although many investigators use the term to refer to memory, association, concept formation, language, and problem solving (all of which simply take the act of perception for granted), other investigators include the processes of attention and the conscious representation and interpretation of stimuli as part of the cognitive process. At the very least, cognitive theories of perception attempt to integrate memory and reasoning processes into the perceptual act.

All of these viewpoints suggest that reasoning processes and experience can add to the perceptual experience and that there is much more to perception than is available in the stimulus array. There is, however, one theoretical approach that harkens back to the early sensist approaches and includes a relatively emphatic denial of contributions from reason or intellect. This position was offered by James J. Gibson (1908–1979) and is called *direct perception* (e.g., Gibson, 1979). Like the early sensist viewpoints, it begins with the premise that all the information needed to form the conscious percept is available in the stimuli that reach our receptors. For example, even though the image in our eye is continually changing, there are certain aspects of the stimulation produced by any particular object or environmental situation that are invariant predictors of certain properties, such as the actual size, shape, or distance of the object being viewed. These perceptual invariants are fixed properties of the stimulus even though the observer may be moving or changing viewpoints, causing continuous changes in the optical image that reaches the eye. This stimulus information is automatically extracted by the perceptual system because it is relevant to survival. Invariants provide information about *affordances,* which are simply action possibilities afforded or available to the observer, such as picking the object up, going around it, and so forth. Gibson argued that this information is directly available to the perceiver and was not dependent on any higher level cognitive processing or computation.

For researchers who are interested in developing theories in the form of computer programs and those who are interested in creating computational systems that might allow machines to directly interpret sensory information in the same manner that a human observer might, direct perception is attractive. Typical of such theorists is David Marr (1982), who began with the general presumption made in direct perception that all of the information needed is in the stimulus inputs. Marr’s approach adds to direct perception the process of piecing together information based on some simple dimensions in the stimulus, such as boundaries and edges, line endings, particular patterns where stimuli meet, and so forth, to define objects and spatial relationships. This process of interpretation or synthesis is believed to require a number of computations and several stages of analysis that often can be specified as mathematical equations or steps in a computer program; hence, the name *computational theories* is often used. These are computations associated with certain algorithms that are presumed to be innate or preprogramed; thus, this is not an inferential process but rather application of a fixed processing algorithm, making this viewpoint somewhat reminiscent of the ideas of Kant. While computational perception has a certain allure for the burgeoning field of cognitive science, and there are still some advocates of direct perception, the vast majority of perceptual researchers and theorists seem to have accepted a compromise position that accepts the distinction between sensation and perception. Correspondence between perception and reality is maintained because there is a rich source of information in the direct sensory inputs (in other words, sensation is reliable). However, there are some ambiguities that can be corrected by using experiential and inferential processes to derive the perceived object from the available sensory data (in other words, there are non-sensory contributions that shape the final conscious percept).

PHYSICS AND VISUAL PERCEPTION

The understanding of sensory events involves an understanding of physics. We rely on physics to define stimuli such as the electromagnetic radiation that we register as light, the mechanical vibrations that we call sound, the mechanical forces that result in touch, and so forth. The scientific contributions to our understanding of perception begins with physics, or at least with a proto-physics, in which the only measurement instruments available were the eyes, ears, nose, and touch senses of the scientist. Since we learn about the world through the use of our senses, this inevitably leads to a belief that the world is what we perceive it to be—an idea that would ultimately come to be abandoned when it became clear that correspondence between percept and reality is not guaranteed.

The philosopher-scientists of earlier ages held a presumption consistent with the fact that our faith in the accuracy of our perception seems to be built into the very fabric of our lives as evidenced by homilies such as “Seeing is believing.” Lucretius (ca. 98–55 B.C.), the Roman philosopher and poet known for his postulation of purely natural causes for earthly phenomena and who tried to prove that fear of the supernatural is consequently without reasonable foundation, stated this article of faith when he asked, “What can give us surer knowledge than our senses? With what else can we distinguish the true form from the false?”. Thus, we see things as having a color because they are colored. We perceive that a person is larger than a cat because people are larger than cats, and so forth.

Thus, taking an inventory of our sensory experience is equivalent to taking an inventory of the state of the world. Since the main tool of the physicist was his own sensory apparatus, we find chapters of physics books are entitled “light” and "sound," which are sensory terms, rather than "electromagnetic wave phenomena" and "the propagation and properties of mechanical and pressure variations in an elastic medium." You can see how far this attitude of belief in sensory data went by considering the medieval opinions about the use of eyeglasses. In the twelfth and thirteenth century, the art of grinding lenses was widely known. It was Roger Bacon (1220–1292) who, in 1266, first thought of using these lenses as an aid to vision by holding or fixing them in front of the eye to form spectacles. Such eyeglasses were in relatively common use during succeeding centuries; however, you will find little mention of these aids to vision in scientific works until the sixteenth century. The principle reason for this absence appears to be condemnation of their use on theoretical grounds. Since lenses distort the appearance of objects, they can be seen as creating illusions. This means that the use of eyeglasses can only lead to deception.

However mistaken this condemnation appears, it clearly reflects the concern of the medieval physicists and natural scientists that our vision must remain unmodified by any instrument if we are to obtain an accurate picture of the world. Before this negative view of the use of eyeglasses would be abandoned, the optics of refraction, which is common to both external glass lenses and the internal lens of the eye, would have to be recognized. Only then would there be acceptance that one was indeed *correcting* the inadequacy of internal physiological optics by the addition of those of the glass that the world was viewed through rather than distorting the semblance of the percept to the outside reality. It would be Galileo Galilei (1564–1642) who would eventually settle the issue. He inverted the reasoning of the medieval critics of eyeglasses by demonstrating that reality can be better known by images seen through a telescope (another combination of glass lenses) rather than by images seen through the naked eye. In this belief he is actually exhibiting the metaphysic behind the scientific revolution. In essence, this metaphysic is that it often takes more than just an observer's eye to know the nature of the external reality.

It may be useful to expand a bit on the optical issues associated with vision, since it is here that we can see that physics and physiology had a difficult time making their influence felt on the study of perception. In so doing we may also see just how clever, if still wrong, some of the early theories of vision were. It all begins with a few simple observations. First, it is immediately obvious that the eye is the organ of sight; hence, any information pertaining to vision must enter the eye. Yet this leads us to an immediate paradox. How can I see objects in their correct size with this organ? Obviously some aspect of the perceived object must enter the eye. Classical theories asserted that multiple copies of the object (the eidolas that Locke spoke of) detach themselves, flying in all directions and entering the eye if it is looking in the right direction.

Each eidolon is a perfect copy of the whole entity that produced it, since the external world is composed of entities that are perceived as wholes. It is in this way that the eye, and more importantly the *sensorium*, or perceiving mind that is behind the eye, gains knowledge of the object. Herein lies a problem. The commonly asked critical question is, How is it that an eidolon as large as that which you might get from a soldier, or even of a whole army, can enter through the pupil of the eye, which may be only 3 or 4 millimetres in diameter?

In a manner that is all too common in scientific theorizing, these early perceptual theorists simply assumed the final outcome and postulated anything that might be needed to make the conscious percept correspond to the external reality. The presumed answer is that the eidolon shrinks to a size appropriate for entering the pupil as it approaches the eye. The problem with simple presumption is that it rapidly leads to complications or contradictions. If the eidolon from an object is only a short distance from the eye, it must shrink very quickly in comparison to the eidola from farther objects, which must shrink at a slower rate to arrive at the eye the same size as all of the other eidola from similarly sized objects. This means that each copy of the object must know its destination prior to its arrival at the eye in order to shrink at the rate appropriate for entering the pupil. Even if we suppose that the shrinkage works, we are now left with the question of how the mind gains information about the true size and distance of objects. Remember that all of the shrunken eidola entering the pupil from all objects must be the same size to pass through the pupillary aperture. Thus, both a nearby soldier and a distant army must be 3 millimetres or less in size to enter a 3-millimeter-diameter pupil. This means that the received copy of the object contains no information about the actual size of the original objects from which they emanated.

In the absence of a knowledge of optics, and given the numerous difficulties associated with this *reception theory* of vision, an alternate theory took the field and held sway for millennia. To understand this theory, consider the way in which we learn the size and shape of things by touch alone. To tactually perceive the size and shape of a piece of furniture if I am blind folded or in the dark, I simply reach out with my hands and palpate it. Running my fingers over the surface gives me its shape; the size of the angle between my outstretched arms as I touch the outermost boundaries gives me its size, even though that size may be much larger that the size of the hands or fingers that are doing the actual touching. It was reasoning like this that led to the *emission theory* of vision.

The emission theory suggests that light is actually emitted from the eye to make contact with objects. These light rays thus serve as the “fingers of the eye.” Information returns along these same extended rays, in much the same way that tactile information follows back through extended arms. This is all consistent with the observation that we cease seeing when we close our eyes, thus preventing emission of the light rays; that what we see depends on the direction that we are looking; and that we can perceive objects that are much larger than the aperture size of our pupil.

This emission theory of vision anticipates another trend in perceptual theorizing, namely, that things that can be represented mathematically are more likely to believed as true, even though there is no evidence that the underlying mechanisms are valid. All that seems to be required is a predictive model. This was provided by an early believer in the emission theory, the great Greek mathematician Euclid (ca. 300 B.C.).

All that Euclid needed to do was to appreciate that light travels in straight lines. Given this fact, and a knowledge of geometry, he was able to present a system of laws of optics that derive from simple principles and can predict the geometry of refraction and reflection of light. However, for Euclid, the scientific study of optics was not separable from the study of visual response. While considering the nature of vision, Euclid proposed the idea of the visual cone, which is a broad cone (or an angle when represented as a two-dimensional slice) with its apex at the eye. He also invented a way of representing the initial stages of the visual process that is still used in modern diagrams. Each light ray is drawn as a straight line that joins the object and the eye as it would if light were emitting like a long finger emerging from the pupil. This is shown in Figure 5.1. Notice that each object is defined by its visual angle. Euclid would use a diagram like this to explain why the more distant of two identical objects would appear smaller. As the figure demonstrates, the arrow *AB* is farther away from the eye and thus appears smaller than the closer arrow *CD* because the visual angle *AEB* is smaller than visual angle *CED*.

We have advanced well beyond Euclid, and obviously we now know that light is reflected from every point of an object and then reforms into an image after entering the eye. Despite this knowledge, even today, visual diagrams are routinely drawn as if the geometrical lines of emitted light actually existed. We do so, still ignoring the cautions of Bishop George Berkeley (1685–1753) that were given some 2,000 years after Euclid. Berkeley admonished “those *Lines* and *Angles* have no real Existence in Nature, being only *Hypotheses* fram’d by *Mathematicians,* and by them introduced into *Optics,* that they might treat of that *Science* in a *Geometrical* way” (Berkeley, 1709).

The first steps toward a more modern optics of vision comes from Alhazen (965–1040?), a scientist and natural philosopher who worked most of his life in Egypt and whose Arab name was Abu Ali al-Hasan ibn al-Haytham. He became fascinated by an illusion or failure of correspondence, namely the afterimages that one has after viewing bright objects. The existence of this failure of correspondence caused him ultimately to reject the emission theory. The fact that a residual effigy of an object remains after the object is removed, and even after the eyes were closed, suggested that this phenomenon was caused by light from the object having a persistent effect in the eye. In the process of rejecting the emission theory, Alhazen modified the reception theory. Most importantly, he abandoned the idea that whole copies of objects reach the eye, an idea that had persisted because when people viewed their world, their phenomenological impression was that they were viewing a set of whole objects. Instead, he claimed that light, conceived of as a stream of minute particles, is thrown off by illuminated objects and is disseminated in all directions in straight lines. This light comes from each point on the object. Such tiny “point-eidola” would have no difficulties entering the pupil of the eye. It is here that he confronts the problem that frustrated those theorists who preceded him, namely that it seemed unnatural to assume that the copy of a unified entity should be broken up into pieces. If the information coming from an object is actually decomposed into parts, how could it ever be put together again to recreate the whole? Furthermore, if so many of these points from so many points on the object entered the pupil simultaneously, it would be likely that they would mix in the eye and confuse the relation of one part to another. Alhazen solved this issue by the use of some information about refraction of light and a misinterpretation of anatomy that placed the crystalline lens of the eye in the center of the eye. According to this idea, the cornea and the lens of the eye effectively consist of concentric spherical surfaces, and only the projected rays of light that enter perpendicularly to these surfaces would be unbent by refraction. These rays produce a replicate image of the object according to the following logic. Of all the lines projecting from any point on an object, only one will be perpendicular to the cornea (the front surface of the eye). Only this ray is seen, and since from each object point there is only one effective ray, the complete set of rays preserves the topographic structure of their points of origin on the object.

Alhazen was basically a sensist in his approach, with the idea that we ought to be able to accurately perceive the world without the intervention of any higher, no perceptual processes. This theoretical position was, however, impossible for object properties such as size, given the limited size of the final image, and also for location, since obviously the image is fixed at the location of the person's retina. Therefore, Alhazen was forced to allow a mental process to intervene, and he suggested that it was the mind that assigned an appropriate size and location to the object based on its image.

However, he balked at the issue of orientation. Based on his knowledge of optics, he knew that an image passing through a simple lens was inverted and left–right reversed. To avoid dealing with this problem, he simply presumed that the light's final image to be analyzed by the mind was formed upright on the front surface of the crystalline lens of the eye. To ask a mental process to rotate the world 180 degrees plus correcting the left and right inversion of the image, and to do so instantaneously enough for us to coordinate properly in the world, was too much of leap of faith for him to accept. Alhazen's analysis of light into points would set the stage for Kepler's correct description of the optics of the eye. Alhazen had failed when he had to deal with the inversion of the retinal image because he could not accept that much non-correspondence between the input and the external world and others would show a similar weakness. Thus, Leonardo da Vinci (1452–1519), who was familiar with a pinhole version of the camera obscura and the inverted image that it casts on a screen, speaks in his fifteenth-century *Notebooks* of the eye as the window to the soul. He and others resorted to an odd sort of physical optics to solve the problem. They Physiology and Perception 93 suggested that there must be a second inversion of the image in the eye, perhaps because the fundus or inside surface of the eye acts as a concave mirror that could then cast an upright image on the rear surface of the lens.

Johannes Kepler (1571–1630) was the first to describe the true nature of image formation in the eye in 1604. He depicted how a lens bends the multitude of rays approaching it from a point on one side of the lens in such a way that it causes the rays to converge and to meet in an approximation to a point on the other side of the lens. The order of object and image points is thus preserved, and an accurate, although inverted, image is formed of the object. By 1625, Scheiner would verify Kepler’s theory. He removed the opaque layers at the back of a cow’s eye and viewed the actual picture formed on the retina and found that it was inverted. Others would repeat this experiment, including Descartes, who described the results in detail. Kepler was not unaware of the problems that the inverted image had caused for previous theorists. However, he simply relegated its solution to what we would call physiological processing or psychological interpretation, much as Alhazen had relegated to the mind the assigning of size and location in space to objects some six centuries earlier.

An interesting example of how the study of physics became intertwined with the study of vision comes from Sir Isaac Newton (1642–1727). Newton, whose name is one of the most distinguished in the history of physics, had already started almost all of his important lines of thought before he was 30. During the short span of time from 1665 to 1666, while Newton was in his early 20s and was a student (but not yet a Fellow) at Trinity College in Cambridge University, he achieved the following ideas: (a) he discovered the binomial theorem; (b) he invented both differential and integral calculus; (c) he conceived his theory of gravitation and applied it to the behavior of the moon; and (d) he purchased a glass prism at the Stourbridge Fair for the purpose of studying the refraction of light. It was this last item that would turn him into a perceptual researcher.

Newton began his study of the refraction of light by prisms in an attempt to improve the telescope. Descartes had already shown that spherical lenses, because of their shape, cause aberrations in image formation, namely colored fringes. Experimenting with prisms first led Newton to the erroneous conclusion that all glass has the same refracting power, which would mean that it would forever be impossible to correct for this distortion. To get around this problem, he used the fact that there is no chromatic dispersion in reflected light. He therefore substituted a concave mirror for the lens and thus created the reflecting telescope. It was this invention that created his reputation and earned him an appointment to the Royal Society.

It is important to remember that Newton began with the belief system of a physicist and thus felt that the spectrum of colors that one got when passing light through a prism was a property of the glass. However, during his experimentation he was able to demonstrate that the spectrum could be recombined into white light if he used a second prism oriented in the opposite direction. This would be an impossibility, since all that a glass should be able to do is to add chromatic aberrations. He soon determined that what the prism was doing was differentially bending the light inputs, with shorter wavelengths bent to a greater degree. This means that the resulting light output is nothing more than a smear of light with gradually differing wavelength composition from one end to the other. Since we see an array of spectral colors, it led him to the conclusion that color is a perceptual experience that depends on the wavelength of the light hitting the eye. White light is then simply the perception resulting from a mixture of all of the colors or wavelengths. Thus, we have another case where only when the physics fails to explain the phenomena observed does the scientist resort to a perceptual explanation.

Other physicists would eventually contribute to knowledge of vision. Prominent among them would be Hermann Helmholtz, whose contributions to physics included development of the theory of conservation of energy and also understanding of wave motions and vortexes. Another was Ernst Mach, whose contribution to ballistics formed an important basis for our understanding of the mechanics of flight and who also would go on to study brightness perception in humans. However, in their contributions, they would use not only the principles of physics but data from the newly emerging fields of physiology and neurophysiology.

PHYSIOLOGY AND PERCEPTION

The physiological research that directly stimulated and guided the scientific study of sensation and perception was a product of the nineteenth century. However, the conceptual breakthrough that set the stage for these new findings was the acceptance of a mechanistic conception of the body that had been anticipated two centuries earlier. Henry Power, an English physician and naturalist who was elected to the Royal Society while it was still in its infancy, stated this emerging viewpoint in his *Experimental Philosophy* in 1664.

Of perception he noted: “Originals in Nature, as we observe are producible by Art, and the infallible demonstration of Mechanicks,” suggesting that principles of art (here to include mathematics and geometry) and mechanistic principles (here to include physics and physiology) should form the basis of the study of perceptual and mental processes. He then goes on to make it quite explicit that to understand mental phenomena we must understand “the Wheelwork and Internal Contrivance of such Anatomical Engines,” including those that are responsible for perception (e.g., the eye and the ear).

This kind of thinking could encourage study of the body as a machine and leave the issue of soul to a more divine province. As an example, consider René Descartes (1596–1650), who accepted a dualistic approach. While sensory processing and response to stimulus inputs from the environment could be solely mechanical and could be studied empirically, Descartes felt that the higher levels of mental life, such as conscious perception, would require a soul and the intervention of God. According to Descartes, animals could process sensory inputs mechanically with no consciousness and no intelligence. He was convinced that this was a reasonable position after observing the statues in the royal gardens of Saint-Germain-en-Laye, the birthplace and home of Louis IV. These human-sized statues, constructed by the Italian engineer Thomas Francini, were automated and could behave in surprisingly lifelike ways. Each fifigure was a clever piece of machinery powered by hydraulics and carefully geared to perform a complex sequence of actions. For instance, in one grotto a fifigure of the mythological Greek musician Orpheus makes beautiful music on his lyre. As he plays, birds sing and animals caper and dance around him. In another grotto, the hero Perseus fights with a dragon. When he strikes the dragon’s head, it is forced to sink into the water. The action of each figure was triggered when visitors stepped on particular tiles on the pathway. The pressure from their step tripped a valve, and water rushing through a network of pipes in the statue caused it to move.

In the *Treatise on Man* published in 1664, Descartes draws a parallel between the human body and the animated statues or automata in the royal gardens. He reasons that the nerves of the human body and the motive power provided by them are equivalent to the pipes and the water contained in the statues. He compares the heart to the source of the water, the various cavities of the brain with the storage tanks, and the muscles with the gears, springs, and pulleys that move the various parts of the statues. These statues do, of course, have the capability to respond to some aspects of stimulation from the outside world. In this case, the “stimulation” might be the pressure of the visitor’s weight on a hidden lever beneath a tile, which causes a figure of Diana, who is caught bathing, to run away into the reeds to hide. If the visitor tries to follow her, pressure on another tile causes Neptune to rush forward, brandishing his trident protectively.

Using the figures in garden as his example, Descartes notes that in some ways the human body is like one of these mechanical contrivances, moving in predictable ways and governed by mechanical principles. Because he misunderstood what he was looking at by confusing the blood vessels that are found in the optic nerve with the nerve itself, he suggested that the optic nerve was simply a tube that contained “animal spirits” where motions are impressed by an image and are thus carried to the brain. He argued that there is nothing in animal behavior that could not be reproduced mechanically. While there appear to be complex activities going on in animals, these take place without any consciousness or thought. A number of activities that seem to require reason and intelligence, such as some of our protective reflexes, do not really require or use consciousness. An example is when you touch a hot surface. You usually withdraw your hand, without any voluntary or conscious command to your muscles to do so. In fact, most people who have experienced this find that their hand had already lifted from the hot surface before they were even conscious of the pain from their fingers.

The consciousness of pain actually *follows* the protective withdrawal of the hand. According to Descartes, this is the level at which animals work. Their basic bodily functions and their basic apparent responsiveness to the environment are all without the need for consciousness, intelligence, self-awareness, or a soul. However, no matter how complex the movements of any machine might be, and no matter how variable and intricate the engineers have made its behavior, machines will always differ from a human being. The reason is that human beings have not only a body (controlled by mechanics) but also a soul (controlled by spirit). To have a soul or a mind is to have the capacity to think and to have consciousness and hence perception. By the early nineteenth century, the study of the nervous system was beginning to advance. The world’s first institute for experimental physiology was established by Johannes Müller (1801–1858) in Berlin. Müller’s *Handbook of Physiology,* which summarized the physiological research of the period and contained a large body of new material from his own lab, was eagerly accepted, as is shown by its rapid translation and republication in English only fifive years later. Müller’s conceptual breakthrough, the *Doctrine of Specifific Nerve Energies,* was actually a direct attack on the image or eidola notion.

To see the problem facing Müller, one must fifirst recognize that the classical view of the mind was that there exists within the brain something like a sentient being, a Sensorium, that wants to learn about the external world but can never come closer to it than the direct contact provided by the nerves. Imagine that the Sensorium is a prisoner in the skull and wants to know about the Eiffel Tower. The only ways that it could learn about it would involve having pictures of the tower, or small copies of it (eidola) brought in, or failing that, at least a verbal description of it. Notice that the representation of the object to the mind is a real copy in kind. If there are no copies of the object, or if the nerves cannot carry them, then we could still have a symbolic representation of them, such as word like symbols, as long as these have a fixed functional relationship to the object so that the mind can recreate its properties by inference. However, there was already some data that suggested that images, or symbols representing images, were not being passed down the nerves. For instance, Charles Bell (1774–1842) pointed out that we perceive sensory qualities based on the specific nerve that is stimulated, not on the basis of the object providing the stimulation. If, for example, you put pressure on the eyeball, you will stimulate the retina; however, what you perceive will be light, not pressure.

Müller introduced the concept that the Sensorium is only directly aware of the states of the sensory nerves, not of the external object. Each nerve can only transmit information about one specific energy source, and there are fifive such nerve energies, one for each of the senses. Thus, a stimulus acting on a nerve that is tuned for visual energies will be perceived as visual, regardless of whether the actual stimulus was light, mechanical, or electrical stimulation. Finally, he suggested that the actual specificity is recognized only at the termination of the nerve in the brain. In doing this, he was incorporating the work of Pierre Fluorenes (1794–1867), who had demonstrated that specific locations in the brain controlled specific functions. Fluorenes based this upon data from animals that had had parts of the brain systematically destroyed and thus lost particular motor functions, as well as various visual and auditory reflflexes. Later on this would be confirmed using human subjects who had head injuries due to war or accident and who also suffered from sensory impairments dependent on the location of the injury. Müller’s break with the eidola theory was not complete, however. He felt that each “adequate stimulus” impressed a wealth of information on the appropriate neural channel by exciting a *vis viva* (life force) or *vis nervosa* (neural power), which took an impression of all the information that would have been present had there been an actual eidola or image present. In this he was expressing the old physiological doctrine of vitalism, which maintained that living organisms were imbued with some special force that was responsible for life and consciousness but not subject to scientific analysis.

This is very similar in tone to the concept of animal spirits postulated by Descartes. It was Müller’s students who would take the next steps. In addition to his writing and research, Müller was a splendid teacher who attracted many brilliant students. Among these was Hermann Helmholtz (1821–1895), who played a pivotal role in this history, and his classmates Émile du Bois-Reymond (1818–1896), who later collaborated with Helmholtz and gained fame by establishing the electrochemical nature of the nervous impulse; Rudolf Virchow (1821–1902), who later pioneered the cellular theory of pathology; and Ernst Brücke (1819–1893), who would later do work on the interactions between color and brightness but who would be best known as the most influential teacher of Sigmund Freud. Together these students rejected the idea that there was any life force that was so mysterious that it could not be analyzed, and so different that it did not follow the know rules of physics and physiology.

As a rebellion against vitalism, they drew up a solemn article of faith in the mechanistic viewpoint, which stated that No other forces than the common physical-chemical ones are active within the organism. In those cases which cannot at the time be explained by these forces one has either to find the specific way or form of their action by means of the physical mathematical method, or to assume new forces equal in dignity to the physical-chemical forces inherent in mater, reducible to the force of attraction and repulsion. (Bernfeld, 1949, p. 171) Then, with the passion generated by youthful fervour for a cause, they each signed the declaration with a drop of their own blood. It is ironic, in some ways, that a blood oath, so common in mysticism and magical rites, would be the beginning of a movement to purge spirits, demons, spirits, and the soul from psychology.

The full implications of specific nerve energies were not immediately apparent, but this idea would come to change the nature of perceptual research. In 1844, Natanson made the obvious mechanistic extension when he argued that every neural organ must have a function and conversely every function must have an organ. In sensory terms, he thought that there might be three different energies for touch, three for taste, three for vision, and an indeterminate number for smell. In that same year, A. W. Volmann attempted to criticize Müller on the ground that his theory would require not merely five specific energies but one for every sense-quality. This might require different channels for pressure, temperature, pain, every one of the 2,000 recognizable colors, every discriminable taste, and so forth. At the time, this seemed like almost a reductio ad absurdum, since it seemed to require an infinity of specific channels for the infinity of specific perceived sensory qualities. However, a solution would show itself. The groundwork for saving the specific nerve energy theory had already been laid before the theory was announced. It appeared in a paper by Thomas Young (1773–1829), which went relatively unnoticed until it was rediscovered by Helmholtz. Young is best known for his linguistic research, particularly on the Egyptian hieroglyphs, and this included his work on translating the Rosetta Stone. However, when he accepted election into the Royal Society, instead of speaking about his linguistic and archaeological studies, he gave a paper on the perception of color in 1801. In it, he proposed that although there is a myriad of perceivable colors, it is possible to conceive that they all might be composed of mixtures of three different primaries. He speculated that these would be red, blue, and yellow, since artists are capable of mixing most colors using paints of only these hues.

By extension, the visual system could do the same with three separate sets of specific neural channels, one for each of the primary colors. He had no empirical support for his speculations, however, and reasoned mostly from the artistic analogy. Helmholtz had independently reached the same conclusion that only three primaries, hence three specific nerve energies, would be required. He would, however, modify the primaries to red, blue, and green. Helmholtz based his selection on some color-mixture studies conducted by another brilliant physicist, James Clerk Maxwell (1831–1879). Maxwell is best known for having demonstrated that light is an electromagnetic wave and for developing the fundamental equations describing electrical and magnetic forces and fields. This led to some of the major innovations made in physics in the twentieth century, including Einstein’s special theory of relativity and quantum theory. Maxwell’s color-mixture data was not based on the mixture of pigments that artists use, since such subtractive mixtures are often difficult to control and analyze. Instead, he used colored lights, generated by capturing small regions of a spectrum generated by passing sunlight through prisms and blocking off all but a small section. These additive mixtures are easier to control and to analyze. Maxwell eventually “proved” the adequacy of three color primaries for full color perception in 1861. This was done by producing the first color photograph. Maxwell took a picture of a Scotch tartan–plaid ribbon using red, green, and blue filters to expose three separate frames of fifilm. He then projected the images through the appropriate filters to recombine them to form the perception of a true colored image. This set the stage for color photography, color television, and color printing while at the same time demonstrating that three primaries would suffifice to produce the full range of colors that humans can see.

Helmholtz next suggested that the specificity need not actually be in the nerves that are doing the conducting. All nerves might be equivalent as information channels; however, there might be specific receptors at the first stage of input that are tuned for specific sensory qualities. We now know that this was a correct assumption and that there are three cones with differential tuning to short wavelengths (blue), medium (green), and long wavelengths (red). This has been confirmed using microelectrode recording and also by using microspectroscopy and directly determining the absorption spectra of individual cones.

Helmholtz also recognized that in some modalities, such as hearing, the idea of only a few specific channels to carry the various sensory dimensions might not work. Certainly at the phenomenological level it is difficult to reduce the auditory sense to a small number of primary qualities. He thus suggested that further processing might be required at intermediate stages along the sensory pathways, and perhaps there may be specific centers in the brain that might selectively respond to specific sensory qualities. The fifirst theory to formalize the idea of pre-processing sensory information to reduce the number of channels needed actually came from Hering,

Helmholtz's major academic opponent. Ewald Hering (1834–1918) was a physiologist who would also go on to be known for his work in establishing the role the vagus nerve plays in breathing. Hering approached questions of perception from the point of view of a phenomenologist. This is, perhaps, not surprising, because he succeeded Johannes E. Purkinje (1787–1869), who was probably the best-known phenomenologist of his time. In addition to his work in microscopy, Purkinje is also known for his discovery of the wavelength-dependent brightness shifts that occur as the eye goes from a light to a dark adapted state (now called the *Purkinje shift*). This set of observations suggested to Purkinje that there might be two separate receptors in the eye, with different photic sensitivity. His speculation was eventually proven by discovery of rods and cones and the demonstration, by Max Johann Sigizmund Scultze (1825–1874), that rods functioned in low-light-level vision and cones in bright light.

Hering was himself a fine analytic phenomenologist like his predecessor Purkinje. He was not completely satisfied with the idea of three primaries as being sufficient to explain the phenomenon of color vision. It seemed to him, rather, that human observers acted as if there were four, rather than three, primary colors. For instance, when observers are presented with a large number of color samples and asked to pick out those that appear to be pure (defined as not showing any trace of being a mixture of colors), they tend to pick out four, rather than three, colors. These unique colors almost always include a red, a green, and a blue, as the Helmholtz-Young trichromatic theory predicts; however, they also include a yellow. Hering also noted that observers never report certain color combinations, such as yellowish blue or a greenish red. This led him to suggest some hypothetical neural processes in which the four primaries were arranged in opposing pairs.

One aspect of this opponent process would signal the presence of red versus green, and a separate opponent process would signal blue versus yellow. An example of such a process could be a single neuron whose activity rate increased with the presence of one color (red) and decreased in the presence of its opponent color (green). Since the cell's activity cannot increase and decrease simultaneously, one could never have a reddish green. A different opponent-process cell might respond similarly to blue and yellow. A third unit was suggested to account for brightness perception. This was called a black-white opponent process, after the fact that black and white are treated psychologically as if they were "pure colors." Evidence from colored afterimages seemed to support this theory.

One might have expected that Hering's notions would be met with enthusiasm, since the opponent-process concept would allow alternate forms of qualitative information to travel down the same pathway (e.g., red and/or green color), thus reducing the number of neural channels required to encode color from three under the trichromatic theory to two. Yet this idea was extremely unpopular. It appeared unconvincing because the theory was purely speculative, with only phenomenological evidence from a set of "illusions," namely afterimages and color contrast, to support it, and no proven physiological processes that demonstrated the required mode of operation. Furthermore, even as neurophysiology became more advanced in the early part of the twentieth century, the theory did not seem appealing, since it seemed to flfly in the face of the newly discovered all-or-none neural response pattern. It implied some form of neural algebra, where responses are added to or subtracted from one another. Additive neural effects could easily be accepted; however, subtractive effects were as yet unknown. The first hints that some neural activity could have subtractive or inhibitory effects came from the phenomenological data and an application of mathematical reasoning by physicist and philosopher Ernst Mach (1838–1916). Mach was a systematic sensist in that he felt that science should restrict itself to the description of phenomena that could be perceived by the senses. His philosophical writings did much to free science from metaphysical concepts and helped to establish a scientific methodology that paved the way for the theory of relativity. However, if the fate of science was to rest on the scientist's sensory systems, it was important to understand how the senses function and what their limitations are.

This led him into a study of brightness phenomena, particularly of brightness contrast. At the time, brightness contrast was just another illusion or instance of noncorrespondence. It was demonstrated by noting that a patch of gray paper placed on a white background appears to be darker than an identical patch of gray paper placed on a dark background. This suggested to Mach that there was some form of inhibition occurring and that this inhibition could be between adjacent neural units. He suggested that the receptors responding to the bright surrounds inhibited the receptors responding to the gray paper in proportion to their activity, and this was more than the inhibition from the cells responding to the dimmer dark region surrounding the other patch, thus making the gray on white appear darker. This led to the prediction of the brightness phenomenon that now bears his name, *Mach bands*. This effect is seen in a light distribution that has a uniform bright region and a uniform dark region with a linear ramplike transition in light intensity between the two. At the top of the ramp a bright stripe is perceived, while at the bottom a dark stripe is seen. These stripes are not in the light distribution but can be predicted by an algebraic model in which neural intensities add to and subtract from those of adjacent neural units. This obviously suggests that some form of inhibition, such as that required by Hering's model of color vision, can occur in sensory channels. Unfortunately, psychologists sometimes look at phenomenological data with the same suspicion that they might look at reports of extrasensory phenomena such as the perception of ghosts. Truth seems to depend on identifiable physiology rather than phenomenology; hence, neural inhibition remained unaccepted. The breakthrough would come with Ragnar A. Granit (1900–1991), who would usher in the era of microelectrode recording of sensory responses. Granit was inspired by the work of British physiologist Lord Edgar Douglas Adrian (1889–1977), who was the first to record electrical impulses in nerve fibers, including optic nerves, and eventually developed a method to use microscopic electrodes to measure the response to stimulation by the optic nerve. Granit's data began to show that when light is received by the eye, under some circumstances it could actually inhibit rather than excite neural activity. To confirm this in humans he helped to develop the electroretinogram (ERG) technique to measure mass activity in the retina.

Haldan Keffer Hartline (1903–1983), who would go on to share the 1967 Nobel Prize with Granit, was also fascinated by Lord Adrian's work. Hartline set about to use the microelectrode measures Granit developed to record electrical impulses in individual nerve cells. His goal was to extend that research into analysis of how the visual nerve system worked. He did much of his work with the horseshoe crab, which has a compound eye (like that of a fly) and has the advantage of having large individual cells that receive light (photoreceptor cells) and long, well-differentiated optic nerve fibers. In the 1930s he recorded electrical response from single fibers of the horseshoe crab's optic nerve and found that the neurons generated a response frequency that was proportional to the intensity of light shining on the photoreceptors. This is the sort of signal that had been expected.

However, later work showed that under some circumstances shining a light on an adjacent receptor could decrease (inhibit) the response rate in a stimulated cell. This was the inhibitory response activity predicted by Mach and needed by Hering's theory. However, things became much more complicated when he began to study the more complex neural visual system of the frog. Now he found that optic nerve fibers were activated selectively, according to the type of light, and varied with brightness or movement. Further, under certain circumstances, increasing light stimulation might actually decrease neural response. This discovery convinced researchers that, even at the level of the retina, some sort of neural algebra could be taking place. Perhaps the sensory inputs were being processed and refined before being sent to higher neural centers.

At this same time, researchers were beginning to modify the doctrine of specific nerve energies because it still seemed to suffer from the major limitation pointed out by some of its early detractors. To put it into its simplest form, we perceive an indefinite number of different sensory qualities in each modality and we do not have an infinity of neural pathways. For example, in the visual realm, a stimulus will have a color, size, location, and state of motion. In addition, the stimulus will contain features such as contour elements that delineate its boundaries, and each of these will have a length and orientation. There may also be prominent defining elements such as angles or concave or convex curves, and so forth. The doctrine of specific nerve energies had evolved from simply positing a separate channel for each sensory modality to a supposition that there is a separate channel for each sensory quality or at least a limited set of qualities.

While this is not practical at the input and transmission stages of perception, it is possible if we consider the end points or terminations in the brain and if, as Hartline seemed to be suggesting, there is some form of pre-processing that occurs before information is sent down specific channels.

In the 1950s Stephen Kufflfler's laboratory at Johns Hopkins University was studying the visual response of retinal neurons using microelectrodes. It was in 1958 that two young researchers who had come to work with Kufflfler met: David H. Hubel (b. 1926) and Torsten N. Wiesel (b. 1924). They decided to look at the response of single neurons in the visual cortex to see if they had any differential responses to stimuli presented to the eye. In experiments with cats and monkeys, Hubel and Wiesel were able to show that varying the spatial location of a light spot caused variations in the response of the cortical cell in either an excitatory or inhibitory manner. By carefully mapping these changes in response to points of light, they later were able to demonstrate that there were complex cells in the brain that were "tuned" to specific visual orientations. This meant that they responded well to lines in one orientation and poorly or not at all to others with different degrees of inclination. Other cells responded to movement in a particular direction, and some were even tuned for particular speed of movement across the retina. There were even hypercomplex cells that responded to particular angles, concavity versus convexity, and lines of particular length.

In a series of clever experiments, they also injected radioactively labeled amino acids into the brain under specific conditions of stimulation to show that there is a complex cytoarchitecture in the visual cortex. Feature-specific cells are vertically organized into columns and separated according to which eye is providing the input. The act of vision, then, involved a decomposition of an input into an array of features that then, somehow or other, would be resynthesized

into the conscious percept.

Hubel and Wiesel's work was initially greeted with skepticism when it was announced in the 1960s. It seemed to be expanding the doctrine of specific nerve energies to a ridiculous degree. Adversaries suggested that, taken to the limit, one might argue that every perceived quality and feature in vision might require its own tuned neural analyzer. Thus, one might eventually find a "grandmother cell" or a "yellow Cadillac detector" that responds only to these particular stimuli. The strange truth here is that these critics were correct, and in the late 1970s, Charles Gross's laboratory at Princeton University began to find cortical neurons that are extremely specialized to identify only a small range of particular targets with special significance. For instance, one neuron in monkeys seems to produce its most vigorous response when the stimulus is in the shape of a monkey's paw. Gross, Rocha-Miranda, and Bender (1972) report that one day they discovered a cell in the cerebral cortex of a monkey that seemed unresponsive to any light stimulus. When they waved their hand in front of the stimulus screen, however, they elicited a very vigorous response from the previously unresponsive neuron.

They then spent the next 12 hours testing various paper cut outs in an attempt to find out what feature triggered this specific unit. When the entire set of stimuli were ranked according to the strength of the response they produced, they could not find any simple physical dimension that correlated with this rank order. However, the rank order of stimuli, in terms of their ability to drive the cell, did correlate with their apparent similarity (at least for the experimenters) to the shadow of a monkey's hand. A decade later there were an accumulation of reports of finding cells that are tuned for specific faces, namely monkey faces in the monkey cortex and sheep faces in sheep cortex (e.g., Bruce, Desimone, & Gross, 1981; Kendrick & Baldwin, 1987). One wonders what Johannes Müller would think of his theory now.

THE SCIENCE OF ILLUSION

While Müller is best known to psychologists for his work on specific nerve energies, he is also an important contributor to philosophical shift in thinking that resulted in the definition of psychology as a separate science by influencing its founder. In 1826 Müller published two books, the first on physiology and the second the phenomenology of vision.

This second volume contained discussions of a number of phenomena that Müller called *visual illusions*. These visual illusions were not the distortions in two-dimensional line drawings that we tend to use the label for today; rather, they were such things as afterimages and phantom limbs. Müller also included the fact that the impression of white may be produced by mixing any wavelength of light with its complement and the resulting percept contains no evidence of the individual components as another form of illusion. In other words, he was fascinated by the fact that there were some situations in which the conscious percept does not correspond with the external situation as defined by physical measurements. Müller's book posed some questions that would remain unanswered during his lifetime but would lead to a burst of empirical work a quarter of a century later.

In 1855, Oppel published three papers in which he included a number of size distortions that could be seen in figures consisting of lines drawn on paper. In his first paper, he noted a distortion that was small in magnitude but quite reliable and could be induced by lines drawn on paper. It appears in drawings such as that in Figure 5.2A and involves the perception that the upper divided extent appears to be slightly longer than the lower undivided space. By the third paper, he had developed more powerful distortions such as that shown in Figure 5.2C. Here the vertical line seems considerably longer than the horizontal line, and this apparent difference in length is usually in excess of 15 percent. Oppel cited Müller, crediting him with sparking the interest in this type of illusory phenomenon.

Oppel was certainly not the first to recognize visual illusions as instances of non correspondence between perception and reality. Remember that Ptolemy, for example, had extensively discussed the moon illusion. Other researchers had noticed that the scale or shape of common items could be distorted in certain environments. For example, Smith (1738) noted that “Animals and small objects seen in valleys, contiguous to large mountains, appear extraordinarily small” (p. 314). For some reason, such descriptions simply do not create the same impact as a simple graphic display, such as Figure 5.2B, where the two black circles (which are simply surrogates for two animals) are the same size, yet the circle surrounded by large forms (which are mere the graphic analogues of mountains) seems to be somewhat smaller than its counterpart, which is surrounded by only small items. It may well have been that having such portable demonstrations of the failure of vision to accurately represent reality generated more interest because more people could so readily and reliably see the effects. Perhaps these line figures appealed to the rising interest in experimentation. The juxtaposition of environmental elements that might cause illusions to appear (such as mountains or moons) cannot be arranged and rearranged at will. The major advantage of lines drawn on paper lies in their flexibility. To begin with, one can easily manipulate the array by bringing large and small objects in close proximity to one another in the picture plane. One can also select stimuli, such as circles, squares, or lines, that have no necessary and familiar size. One can manipulate stimulus elements along many dimensions, such as brightness, chromaticity, spatial proximity, identity, and so forth. Furthermore, one can verify the true dimensions of the perceptually distorted figural elements with tools as simple as a ruler. With the opportunities for easy experimentation so readily available, perhaps it is not surprising that between 1855, when Oppel's papers appeared, and 1900, over 200 papers demonstrating and analyzing various visual distortions appeared. New illusion configurations began to appear in a vast unsystematic flood. There were new distortions described by the astronomer Johann Karl Friedrich Zöllner (1834–1882), the sociologist Franz Müller-Lyer (1857–1916), the physiologist Jacques Loeb (1859–1924), and the philosopher psychologist Franz Brentano (1838–1917). Many psychologists whose main interests seem to lie far from perception also took their turn at producing illusion configurations. Included in this group are Charles Hubbard Judd (1873–1946) and Alfred Binet (1857–1911), both interested in education and child development; the philosophically oriented James Mark Baldwin (1861–1934) and William James (1842–1910); the clinician Joseph Jastrow (1863–1944); the founder of applied psychology, Hugo Münsterberg (1863–1916); as well as a host of workers interested in aesthetics, including Karl Stumpf (1848–1936) and Theodor Lipps (1851–1914). This is not to say that specialists in perception were excluded, since many of these joined this merry frenzy of exposing instances of non correspondence, including Wundt, Hering, Helmholtz, Titchener, and Ehrenfels, to name but a few.

It is difficult to believe, but it was in the midst of all of this activity of drawing lines on paper to produce illusory percepts that the science of psychology was born. Wilhelm Wundt (1832–1920) was probably the first person to call himself a psychologist and was certainly the first to found a formal administrative unit for psychological research. Oddly enough he embarked upon the development of exclusively psychological research because of all those line drawings that showed systematic distortions when carefully viewed. Wundt began by considering visual illusions as they were currently being described in his book *Contributions to the Theory of Sensory Perception,* various sections of which were published between 1858 and 1862. By the time he published his *Principles of Physiological Psychology* (in two parts, 1873 and 1874), his deliberations had forced him into a new philosophical and methodological position. For example, when he considered Oppel's strongest illusion, which demonstrated the fact that a vertical line looks longer than a horizontal line of equal length, he recognized that this perceived illusion could not be predicted by any of the known laws of physics, biology, or chemistry. To explain this phenomenon, then, we would need a new set of laws. These laws would be the laws that govern mental science. He suggested that we need a science of mental processes and we could name it "Psychology," as had been suggested earlier by the philosopher and mathematician Christian von Freiherr Wolff (1679–1754). Although he credited Wolff with the name, Wundt chose to ignore the fact that Wolff also maintained that any science of mental life could not be based upon empirical research. Instead Wundt set out to create a new empirical science with its own methods and its own basic principles to study issues such as the noncorrespondence between the physical and the perceived world.

When Wundt first began his research, he had already accepted the concept that psychology should use a variety of experimental methods depending on the question being asked. One such technique was *analytic introspection*. Wundt initially adopted the atomistic viewpoint, which earlier in the century had proved to be so successful in physics, biology, and chemistry. It seemed reasonable to assume that consciousness could be viewed as the sum of some form of basic mental elements, much as physicists had come to view matter as the combination of basic elements called atoms and biologists had come to view living organisms as the combination of basic units called cells. Wundt's structuralist viewpoint argued that the total perceptual impression must similarly be composed of the sum of simple sensory impressions. Analytic introspection was one way of training observers to isolate these simple sensory impressions in consciousness and thus reveal the irreducible elements of conscious perception.

There is a misperception about Wundt's methodology that was perpetrated by his student Edward Bradford Titchener (1867–1927). The fallacy is that analytic introspection was the main, and perhaps the only, technique of choice in Wundt's lab. This is not true, since Wundt advocated many methods, including observation without intervention, experimentation, and the use of objective indexes of mental processes such as discriminative responses to sensory stimuli and reaction time. Furthermore, well before his long career was through, the same stimulus configurations that brought him to consider psychology as a separate discipline would cause him to abandon analytic introspection.

If analytic introspection worked, then the observer should be able to reduce consciousness to basic sensory elements. If this is the case, then it seems reasonable to assume that visual illusion stimuli, when dealt with in this manner, would no longer produce any perceptual distortion. Thus, analytically viewing the items in Figure 5.2 should produce accurate assessments of all relevant sizes and lengths, and the illusions themselves should turn out to be nothing more than judgmental errors added to the basic sensory elements by not-socareful observers. Unfortunately, such was not the case, and the illusions persisted, suggesting to Wundt that perhaps the atomistic view was untenable and the technique of analytic introspection might not be as useful as originally thought.

Instead, he began to argue for a much more modern-sounding view of perception, which he called *creative synthesis*. According to this view, perception might be considered to be an amalgam between sensory and nonsensory elements. These nonsensory elements might arise through memories or associations established by an individual's experience or history, or information from other modalities.

THE RISE OF THE BEHAVIORAL LABORATORIES

Although Helmholtz was doing experimentation on perceptual phenomena, he did not call himself a psychologist and would have claimed that he was studying physiology or physics rather than psychology. Hence, no one credits

Helmholtz with having the first experimental lab in psychology. Helmholtz, however, did set the stage for the first labs by establishing a particular methodology that would find immediate acceptance and is still used today. Prior to his time, it was believed that sensory information was transmitted to whatever center needed to turn it into conscious awareness instantaneously. Helmholtz's friend, Émile du Bois-Reymond (1818–1896), had studied the chemical structure of nerve fibers and shown that the neural response was an electrochemical event. Helmholtz theorized that this meant that the nervous impulse might travel more slowly than anyone had previously imagined–perhaps even slow enough to be measured in a laboratory.

Unfortunately, to test his hypothesis, Helmoltz needed an instrument capable of measuring very small fractions of seconds, smaller than could be reliably detected by any existing timepiece. He devised such a "clock" from a simple laboratory galvanometer. A galvanometer is an instrument that detects the presence and strength of an electrical current by causing a needle to deflect, with the amount of deflection corresponding to the strength of the current. Helmholtz knew that when the current was first turned on it took a short, but measurable, amount of time to reach its maximum level and to cause the needle to reach its maximum deflection. If the current was turned off before it reached its maximum, the proportion of needle deflection registered was an accurate measure of the very small amount of time the current had been on.

Now armed with this “galvanometric stopwatch,” Helmholtz measured the speed of the neural impulse in a frog’s leg. He knew that mild electrical stimulation of the motor nerve that ran the length of the leg would cause a twitch in the foot muscle, and by balancing the foot on a switch, this movement could be used to turn off a current. When the current was turned on the galvanometer was set in motion, but when the foot twitched it was turned off. He now compared the times when the nerve was stimulated at different locations along the nerve fiber. He found that a point four inches from the muscle took 0.003 seconds longer than a point only one inch away, meaning that the nerve impulse was traveling at about 83 feet per second.

The next step was to apply this technique to humans. He trained subjects to press a button whenever they felt a stimulus applied to their leg. Although the results were more variable than those for the frog, reaction times tended to be longer when the stimulus was applied to the toe than when applied to the thigh. Calculations showed that humans had a faster neural impulse travel speed than the frog, in excess of 165 feet per second, and perhaps up to around 300 feet per second.

It would take a few years for the significance of these experiments to register with the scientific world—partly because the results were too astonishing to believe. From a phenomenological perspective mental processes are subjectively experienced as occurring instantaneously, and physiologists believed that the neurological events associated with them should be instantaneous as well. The idea that it takes a finite time for events to occur was difficult to believe. Nonetheless, this new *reaction-time* methodology would allow the first true psychological laboratory to begin its testing program.

Wundt was quite aware of Helmhotz’s work, since he had not only trained briefly with Helmholtz’s mentor Johannes Müller but served as Helmholtz’s assistant at Heidelberg.

When Wundt established the fifirst psychological laboratory at Leipzig in 1879, one of the major objective methodological tools that he would employ would be “mental chronometry,” or reaction time, building on some earlier work of the Dutch physiologist Frans Cornelis Donders (1817–1881). Reaction time methodology allowed Wundt to demonstrate a scientific basis for psychological research. The philosophic basis for this undertaking would come from Johann Friedrich Herbart (1776–1841), who suggested that the study of mental phenomena should be (a) empirical; (b) dynamic, in the sense that ideas and experiences can interact and vary over time; and (c) mathematical. To this substrate, Wundt added that the study of mental phenomena should use the technology, fundamental data, and empirical strategies that had been developed by physiology, since ultimately humans are simply physiological machines. It was in this context that Wundt developed the *subtractive method* to measure mental function.

An example of how the subtractive method works would be to first measure the reaction time for a simple task, say by tapping a key at the onset of a light (call this Ts). Next the observer is given a more complex task, say one in which he had to make a decision as to whether the light was red or green, tapping a key with his right hand for red and with his left hand for green (call this Tc). Since the more complex task takes more mental computation, Tc is longer than Tn, and Wundt reasoned that the actual time that the decisional process takes, Td, could be computed by the simple subtraction $Td\ \ Tc\ \ Ts$. This should give the researcher a metric.

Reaction time should increase in direct proportion to the dif- fificulty of the decision or the number of decisions that had to be made. Although this methodology generated a lot of research, concerns began to be expressed by some researchers. N. Lange, working in Wundt's lab, found that attentional processes affected the length of the reaction time. Unattended or unexpected stimuli took longer to respond to, and paying attention to the response rather than to the stimulus also altered the reaction time. Other researchers, such as Oswald Klüpe (1862–1915), suggested that the method was not valid because the entire perceptual act is not simply the sum of simple sensory and decision times. Returning to the example above, suppose that we compare the time that it takes to detect a light (Ts) to the time that it takes to discern the locus of lights (e.g., whether a pair of lights were side by side or one above the other–Tl); now, following this decision we will also require the observer to add the color discrimination task that we described earlier (Tc). The addition of a second mental operation or sensory input was known as the *complication method*. Computing the decision time for the color task should produce the same value whether we base it on $Tc\ \ Tl$ (where subjects are making two sequential decisions in a complication study) or $Tc\ \ Ts$ (the single decision compared to the simple detection task), since the color decision (red versus green) added on to the fifirst task is identical. Yet this was never the case, which suggested that mental activity was not a linear process and was not subject to simple algebraic analysis. Because of this, studies of reaction time came to be viewed as suspect, and their popularity declined during the first half of the twentieth century.

Reaction time would spring back into prominence as cognitive and information-processing approaches to perception became a problem of interest. The changes in reaction time with shifts in attention no longer would be viewed as a methodological artifact but rather could be used as a method of studying attention itself. Furthermore, the underlying conception that processing was a serial and linear process would be challenged, and reaction time would provide the vital measures. It was Saul Sternberg, in a series of visual search and recognition studies (e.g., Sternberg, 1967), and Ulric Neisser in his 1967 book *Cognitive Psychology,* who rebuilt the reputation of reaction-time methodology. They turned the apparent breakdown of the subtractive method into an investigative tool. Thus, in those instances in which addition of tasks or sensory inputs increases reaction time, we clearly have a serial processing system where the output from an earlier stage of processing becomes the input for the next stage of processing. Because of this serial sequence, processing times increase as the number of mental operations increases. However, in those instances where adding tasks, stimuli, or sensory channels does not increase the reaction time, we are dealing with a parallel and perhaps distributed processing network where many operations are occurring simultaneously. In this way, reaction time methodology allows us to ascertain the pattern or network of processing and not simply the complexity of processing.

An example of parallel processing as it was originally conceptualized can be seen in a visual pattern recognition theory that emphasized feature extraction processes that all occur at the same time. It was originally called *pandemonium,* because, as a heuristic device, each stage in the analysis of an input pattern was originally conceived of as a group of *demons* shouting out the results of their analyses (Selfridge, 1959). According to the model, the contents of the retinal image are simultaneously passed to each of a set of *feature demons,* which actually are neurons that act like filters to detect specific features. All of these neurons do their processing at the same time, since copies of the original stimulus input are passed on to a number of neurons simultaneously. The response of these filtering neurons (the loudness with which the demons shout) is proportional to the fit of the stimulus to the filter’s template. These outputs are judged simultaneously by a large set of *cognitive demons,* which are actually more complex filters or neurons that respond to a particular combination of features in proportion to their fit to the template. One of these will be a best fit, and thus respond most vigorously. At the final stage, a *decision demon* listens to the “pandemonium” caused by the yelling of the various cognitive demons. It chooses the cognitive demon (or pattern) that is making the most noise (responding most vigorously) as the one that is most likely to be the stimulus pattern presented to the sensory system and represents this as the final conscious percept. Such parallel-distributed processing theories have become popular because they are easily represented in a network form and thus can be implemented and tested as computer models. In this way, the reaction-time data confirms Herbart’s contention that theories of psychology should be dynamic and can be mathematical.

THE PSYCHOPHYSICISTS AND THE CORRESPONDENCE PROBLEM

The ultimate battle over the conceptualization of perception would be fought over the correspondence problem. The issue has to do with the perceptual act, and the simple question is, “How well does the perceived stimulus in consciousness correspond or represent the external physical stimulus?” By the mid-1800s, the recognition that sensory systems were not passively registering an accurate picture of the physical world was becoming an accepted fact. The most common situations in which this became obvious were those that taxed the sensitivity of an observer. In these instances, stimuli might not be detected and intensity differences that might allow one to discriminate between stimuli might go unnoticed. These early studies were clearly testing the limitations of the receptivity of sensory organs and hence were consistent with both the physical and physiological view of the senses as mere stimulus detectors. However, as the data on just how sensitive sensory systems were began to be amassed, problems immediately arose.

Ernst Heinrich Weber (1795–1878) at the University of Leipzig did research on touch sensitivity. He noticed that the ability to discriminate between one versus two simultaneous touches and the ability to discriminate among different weights was not a simple matter of stimulus differences. As an example, take three coins (quarters work well) and put two in one envelope and one in the other. Now compare the weight of these two envelopes and you should have no difficulty discriminating which has two coins, meaning that the stimulus difference of the weight of one quarter is discriminable. Next take these two envelopes and put one in each of your shoes. When you now compare the weight of the shoes you should find it difficult, and most likely impossible, to tell which of them is one coin weight heavier, despite the fact that previously there was no difficulty making a discrimination based on the same weight difference. Physical measuring devices do not have this limitation. If you have a scale that can tell the difference between a 10-gram and 20-gram weight, it should have no difficulty telling the difference between a 110-gram and 120-gram weight, since it clearly can discriminate differences of 10 grams. Such cannot be said for sensory systems.

These observations would be turned into a system of measuring the correspondence between the perceived and the physical stimulus by Gustav Teodore Fechner (1801–1887). Fechner was a physicist and philosopher who set out to solve the mind–body problem of philosophy, but in so doing actually became, if not the first experimental psychologist, at least the first person to do experimental psychological research. Fechner got his degree in medicine at Leipzig and actually studied physiology under Weber. He accepted a position lecturing and doing research in the physics department at Leipzig, where he did research on, among other things, the afterimages produced by looking at the sun through colored filters. During the process of this, he damaged his eyes and was forced to retire in 1839. For years he wore bandages over his eyes; however, in 1843 he removed them, and revelling in the beauty of recovered sight he began a phenomenological assessment of sensory experience. On the morning of October 22, 1850, Fechner had an insight that the connection between mind and body could be established by demonstrating that there was a systematic quantitative relationship between the perceived stimulus and the physical stimulus. He was willing to accept the fact that an increase in stimulus intensity does not produce a one-to-one increase in the intensity of a sensation. Nonetheless, the increase in perceived sensation magnitudes should be predictable from a knowledge of the stimulus magnitudes because there should be a regular mathematical relationship between stimulus intensity and the perceived intensity of the stimulus. He described the nature of this relation in his classic book *The Elements of Psychophysics,* which was published in 1860. This book is a strange mixture of philosophy, mathematics, and experimental method, but it still had a major impact on perceptual research. Fechner's description of the relationship between stimulus and perception began with a quantitative manipulation of Weber's data. What Weber had found was that the discrimination of weight differences was based on proportional rather than arithmetic difference. For example, suppose an individual can just barely tell the weight difference between 10 and 11 quarters in sealed envelopes; then this minimally perceptible difference between 10 and

11 represents a 110 increase in weight (computed as the change in intensity of 1 quarter divided by the starting intensity of 10 quarters). This fraction, which would be known as the Weber fraction, then predicted the stimulus difference that would be just noticeable for any other starting stimulus. Thus, you would need a 10-quarter difference added to an envelope containing 100 quarters to be discriminated (e.g., 100 versus 110), a 5- quarter difference if the envelope contained 50 quarters, and so forth. Since these minimal weight changes are just barely noticeable, Fechner assumed that they must be subjectively equal. Now Fechner makes the assumption that these just noticeable differences can be added, so that the number of times a weight must be increased, for instance, before it equals another target weight, could serve as an objective measure of the subjective magnitude of the stimulus. Being a physicist gave him the mathematical skills needed to then add an infinite number of these just noticeable differences together, which in calculus involves the operation of integration. This resulted is what has come to be known as Fechner's law, which can be stated in the form of an equation of $S \ W \log I$, where S is the magnitude of the sensation, W is a constant which depends on the Weber fraction, and I is the intensity of the physical stimulus. Thus, as the magnitude of the physical stimulus increases arithmetically, the magnitude of the perceived stimulus increases in a logarithmic manner. Phenomenologically this means that the magnitude of a stimulus change is perceived as being greater when the stimulus intensity is weak than that same magnitude of change is perceived when the starting stimulus is more intense. The logarithmic relationship between stimulus intensity and perceived stimulus magnitude is a better reflection of what people perceive than is a simple representation based on raw stimulus intensity; hence, there were many practical applications of this relationship. For instance, brightness measures, the density of photographic filters, and sound scales in decibels all use logarithmic scaling factors.

One thing that is often overlooked about Fechner's work is that he spoke of two forms of psychophysics. *Outer psychophysics* was concerned with relationships between stimuli and sensations, while *inner psychophysics* was concerned with the relationship between neural or brain activity and sensations. Unfortunately, as so often occurs in science, inner psychophysics, although crucial, was inaccessible to direct observation, which could create an insurmountable barrier to our understanding. To avoid this problem, Fechner hypothesized that measured brain activity and subjective perception were simply alternative ways of viewing the same phenomena. Thus, he hypothesized that the one realm of the psychological universe did not depend on the other in a cause-and-effect manner; rather, they accompanied each other and were complementary in the information they conveyed about the universe. This allowed him to accept the thinking pattern of a physicist and argue that if he could mathematically *describe* the relationship between stimulus and sensation, he had effectively *explained* that relationship. Obviously, the nonlinearity between the change in the physical magnitude of the stimulus and the perceived magnitude of the stimulus could have been viewed as a simple failure in correspondence, or even as some form of illusion.

Fechner, however, assumed that since the relationship was now predictable and describable, it should not be viewed as some form of illusion or distortion but simply as an accepted fact of perception. Later researchers such as Stanley Smith Stevens (1906–1973) would modify the quantitative nature of the correspondence, suggesting that perceived stimulus intensities actually vary as a function of some power of the intensity of the physical stimulus, and that that exponent will vary as a function of the stimulus modality, the nature of the stimulus, and the conditions of observation. Once again the fact of non correspondence would be accepted as non illusory simply because it could be mathematically described.

Stevens did try to make some minimal suggestions about how variations in neural transduction might account for these quantitative relationships; however, even though these were not empirically well supported, he considered that his equations “explained” the psychophysical situation adequately. While the classical psychophysicists were concerned with description and rarely worried about mechanism, some more modern researchers approached the question of correspondence with a mechanism in mind. For instance, Harry Helson (b. 1898) attempted to explain how context can affect judgments of sensation magnitudes. In Helson’s theory, an organism’s sensory and perceptual systems are always adapting to the ever-changing physical environment. This process creates an *adaptation level,* a kind of internal reference level to which the magnitudes of all sensations are compared. Sensations with magnitudes below the adaptation level are perceived to be weak and sensations above it to be intense. Sensations at or near the adaptation level are perceived to be medium or neutral. The classical example of this involves three bowls of water, one warm, one cool, and one intermediate. If an individual puts one hand in the warm water and one in the cool water, after a short time both hands will feel as if they are in water that is neither warm nor cool, as the ambient temperature of the water surrounding each hand becomes its adaptation level. However, next plunging both hands in the same bowl of intermediate temperature will cause the hand that was in warm to feel that the water in the bowl is cool and the hand that was in cool to feel that the same water is warm. This implies that all perceptions of sensation magnitude are relative. A sensation is not simply weak or intense; it is weak or intense compared to the adaptation level.

One clear outcome of the activity of psychophysicists was that it forced perceptual researchers to learn a bit of mathematics and to become more comfortable with mathematical manipulation. The consequence of this has been an acceptance of more mathematically oriented methods and theories.

One of these, namely *signal detection theory,* actually is the mathematical implementation of a real theory with a real hypothesized mechanism. Signal detection theory conceptualized stimulus reception as analogous to signal detection by a radio receiver, where there is noise or static constantly present and the fidelity of the instrument depends on its ability to pick a signal out of the noisy environment. Researchers such as Swets, Tanner, and Birdsall (1961) noted that the situation is similar in human signal reception; however, the noise that is present is noise in the neural channels against which increased activity due to a stimulus must be detected.

Furthermore, decisional processes and expectations as well as neural noise will affect the likelihood that a stimulus will be detected. The mathematical model of this theory has resulted in the development of an important set of analytic tools and measures, such as d as a measure of sensitivity and as a measure of judgmental criterion or decision bias.

This same trend has also led to the acceptance of some complex mathematical descriptive systems that were offered without physical mechanisms in mind but involve reasoning from analogy using technological devices as a model. Concurrent with the growth of devices for transmitting and processing information, a unifying theory known as *information theory* was developed and became the subject of intensive research. The theory was first presented by electrical engineer Claude Elwood Shannon (b. 1916) working at the Bell Labs.

In its broadest sense, he interpreted information as including the messages occurring in any of the standard communications media, such as telephones, radio, television, and data-processing devices, but by analogy this could include messages carried by sensory systems and their final interpretation in the brain. The chief concern of information theory was to discover mathematical laws governing systems designed to communicate or manipulate information. Its principal application in perceptual research was to the problems of perceptual recognition and identification. It has also proved useful in determining the upper bounds on what it is possible to discriminate in any sensory system (see Garner, 1962).

THE GESTALTISTS AND THE CORRESPONDENCE PROBLEM

We have seen how psychophysicists redefined a set of failures of correspondence so that they are no longer considered illusions, distortions, or misperceptions, but rather are examples of the normal operation of the perceptual system. There would be yet another attempt to do this; however, this would not depend on mathematics but on phenomenology and descriptive psychological mechanisms.

The story begins with Max Wertheimer (1880–1943), who claimed that while on a train trip from Vienna for a vacation on the Rhine in 1910, he was thinking about an illusion he had seen. Suddenly he had the insight that would lead to Gestalt psychology, and this would evolve from his analysis of the perception of motion. He was so excited that he stopped at Frankfurt long enough to buy a version of a toy stroboscope that produced this "illusion of motion" with which to test his ideas. He noted that two lights flashed through small apertures in a darkened room at long intervals would appear to be simply two discrete light flashes; at very short intervals, they would appear to be two simultaneously appearing lights. However, at an intermediate time interval between the appearance of each, what would be perceived was one light in motion. This perception of movement in a stationary object, called the *phi phenomenon*, could not be predicted from a simple decomposition of the stimulus array into its component parts; thus, it was a direct attack on associationist and structural schools' piecemeal analyses of experience into atomistic elements. Because this motion only appears in conscious perception, it became a validation of a global phenomenological approach and ultimately would be a direct attack of on the "hard-line" behaviorism of researchers such as John Broadus Watson (1878–1958), who rejected any evidence based on reports or descriptions of conscious perceptual experience. Wertheimer would stay for several years at the University of Frankfurt, where he researched this and other visual phenomena with the assistance of Kurt Koffka (1886–1941) and Wolfgang Köhler (1887–1967). Together they would found the theoretical school of Gestalt psychology. The term *gestalt* is usually credited to Christian Freiherr von Ehrenfels (1859–1932). He used the term to refer to the complex data that require more than immediate sense experience in order to be perceived. There is no exact equivalent to *gestalt* in English, with “form,” “pattern,” or “configuration” sometimes being suggested as close; hence, the German term has simply been adopted as it stands.

The basic tenants of Gestalt psychology suggest that perception is actively organized by certain mental rules or templates to form coherent objects or “wholes.” The underlying rule is that “the whole is different from the sum its parts.”. Most people would say that they see a square on the left and a triangle on the right. Yet notice that the individual elements that make up the square are four circular dots, while the elements that make up the triangle are actually squares. The gestalt or organized percept that appears in consciousness is quite different from the sum of its parts.

Few facts in perception are as well known as the gestalt laws of perceptual grouping, which include grouping by proximity, similarity, closure, and so forth. There had been a number of precursors to the gestalt laws of organization, and theorists such as Stumpf and Schumann had noticed that certain arrangements of stimuli are associated with the formation of perceptual units. These investigators, however, were fascinated with the fact that such added

A square and a triangle appear as a function of the operation of the gestalt principle of perceptual organization labeled closure. qualities as the squareness or triangularity represented failures in correspondence between the physical array and the conscious perception. For this reason they tended to classify such perceptual-grouping phenomena as errors in judgment analogous the visual-geometric illusions. They argued that it was just as illusory to see a set of dots cohering together to form a square, when in fact there are no physical stimuli linking them, as it is to see two lines as different in length when in fact they are physically identical.

The gestalt theorists set out to attack this position with a theoretical article by Köhler (1913). This paper attacked the prevailing constancy hypothesis that maintained that every aspect of the conscious representation of a stimulus must correspond to some simple physical stimulus element. He argued that many nonillusory percepts, such as the perceptual constancies, do not perfectly correlate with the input stimulus. Perceptual organizational effects fall into the same class of phenomena. He argued that to label such percepts as “illusions” constitutes a form of “explaining away.” He goes on to say, “One is satisfied as soon as the blame for the illusion so to speak, is shifted from the sensations, and a resolute investigation of the primary causes of the illusion is usually not undertaken” (Köhler, 1913, p. 30). He contended that illusory phenomena are simply viewed as curiosities that do not warrant serious systematic study. As he noted, “each science has a sort of attic into which things are almost automatically pushed that cannot be used at the moment, that do not fit, or that no one wants to investigate at the moment,” (p. 53). His intention was to assure that the gestalt organizational phenomena would not end up in the “attic” with illusions. His arguments were clearly successful, since few if any contemporary psychologists would be so brash as to refer to gestalt organizations in perception as illusions, despite the fact that there is now evidence that the very act of organizing the percept does distort the metric of the surrounding perceived space in much the same way that the configurational elements distort the metric of the test elements.

THE PROGRESS OF PERCEPTUAL RESEARCH

Where are we now? The study of the perceptual problem and the issue of noncorrespondence remains an open issue, but it has had an interesting historical evolution. Wundt was correct in his supposition that psychology needed psychological laws, since physical and physiological laws cannot explain many of the phenomena of consciousness. What Wundt recognized was that the very fact of noncorrespondence between perception and the physical reality was what proved this fact and this same noncorrespondence is what often drives perceptual research. Köhler was wrong in saying that instances of noncorrespondence were relegated to the attic of the science. Instances of noncorrespondence or illusion are what serve as the motive power for a vast amount of perceptual investigation. It is the unexpected and unexplainable illusion or distortion that catches the attention and interest of researchers. The reason that there are no great insights found in the category of phenomena that are currently called illusions is that once investigators explain any illusion and find its underlying mechanism, it is no longer an illusion.

Consider the case of color afterimages, which Müller classified as an illusion in 1826. Afterimages would serve as stimuli for research by Fechner, Helmholtz, and Hering. Now that we understand the mechanisms that cause afterimages, however, these phenomena are looked on no longer as instances of illusion or distortion but rather as phenomena that illustrate the operation of the color coding system. Similarly, brightness contrast, which Luckiesh was still classifying as an illusion as late 1922, stimulated Hering and Mach to do research to explain these instances of noncorrespondence between the percept and the physical state. By 1965, however, Ratliff would no longer see anything illusory in these phenomena and would merely look upon them as perceptual phenomena that demonstrate, and are clearly predictable from, the interactions of neural networks in the retina.

The study of perception is fraught with the instances of noncorrespondence and illusion that are no longer illusions. The fact that a mixture color, such as yellow, shows no evidence of the component red or green wavelengths that compose it was once considered an example of an illusion. Later, once the laws of color mixture had been established, the expectation was built that we should expect fusion and blending in perception, which meant that the fact that the individual notes that make up a chord or a sound complex *could be* distinguished from one another and did not blend together into a seamless whole would also be considered to be an illusion. Since we now understand the physiology underlying both the visual and the auditory processes, we fail to see either noncorrespondence or illusion in either of these phenomena. Apparent motion (Wertheimer’s phi phenomena), perceptual organization, stereoscopic depth perception, singleness of vision, size constancy, shape constancy, brightness constancy, color constancy, shape from shading, adaptation to heat, cold, light, dark, touch and smell, the nonlinearity of judged stimulus magnitudes, intensity contrasts, brightness assimilation, color assimilation, pop-out effects, fifilling-in of the blind spot, stabilized image fading, the Purkinje color shift, and many more such phenomena all started out as “illusions” and instances of noncorrespondence between perception and reality. As we learn more about these phenomena we hear less about “illusion” or “distortion” and more about “mechanism” and “normal sensory processing.”

The psychological study of sensation and perception remains extremely eclectic. Perceptual researchers still are quick to borrow methods and viewpoints from other disciplines. Physical, physiological, optical, chemical, and biochemical techniques and theories have all been absorbed into the study of sensory phenomena. It might be argued that a physiologist could study sensory phenomena as well as a psychologist, and, as the history of the discipline shows, if we are talking about matters of sensory transduction and reception, or single cell responses, this is sometimes true. David Hubel and Torston Wiesel were physiologists whose study of the cortical encoding and analysis of visual properties did as much to advance sensory psychology as it did to advance physiology. Georg von Bekesy (1899–1972), who also won the Nobel Prize for physiology, did so for his studies of the analysis of frequency by the ear, a contribution that is appreciated equally by physiology and psychology. Although some references refer to Bekesy as a physiologist, he spent twothirds of his academic career in a psychology department and was initially trained as an engineer. Thus, sensory and perceptual research still represents an amalgam of many research areas, with numerous crossover theories and techniques. It is now clear that on the third major theme, the distinction between sensation and perception, with a possible strong separation between the two in terms of theories and methodological approach, there is at least a consensus. Unfortunately the acceptance of this separation has virtually led to a schism that may well split this research area. Psychology has accepted the distinction between sensation (which is primary, physiological, and structural) and perception (which is based on phenomenological and behavioral data). These two areas have virtually become subdisciplines. Sensory research remains closely tied to the issue of capturing a stimulus and transferring its information to the central nervous system for processing, and thus remains closely allied with the physical and biological sciences. Perceptual research is often focused on correspondence and noncorrespondence issues, where there are unexpected discrepancies between external and internal realities that require attention and verification, or where we are looking at instances where the conscious percept is either too limited or too good in the context of the available sensory inputs. It is more closely allied to cognitive, learning, and information-processing issues. Thus, while sensory research becomes the search for the specific physical or physiological process that can "explain" the perceptual data, perceptual research then becomes the means of explaining how we go beyond the sensory data to construct our view of reality. The importance of non sensory contributions to the final conscious

representation still remains an issue in perceptual research but is invisible in sensory research. The history of sensation and perception thus has seen a gradual separation between these two areas. Today, sensory researchers tend to view themselves more as neuroscientists, while perceptual researchers tend to view themselves more as cognitive scientists. While the distinction between sensation and perception is necessary and useful, the task of the future may be to find some way of reuniting these two aspects of research. Certainly they are united in the organism and are interdependent aspects of behavior.