Chapter 1

Introduction and History

"As used here, the term, cognition, refers to all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used. It is concerned with these processes even when they operate in the absence of relevant stimulation, as in images and hallucinations. Such terms as *sensation, perception, imagery, retention, recall, problem-solving,* and *thinking,* among many others, refer to hypothetical stages or aspects of cognition."

Ulric Neisser, *Cognitive Psychology,* 1967, p. 4

PREVIEW QUESTIONS

- *Where does knowledge come from?*
- *Is it possible to study mental processes if we cannot observe or measure them directly?*
- *Is cognitive psychology the study of human behavior or the study of the human mind?*
- *What roles, if any, do disciplines such as linguistics, computer science, anthropology, and neuroscience have in modern cognitive psychology?*

1.1 Introduction

Try to imagine, if you can, all that is going on around you and within you as you read these first few sentences. You might be seated in some quiet room, but undoubtedly there are other things going on that could distract you. Other people might be talking or you might hear music or traffic noises from outside. Nevertheless you continue on, but you are likely to turn away if someone calls your name, your telephone beeps, or you need to get a drink. As you read you might think of how your eyes move as you take in each new character and word in the line of print. Somehow these ink marks excite memories of words, language, and ideas, and you might generate original thoughts in your mind as you consider the meaning of the text. Finally you might reflect on what you have read, or discuss it with a friend, later to forget about it or recall some idea that might be interesting or important in addressing some problem. All of the acts involved in reading a few simple sentences and thinking about them include the topics that are actively researched and discussed by cognitive psychologists.

Cognitive psychology The study of how the human brain produces mental activity and observable behavior

Cognitive psychology, simply put, is the study of the human mind and how it works. It remains one of the most impenetrably difficult areas of research and theory in all of science. So difficult, in fact, that some psychologists in the early part of the twentieth century decided to study behavior, while at the same time, denying the very existence of the mind itself! This emphasis on behavior alone is an extreme view, but one that is nevertheless held by some scientists even today. The idea that the mind can study itself is fraught with methodological and theoretical problems that are a constant challenge for cognitive researchers. A strict behaviorist argues that observable facts are the only basis of knowledge. By this view, theory, at best, only suggests what observations are likely to be most important. Behaviorism, as set forth by John Watson (1913), maintained that human behavior should be explained only in terms of observable stimuli and responses. He claimed that any explanations based on appeals to hypothetical mental states or processes are simply speculative delusions, not based on observable, scientific facts. If such thoughts dominated psychology today, Neisser's (1967) insightful book, including the quote that begins this first chapter, would have been tossed into an academic trash heap rather than becoming one of the most important intellectual efforts defining the field of cognitive psychology.

It is our purpose in this book to impress upon students of cognitive psychology how modern methods of research and theory are capable of answering questions about what the human mind is like and how it works. We have a common advantage in exploring this discipline in that each of us has a mind to work with. Thus, we can appeal to you to think about what is involved in remembering, say, what you had for breakfast or where you last parked your car or bicycle. Similarly I might ask you to recall what you did on your 16^{th} birthday, who your 3^{rd} grade teacher was, what "vicissitude" means, or how to find the square root of 256. You can do these kinds of things, with more or less success, but it is interesting to introspect (i.e., look into one's self) about how they are done. Your introspections might be right or wrong, and they might agree with us or not, but they can result in interesting speculations that lead to testable theories of how the human mind works.

Introspection was a major scientific method used at the beginning of experimental psychology over 100 years ago. It was thought that the mind could study itself through careful thought and recording of one's experiences. Thus, when leaving a building, you might remember where you parked your car by remembering the route you took to approach the building after you parked it. Similarly, you might remember your 3^{rd} grade school building, your classmates, and your teacher's face before recalling his or her name if in fact you can recall any of these very well. Memory sometimes seems to involve a kind of active recollection of one's thoughts or actions produced at an earlier time. Other memories are not so actively recalled, and we are sometimes perplexed about why we cannot remember certain things. Still other thoughts and memories seem to spring to consciousness without effort or will, or even to our own annoyance. It should be obvious that there are many aspects of memory that are hidden from one's own thoughts about the matter, and it is unlikely that we can agree about whether or not each of our memories work in exactly the same way. Introspection fails as a research tool because of this kind of variability across individuals, and behaviorism arose partly as a reaction against introspective research techniques. Cognitive researchers spawned a scientific approach to the study of memory and cognition that, rather than being based on subjective introspection, uses objective laboratory research to find out what we do when we try to perceive, learn, remember, and use information.

1.2 Historical Roots of Psychology

1.2.1 The Dawn of Epistemology

The study of the human mind has its origins in philosophy, particularly in the work of Greek philosophers, beginning about 2,500 years ago. They addressed a fundamental question that confronts us today: How does the mind acquire knowledge? Plato, a student of Socrates, argued that true knowledge could not possibly be based on experience because real-world objects are merely imperfect replicas of more general *ideas* or *forms.* Perfect forms, such a perfect sphere, exist only in our minds, and these are supposedly present from birth. Such internal forms help us to recognize what objects are and to understand how they can be used, but such knowledge generally precedes and is actually more important than any knowledge that can be gained from experience with objects. In fact forms are eternal and unchanging, unlike physical objects themselves, or even worse, our perceptions of them. Some philosophers have credited Plato with an important insight—true understanding of natural phenomena must go beyond mere observations alone. Indeed, our internal representations of object categories might be based on certain ideal members, or prototypes, which are parts of an important, modern theory of how we group things into categories. That is, our idea of whether a given object is a bird or a "good" red color might be based on how close the observed example is to an ideal or prototypical member of the respective category. Plato also anticipated a major contribution of the modern scientific method, namely scientific induction. The idea is that observations of real-world objects and events can lead to idealizations and generalizations that are the basis of theories that can eventually explain our perceptions (Cottingham, 1987).

Nativism The idea that much of our knowledge and behavior is inborn or biologically programmed to develop in a certain way

Plato advocated what came to be known as the **nativist doctrine** of knowledge. Nativists believe that much of what we know is innate. Such innate knowledge is necessary, according to the nativist view, since some aspects of our behavior are too complicated to be the result of learning. For example, it has been argued that our knowledge of language is too complete and acquired too early in life to be based on experience alone (e.g., Chomsky, 1959). Humans are also born with a variety of reflexes and behaviors that appear to be innate, such as startle, rooting (i.e., searching for a nipple when the face is stimulated), and grasping reflexes. These behaviors are common to other primates and have evolved presumably as a means to insure survival of relatively helpless newborns.

Empiricism The idea that much of our knowledge and behavior is learned through experience

Plato's student Aristotle argued, alternatively, that most knowledge could not possibly be inborn and shared by all of us. Rather, he believed that knowledge must be based on experience, a doctrine called **empiricism**. Aristotle originated the empiricist viewpoint that observation is the basis of all knowledge, and that learning is a product of experience. To Aristotle, even one's thoughts are the results of past experiences. He reduced all conscious processes to the internal manipulation of representations of the material world. The nativist-empiricist debate has persisted to the present day. This is at least partly due to the fact that there are hereditary, biological components to all human behaviors, even if they require appropriate experience for their full expression (e.g., Bridgeman, 2003). Although infants will show a stepping reflex if they are held over a hard surface, learning to walk occurs only much later and with appropriate practice after greater voluntary control of leg motions and balance is achieved.

1.2.2 Descartes and Rationalism

Rationalism The idea that much of our knowledge and behavior is created by mental activities alone and is the sole product of neither inheritance nor environment

Rene Descartes (1596–1650) and others developed the rationalist philosophy in the seventeenth century. **Rationalism** is the belief that true knowledge comes only from human reason, and that logical reasoning will reveal life's mysteries. Thus, rationalism denies both nativism and empiricism to some extent by making the human mind the creator of its own knowledge. Descartes was also the founder of the doctrine of dualism; namely that the body can be explained in terms of the physical laws of nature, but the mind exists as a transcendental spirit. Even though the mind and body interact in most behaviors, dualists believe that the human mind can never be reduced to mere biology. In that sense, knowledge does not come from experience alone, but from mental reflection upon experience that transcends physical limitations. It should be noted that not all rationalists were dualists. For example, Spinoza (1632–1677) rejected dualism, and proclaimed that the mind is a product of the body, yet he endorsed rationalism as a means for humans to ascend and prevail over animalistic behaviors. Further, rationalism asserts that we are not limited only to what we have been born with or to what has occurred to us in the past, but that we are capable of creating new ideas and bodies of information based on emergent properties of our inheritance and experiences.

1.2.3 British Empiricism

The ideas of Aristotle were rekindled in Britain in the seventeenth and eighteenth centuries in a reaction not only against rationalism, but also in opposition to centuries of spiritualism and mysticism. Francis Bacon (1561–1626) argued that knowledge grows only through induction of general principles from repeated observations provided through the senses. Since the physical world is supposedly a regular, law-abiding system, our careful observations should lead us to recognize these regularities. When we create formal statements that summarize these regularities, we have defined some of the laws of nature. Bacon was instrumental in separating science from philosophy by arguing that science must be based on rigorous testing of principles induced from observations. He anticipated the modern scientific method by rejecting the notion that we should seek only information that supports our ideas. By seeking confirmations of our beliefs, it would be possible to retain incomplete or erroneous theories indefinitely. Rather, he insisted that we must look for exceptions to proposed general principles in order to limit their generality or disprove them altogether.

John Locke (1632–1704) expanded on Bacon's views by tracing all simple ideas to their origins in specific sensory experiences. Simple ideas based on memories for specific objects and events could be combined through **association**, he argued, into complex concepts and abstract ideas. He also agreed with Isaac Newton that all objects and events in the universe obey lawful relationships of cause and effect. The associations among ideas in the mind were thought to reflect relations among objects in the real world. Further, mental associations could creatively represent imagined or even impossible physical events. The British empiricists' belief that simple associations form the basis of all knowledge has been used by cognitive psychologists today to explain many types of learning (e.g., Anderson, 1983). The empiricist tradition also has contributed to the general faith in the scientific method of inquiry to develop and test explanatory laws of nature, including theories of human behavior.

Associationism The idea that much of our knowledge and behavior can be reduced to simple associations among stimuli, their representations in memory, and responses

Intellectual giants like Galileo (1564–1642) and Newton (1642–1727) contributed to our understanding of natural laws based on observations under carefully controlled conditions. Their successes in physics encouraged the belief that the scientific method could be applied to the study of human behavior and mental processes. These views were supported by Charles Darwin (1871; 1872) despite criticisms from contemporaries that it "… would insult religion by putting the human soul in a pair of scales" (Gregory, 1987, p. 416). Yet, Darwin found himself forced to conclude that the mind has a physical basis in biology. He formed this conclusion from many observations of animal communication through facial expressions and bodily movements and posturing. He believed that not only our physical form, but also some of our abilities to communicate meanings and emotions were inherited from our nonhuman ancestors (Gregory, 1987, pp. 179–180).

1.3 The Birth of Experimental Psychology

1.3.1 Donders and the Subtractive Method

In the nineteenth century there was a flurry of developments to advance psychology as a separate domain of scientific inquiry apart from its roots in philosophy and physiology (Boring, 1950). The goal was to develop scientific psychology, modeled on physics, by using similar research methods, only applied to human behavior and mental processes. For example, F. C. Donders (1869/1969) in Holland sought a method to measure some properties of internal mental events. Although such mental processes remain hidden from direct observation, he thought that he could find a way to time their durations and then have at least something to say about how the mind works.

Donders began his research by using a simple stimulus, such as a light, and a simple response, such as hitting a button, and he timed how rapidly an observer could press the button when the light was turned on. Today we call this experimental procedure a measure of simple reaction time (RT), and for a normal young adult, simple RT can be as short as two-tenths of a second (200 milliseconds). Donders reasoned that if he could complicate this simple situation a bit and measure the RT for the more complicated task, he should be able to measure the time it takes for someone to deal with the complication. For example, he next used two different lights; say a green one and a red one. The observer was instructed to hit the button as rapidly as possible only if the green light appeared, and to do nothing if the adjacent red light turned on. Today we call this a go/no-go task, and it is not surprising that RTs on "go" trials in this task tend to be longer than those in simple RT tasks. The only difference between the two tasks is that in simple RT, there is only one light to attend to, but in the go/no-go task, there are two lights. Any difference in average RT between the two tasks should be equal to the time necessary for someone to make the discrimination between the green light and the red one.

Subtractive method A method of using differences in response times to measure the duration of mental processes (If two tasks differ in only one step, then their RT difference is equal to the time it takes to carry out that step.)

Following this logic, Donders invented the **subtractive method**, whereby a specific mental event, like color discrimination, could be timed by performing the operation (see Figure 1.1).

The subtractive method can be used in any number of applications that are based on observable behaviors. In a simple example, if we notice that someone washes three plates in 45 seconds and four plates in 60 seconds, the difference between these two times should be the time necessary to wash a single plate. Of course, one could easily observe a human plate washer directly and measure the time to wash one plate with a stopwatch. The unique aspect of Donders's method is that it enables us to time mental events that are not directly observable. The subtractive method has been used in numerous laboratory studies to estimate the durations for a variety of different mental events. Although these times do not tell us exactly what is going on inside the head, they do allow us to compare times for different tasks and test theories about why some things should take longer than others.

FIGURE 1.1

Example Application of Donders's Subtractive Method for Timing the Durations of Mental Events

(1) Simple reaction time (SRT) task: One stimulus and one response:

The subject is to push a response button as soon as a light (e.g., a green one) is turned on. Therefore, SRT consists of two processing stages: a stimulus encoding stage, in which the stimulus (e.g., the green light) is perceived, and a response stage, in which the response (push of the button) is executed.

SRT = elapsed time between onset of the green light and onset of the button press.

(2) Go/no-go response time (Go/no-go RT) task: Two stimuli and one response

The subject is to push a response button as soon as one of the lights is turned on (e.g., a green one), but is to withhold a response to the other one (e.g., red). Therefore the Go/no-go RT consists of three stages. The first stage is the stimulus encoding stage that is the same as the SRT. The second stage is a discrimination stage, in which the go stimulus and a no-go stimulus are discriminated. The third is the response stage that is the same as the SRT.

Go/no-go RT = elapsed time between onset of the green light and onset of the button press.

(3) Choice response time (CRT) task: Two stimuli and two responses

The subject is to push one response button for a green light, and a different response button for a red light. Therefore, CRT consists of four stages. The first and the fourth are the Encoding stage and the Response stage which are common across all three tasks. The second stage is the discrimination stage, which is the same as in the go/no-go task. The third stage is the Choice stage, in which the response button is selected.

CRT = elapsed time between the onset of the green light and the onset of the button press.

Therefore, the information processing stages in the three tasks are summarized as follows.

SRT = Encoding + Response

Go/no-go RT = Encoding + Discrimination + Response

CRT = Encoding + Discrimination + Choice + Response

Illustration of the subtractive method to time specific internal mental events:

Go/no-go RT – SRT = time to discriminate between two possible stimuli.

CRT – Go/no-go RT = time to choose between two possible responses

However, there are problems with using the subtractive method that were discovered shortly after its invention. The main problem is that the method assumes that the addition of some task component changes only how the observer deals with that component, and everything else remains the same. In some cases, however, additional components cannot be "purely inserted," but broadly affect other aspects of task performance. That is, the addition of another stimulus can produce qualitative changes in how the task is performed rather than merely quantitative changes. For example, taking a call on a mobile phone while driving might appear to take only a few seconds to pick up the phone and punch a button, but the diversion of attention away from driving for the entire length of the conversation can have serious consequences. A similar situation can occur when two different prescription drugs are taken that have predictable beneficial effects on their own, but their interaction is unpredictable and sometimes dangerous. It was not until 1966 that Saul Sternberg demonstrated how careful restrictions on Donders's method could lead to an improved method to study how the mind works (see Box 1.1).

BOX 1.1

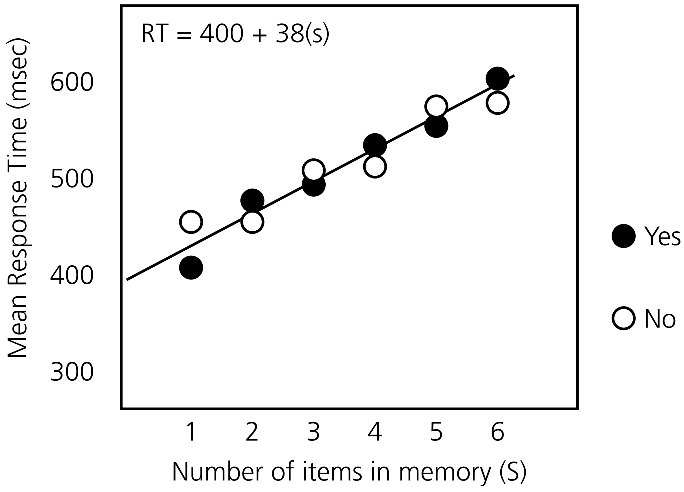
Measuring the Speed of Mental Processes

In 1966, Saul Sternberg published a paper in the prestigious journal *Science* that had an enormous influence on cognitive psychology. In the first place, he refined a method for timing mental events that was based on the subtractive method of Donders. In the second place, he demonstrated how to develop theoretical ways to measure otherwise unobservable processes occurring in immediate or short-term memory.

The task he used was a simple one that can be approximated as follows: Think of your current telephone number. When you have it in mind, answer the following question as rapidly as possible—is there a five in it? Most people can make this decision rapidly and with few errors even if the numbers held in memory (the memory set, in Sternberg's terms) change from trial to trial and so does the single test digit (called the probe). In fact, Sternberg varied the size of the memory set from one to six items so that there would be few problems with forgetting or errors in the task, and the probe was a member of the memory set on half of the trials. People were told to hit a "yes" or "no" button as rapidly as possible to indicate whether or not the probe was a member of the memory set. Each subject was run for many trials with the memory set, and items varied randomly from trial to trial. The average response times (RTs) were then found, and the RT data were plotted along the ordinate (Y axis) and the number of memory set items along the abscissa (X axis), as is normally done when observed data are plotted against experimental conditions.

The data showed one of the most striking results in all of modern psychology: The response times (RTs) were almost a perfect, increasing linear function of the number of memory items. Further, the slopes of the lines (average increase in RT for each additional memory item) were nearly identical for yes and no responses. This result was surprising for two reasons. First, most psychologists thought that immediate, short-term memory should be literally immediately accessible, so that there should be no increase in RT with increasing memory set size. Sternberg incorporated this idea in a parallel search model to reflect the fact that if all items in memory are accessed at once, the RT by set size functions should be flat. Since the functions had a positive slope, the simple parallel model was rejected.

An alternative model is based on the assumption that there is some kind of serial search process operating in short-term memory. If this search consists of an item-by-item scan looking for a match between the probe and each of the memory items, then the linear increase in RT across set size would be expected.



(Graph adapted from Sternberg, 1966)

Again, however, many psychologists objected. Why, they argued, should the linear increase be the same on yes and no trials, since the probe should match one of the memory items sometime during the scanning process on positive trials? On negative trials, the scan would have to go all the way through the memory set before a response could be made, but on positive trials, on average, the scan should have to go only halfway through the set. Therefore, there should be about twice as many comparisons on "no" trials as on "yes" trials. Since the increase in RT with increasing set size (slope of the line of best fit to the data) presumably reflects the number of comparisons that have to be made, the slope of the RT by set size function should be twice as large on negative trials as on positive trials. However, the data showed that the slopes were the same on "yes" and "no" trials. If the slope of the RT by set size function represents scanning time, then the results imply that all comparisons are made on both positive and negative trials even though a match is found sometime during the scan on positive trials.

Sternberg reasoned that on every trial some time is taken up by non-scanning processes that do not depend on the number of items in the memory set. That is, when the probe is presented, it must be visually processed and recognized before it can be compared with the items in memory. Further, when the comparison is complete, a decision must be translated into a motor response to hit the "yes" or "no" response button. Thus, probe recognition, decision, and response execution occur on every trial. The sum of their execution times yields a constant factor to overall RT. Only the number of comparisons changes from trial-to-trial. Thus, the slope of the RT by memory set size function represents the comparison time per item. Sternberg argued that since this comparison process is so fast (the slope was about 38 ms per item), it would make sense to execute all comparisons between the probe and the memory items before deciding whether a match had been found. Switching between a fast comparison process and a slow decision process after every comparison would only slow the whole process down. Sternberg argued that his data supported a serial, exhaustive scanning process operating in short-term memory for determining whether a probe matched one of the items held in memory. The exhaustive scan would be faster, on average, than a scan that checked for a match after every comparison and terminated with the discovery of a match on positive trials. Further, he demonstrated that the time to make a comparison between two codes in memory could be as little as about 38 ms, if his theory is correct.

There have been many replications of Sternberg's results over the past decades, and his theory has been challenged in various ways. Yet, he made several important, lasting contributions to cognitive science. He demonstrated that, with proper care, Donders's subtractive method could be used to measure the times needed for executing otherwise hidden mental processes. That is, by introducing only a simple change into an otherwise complex task, the change could be "purely inserted" to have an effect on only one process in the overall task. Varying the number of items in the memory set should affect only the memory comparison stage of processing, leaving probe encoding, decision, and response processes intact. Sternberg also developed a new methodology for the analysis of RT data to test theories of how mental operations are executed. Many advances and new applications have been made in the use of RT data to induce and test theories of cognitive processes based on Sternberg's original contribution.

1.3.2 Weber, Fechner, and Psychophysics

Ernst Weber and Gustav Fechner in Germany took a unique approach to using the scientific method to measure mental processes. They were interested in how our sensory responses are related to the strength or intensity of physical stimuli. In the mid-nineteenth century, Weber studied the just noticeable difference (jnd) between two similar stimuli, such as two lights that differed in brightness or two tones that differed in loudness. The jnd is the smallest change in stimulus intensity (up or down from some standard stimulus) that an observer can reliably report as a noticeable change. Weber made the important discovery that for almost all stimuli, the jnd was a linear, increasing function of the standard's stimulus intensity. He formulated the

Weber's law The observation that the just noticeable difference (jnd) in stimulus intensity is a constant proportion of stimulus intensity throughout most of the intensity scale

observed linear relation into what became known as **Weber's law**—the ratio of the jnd to stimulus intensity is a constant across stimulus intensity:

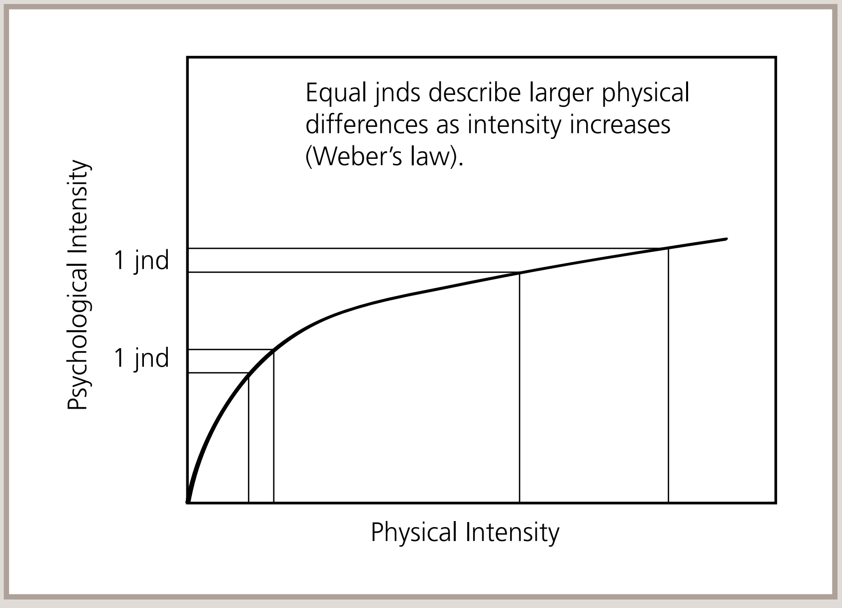
$$\text{jnd} = \frac{\text{Just noticeable change in stimulus intensity}}{\text{A standard stimulus intensity}} = \text{A constant value}$$

As an illustration, if 20 grams added to 100 grams is a just noticeable increase in weight, then 200 grams added to 1000 grams, which maintains the same ratio, should also be a just noticeable difference. This fact was confirmed in Weber's laboratory.

Fechner (1860) took these results one step further. He reasoned that an internal psychological scale must exist for every external physical scale that we are capable of perceiving. Our perceived brightness of a light, loudness of a tone, or heaviness of a weight must all be based on psychological values, not on physical values directly. That is, our sense organs determine the apparent intensity of a stimulus, and the apparent intensity need not change in a direct, linear relation with physical intensity. In fact, he proposed that the function relating psychological intensity to physical intensity should be logarithmic, rather than linear, in order to sustain Weber's law. The logarithmic relation describes diminishing increases in psychological intensity as physical intensity increases by constant increments [i.e., psychological intensity falls off as a negatively accelerating function of physical intensity (see Figure 1.2)]. This was a fundamental discovery—what we perceive is not a literal copy, nor even a simple linear transformation of object and event properties in the physical world. Rather, our senses transform aspects of physical objects and events into psychological variables that have different qualitative as well as quantitative properties than the underlying physical variables.

FIGURE 1.2

A Logarithmic Relationship between Psychological Intensity (ordinate) and Physical Intensity (abscissa) can Produce Equal jnds for Small Stimulus Changes at Low Intensities and Large Changes at High Intensities.



The study of the relation between some physical variable and its psychological representation is called **psychophysics**. Plato was right in the sense that physical objects are imperfect representations of our mental ideas, but he was wrong in asserting that we could not learn about one from the other. Rather, research supported Aristotle's position that observations can determine what the world is like. There are lawful relationships between physical events and psychological interpretations, a fact anticipated by Fechner's psychophysics.

Psychophysics The study of the lawful relation between some physical property of a stimulus and the psychologically perceived property

1.3.3 Ebbinghaus's Studies of Memory

Other psychologists in Germany applied the scientific method to the study of learning and memory. One of these, Hermann Ebbinghaus, read Fechner's (1860) book and was duly impressed with the new application of the scientific method to mental processes. He decided to undertake a similar study of memory. His classic book (Ebbinghaus, 1885) describes a heroic study using himself as his only subject for many years of research. He daily studied lists of nonsense syllables (like DAF and KUD—chosen because they had no meaning and therefore were being learned for the first time in his experiment). His usual method was to study and test himself on each list repeatedly until he achieved perfect recall of the entire list. Then he put the list away and returned to it only after hours, days, or weeks had passed. Of course, he could recall very few items from the nonsense lists after long intervals between their original study and the subsequent tests, but he did show some memory for the lists, as they were usually learned more quickly the second time, even if he could not remember much about them when they were first recovered from his files. Thus, he discovered a type of implicit memory savings which became very important for later theories of human memory.

Ebbinghaus discovered many other facts about human learning and memory from his simple yet elegant studies using nonsense lists. He found that learning (and forgetting) is rapid at first, then slowly approaches some limit (see Figure 1.3). He also found that additional study even after perfect recall had been achieved (sometimes called *overlearning*) produced higher levels of memory later—a fact well worth considering in preparing for a test some days in the future.

Ebbinghaus also discovered what today is called the memory span—short lists of up to seven items or so can be remembered perfectly after a single study trial, but longer lists inevitably produce errors until they are studied several more times. Finally, he invented the method of **savings**, which is the most sensitive way to measure memory that has ever been devised. People can fail to recall or even recognize something like a game or a poem presented to them, but if they had ever played the game before or studied the poem for any length of time, it can usually be relearned with greater ease than if it never had been experienced before. This is but one example in which one's introspections about memory can be wrong; memory can be shown to exist for some things even when people deny ever having seen them before.

Savings The most sensitive measure of memory, developed by Ebbinghaus; the reduction in time to learn something a second time given that it was once learned earlier

FIGURE 1.3

Examples of Simple Learning and Forgetting Curves

From Hilgard, E. R., Atkinson, R. C., & Atkinson, R. L. (1975). *Introduction to Psychology,* 6th Ed. New York: Harcourt, Brace, Jovanovich, p. 214 (Figure 1.3.1) and p. 225 (Figure 1.3.2).

Figure 1.3.1 shows the proportion of correct responses after each study trial for a list of items. Learning is more rapid for the shorter list (50 items) than for the longer list (100 items), but the learning curve has the same shape. The data are from Atkinson (1972).

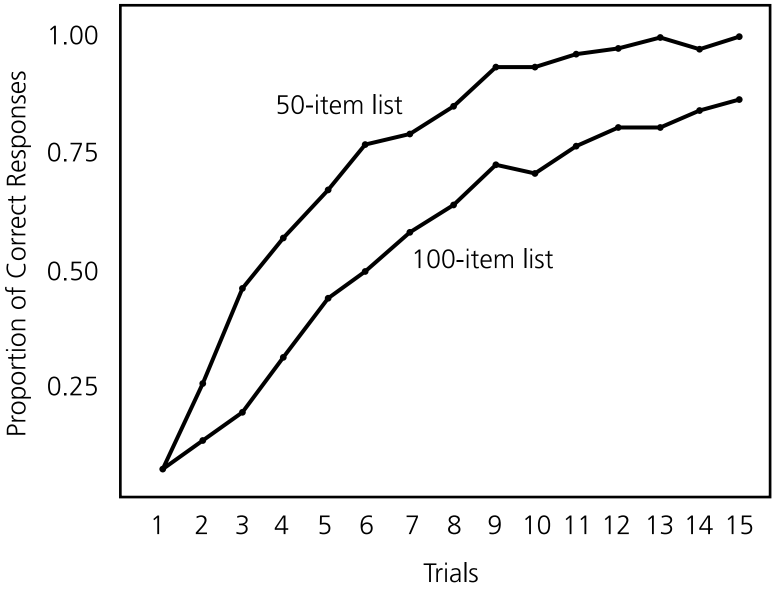
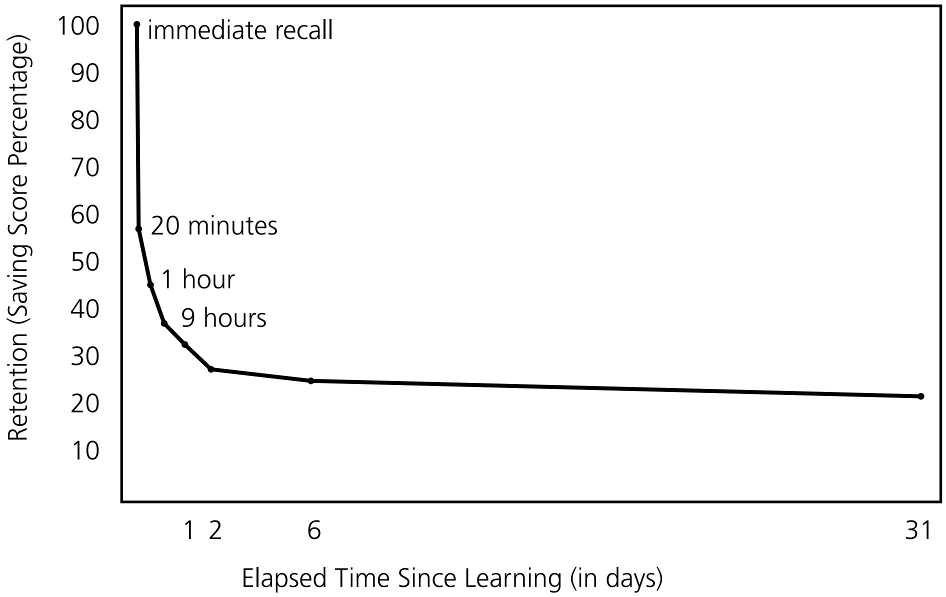


Figure 1.3.2 shows the amount of retention (measured as savings) for lists of nonsense syllables as a function of delay since the initial study to a level of perfect recall. The data are from Ebbinghaus (1885).



1.3.4 The First Laboratory in Experimental Psychology

Psychology as a formal discipline has often been traced to the founding of the first psychology laboratory by Wilhelm Wundt at the University of Leipzig in 1879. Many eminent psychologists began their careers in Wundt's lab, including James McKeen Cattell, the founder of the American Psychological Association and the American Association for the Advancement of Science. Wundt was a pioneer of many laboratory procedures that have remained in use to the present day. However, he is perhaps most famous for his unfortunate choice of **introspection** as a major method of studying mental events. He and his students were interested in reducing complex experiences to the simplest elements of conscious awareness. This choice was based on an analogy with physics—just as matter could be decomposed to its molecular and atomic components, Wundt hoped that introspection could reduce sensations to the "atoms of consciousness." Observers in his lab were presented with simple lights or tones and taught to think deeply about what they experienced. The method followed the rationalist tradition in that the power of human reason was supposed to reveal the true nature of mental processes. Further, it was believed that deep insight into one's mental processes could lead to the discovery of the elementary components of consciousness, just as physicists were discovering the fundamental structures of matter.

Introspection The subjective study of one's own mental processes by looking inward into oneself

Unfortunately, the method of introspection suffers from at least two fatal flaws. First, the method is unreliable. What you claim to experience and what I think I experience even in very similar situations is often different, sometimes startlingly so. Training in introspection was geared toward uniformity across individual experiences, so that one's success in graduate school could depend on having the same "mind's eye" as one's major professor. Yet, people can and do perceive things differently, even when trying to arrive at a consensus description of an observed event. Consider the common observation that different eyewitnesses of an accident or a crime often provide conflicting testimony.

A second fatal flaw for introspection is the fact that the method is insufficient to reveal many mental processes. Many things that we do in response to a stimulus, even a very simple one, occur too rapidly and at too low a level to be available to conscious introspection. For example, let's think about what happens when a light is suddenly turned on. Light striking the retina of the eye initiates a cascade of chemical and electrical processes that decades of study have failed to reveal completely. The first tenth of a second (100 milliseconds) after a flash of light results in propagation of millions of neural signals from the retina to several parts of the brain, most of which never result in conscious experiences. Introspection is obviously incapable of "shedding light" on early visual processes. Many other psychological processes, from simple reflexes to complex associations that come readily to mind, are also immune to conscious introspection about their origins and their effects on our behavior.

From this discussion you should not conclude that there is no use for introspection in psychology. All of us think about why we favor one friend over another or why we forget important appointments. However, our thoughts about these matters cannot be regarded as data in the sense that data are independently replicable observations. Nonetheless, introspections can lead to theories that are testable against data, as in the classic research of Sperling (1960), who asked how much information is visible in a single, brief exposure to a simple visual stimulus (see Box 1.2).

1.4 The Rise of Behaviorism

1.4.1 The Empirical Approach of Watson and Skinner

European psychologists' emphasis on introspection and conscious experience was one of the main causes of the rise of behaviorism in America early in the twentieth century. Scientists like John Watson and B. F. Skinner objected to the direction that psychology was taking, wandering far from its scientific beginnings in psychophysics (Fechner) and memory research (Ebbinghaus). In order to restore its place among the physical and biological sciences, they believed that psychologists should insist on replicability of research results. In other words, observations should be carefully made of the exact physical conditions of the stimulus environment, the exact properties of the subject's responses, and the relationships that exist between them. Only measurable stimuli and responses were to be included in behaviorism, along with manipulations of rewards and punishments that could influence the associations between stimuli and responses.

Behaviorists adopted the British empiricists' views that the acquisition of simple associations is the basis of all learning. For example, the repeated pairing of two stimuli, such as a bell and the presentation of food to hungry dogs in Pavlov's (1927) **classical conditioning** research, results in a learned association between the two stimuli. After repeated pairings, the bell alone could come to control the response—salivation in anticipation of feeding—almost as well as the original presentation of food alone. Pavlovian, or classical, conditioning shows that some types of learning can be based on the acquisition of associations between different, previously unrelated stimuli. Such associations are common in all of our experiences, such as when we associate an object or person with a name or associate fear with novel stimuli (e.g., a phobic fear of spiders or a prejudicial avoidance of members from another ethnic or religious group).

Classical (Pavlovian) conditioning The learned association between two stimuli due to repeated reinforced pairings (A bell followed by food leads to salivation to the bell alone.)

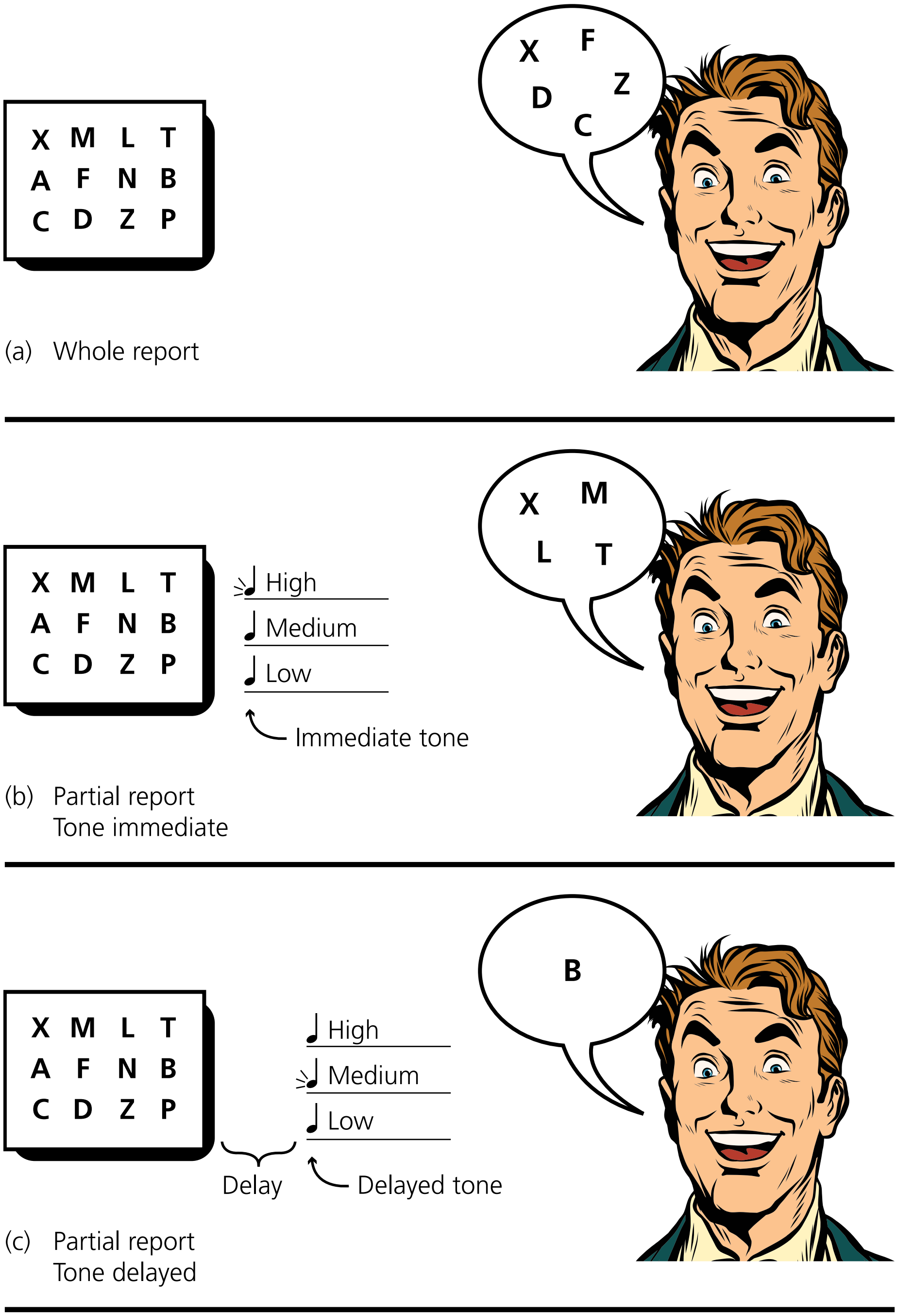
Operant, or Skinnerian, conditioning is also based on learning simple associations, but in this case, between a stimulus and a response that initially have weak or no associations. Skinner showed that a hungry rat would explore a cage thoroughly in search of food, and when it pressed a lever in the cage and a food pellet appeared, the rat would be likely to push the lever again. Very soon the hungry rat will push the lever

Operant (Skinnerian) conditioning A learned association between a stimulus and a response due to reinforced practice (A bar press followed by a food pellet increases the probability of a bar press in the future.)

BOX 1.2

Measuring the Duration of a Visual Image

Many experiments have been devised to answer the question: How much can we see in a single eye fixation? This question was addressed in Wundt's lab by James McKeen Cattell and also by Raymond Dodge and Benno Erdmann in Germany more than 100 years ago (see Huey, 1908/1968, for a thoughtful review of early research on word perception and reading). They used various types of apparatus to present words or letters very briefly that then were to be reported. The general conclusion was that the amount reported depended on the meaning and familiarity of the material. For unrelated consonants, however, only four or five items could reliably be reported even if there were many more letters in the display.



Procedure used in Sperling's (1960) experiment. (a) In the whole report task, subjects report as many letters as possible from a brief (50 ms) display—about 4.5 is the average number. (b) If a cue is given to report the top row (high tone), middle row (medium tone) or bottom row (low tone), performance is almost perfect (4 out of 4) if the tone occurs as soon as the display is offset. (c) If the tone is delayed for as little as half a second, however, performance drops precipitously. [From Goldstein, E. B. (2005). *Cognitive Psychology.* Belmont, CA: Thomson/Wadsworth, p. 144.]

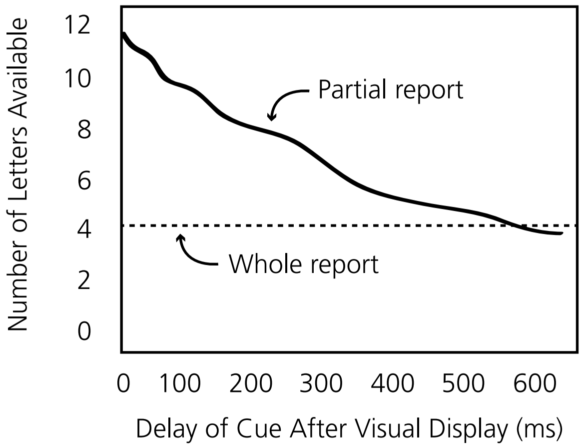
Continues

From the behaviorist tradition, the number of letters reported should be taken as the number seen, since correct report is a reliable behavioral response. Yet almost everyone who has ever participated in these types of experiments has complained that many letters can actually be seen, but they gradually fade away before they can be reported. What can an experimental psychologist do if observers' introspective reports disagree with the data that are collected? What was done for almost a century was to ignore the subjective reports and record the actual data. The number of letters correctly reported after a single brief exposure of a multi-letter display was taken as a measure of what was actually seen.

In 1960, George Sperling published the results from his doctoral dissertation in a paper that became one of the hallmarks of the cognitive revolution. He took his observers' introspections to heart and tried to invent a way to measure how much information was actually available immediately after a brief visual display. He hit on the clever idea that rather than asking his participants to report all the letters in the display (whole report task), he would only ask for part of the display to be reported (partial report task). The trick was that the observers never knew which part was to be reported until after the display was turned off!

Sperling used displays of unrelated consonants in rows and columns centered on the display. For example, the display could include four consonants in each of three rows. Sperling used a tone, sounded shortly after the display ended, to cue the observers which row to report. A high tone indicated the top row, a medium pitch indicated the middle row, and a low tone indicated the bottom row. He found that people could accurately report letters from the cued row if the tone was presented within a fraction of a second after the display was shut off. However, if the tone was delayed further, observers could only guess from the four or five letters that they could remember in short-term memory (whole report level). That is, the partial report technique showed an advantage over whole report that was statistically significant for cue delays up to almost a half second after the display was physically gone.

The important deduction that Sperling made was that since his subjects could report three to four letters from the single cued row, without knowing which row was to be cued, then they must have had three to four letters available for a brief time from each of the rows. This very-short-term visual memory came to be called *iconic memory* to indicate its sensory nature. The icon is a brief image of a display that persists for some time in sensory memory after the display is gone. The iconic image can be scanned with attention much like an actual display can be scanned with eye movements, but its duration is very brief. Once the icon is gone, and Sperling found that little useful information persisted beyond about 300 ms in most conditions, only those letters remain which have been coded into a more durable form, such as letter names in verbal short-term memory.



The importance of Sperling's research rests on its demonstration that although introspections might be unreliable, they nonetheless can be sources of theories to be tested in the laboratory. In this case, people's introspections are correct. A brief visual display is stretched out in time by persisting sensory activity, and as long as it lasts, the sensory image can be looked at by the "mind's eye" in much the same way that we examine a concrete image with eye movements. Since the time of Sperling's research, it has been shown that other sensory modalities, such as hearing and touch, also have brief memories. Sensory memories serve the likely function of lengthening the time that sensory information is available so that we can attend to selected parts and code them into a more permanent form for later use. The image of a tiger illuminated by a flash of lightning or the flickering light of a campfire would be useless if it could not be retained long enough for us to figure out what it is. Similarly, speech sounds cannot be recognized as words or sentences unless we have some type of memory available to integrate them over time. The first operation performed on selected sensory information is to try to match or categorize it with respect to known information in memory. We call this categorization process perception, and it is the topic of Chapter 3.

rapidly and repeatedly when placed in the cage, demonstrating a learned association between the appearance of the lever and the response of pushing it in order to obtain a reward. In general, operant conditioning relies on behavior coming under control of its consequences. Many human behaviors are similarly shaped by the consequences that follow them. Talking at the dinner table is much more likely to be reinforced by one's companions than talking in a movie theater, resulting in different behaviors in the two situations.

Behaviorists developed the scientific method of inquiry to a high level in psychology. They are largely responsible for the scientific rigor we demand in research today, based on careful recordings of the stimulus environment and exact specifications of how a response is defined and measured. They also insisted on strict controls in laboratory science, so that ideally all variables (both environmental and subject variables) could be controlled but one, and that one was deliberately manipulated to observe its effects on behavior. Such precision and control enables research results to infer causal relations among variables, and it allows data to be collected in similar ways in different laboratories to test the generality of causal laws. Then results can be replicated (or not) and theories can be tested in a way that enables knowledge in the field to accumulate.

1.4.2 Limits of Behaviorism

Behaviorism's insistence on observables excluded most of the topics of interest to modern cognitive psychologists, as listed in the quote from Neisser (1967) at the beginning of this chapter. Mentalism was excluded from the scientific endeavor since behaviorists believed that there was no way to measure mental events, only their consequences in observable behaviors. Thus, the study of processes, like thought and imagery along with much of perception and problem solving, were dismissed as unscientific because the underlying variables could not be controlled or directly observed.

To modern cognitive psychologists, behaviorism appears to have "thrown the baby out with the bath water," as mental structures and processes are at the heart of all interesting human behaviors. Further, new methods have been developed to observe and measure mental events, however indirectly (e.g., Sperling, 1960; Sternberg, 1966—see Boxes 1.1 and 1.2). Nevertheless, behaviorists had many positive contributions to make. Mainly, these include insistence on rigorous methodology, precise definition of stimulus and response conditions, replication of results over many trials and with new participants, and the search for lawful relations expressed as associations among stimuli and responses that depend on past learning situations.

1.5 The Cognitive Revolution

1.5.1 The Relevance of Animal Models

Between about 1940 and 1960 psychologists and other scientists in related fields began to have some misgivings about the generality of behaviorism to human psychological issues. The behaviorists were interested in describing basic laws of behavior derived from experiments on learning and forgetting of simple associations. For their research, they commonly used animals, such as rats and pigeons, since the discovery of behavioral laws required tight control of the experimental environment as well the animals' past history of rewards and punishments. Such controls could be unethical for research with humans. Thus, the research was necessarily restricted to simple association learning, and uniquely human abilities—such as language, reasoning, decision making, and complex problem solving—were largely unstudied. Another problem with behaviorism as a model science was its limitation to descriptive laws of behavior rather than more general theories that could explain and predict behavior in a wider variety of situations (see Box 1.3).

Researchers concerned with understanding human abilities were particularly dissatisfied with behaviorism's accounts of how we learn things like our native spoken language. Behaviorists believed that the acquisition of individual words and short phrases developed through imitation of adult speech. Linguists, however, produced convincing evidence that children's speech was very much unlike any adult's. Young children tend to say things like "She goed out the door," "I losted it," and "I no find it" that indicate that rules (however different from the grammatical rules of an adult) rather than specific word combinations are being learned. Linguists, such as Chomsky (1959), marveled at the speed of first language learning and the number of universals across all human languages—both indictors that there is a large innate, biological capacity behind human language acquisition and use. The acknowledgement of inherited abilities and the demonstration that people can learn general rules in addition to specific habits demanded change from the tenets of radical behaviorism.

1.5.2 The Advent of the Computer Age

Another important development occurred in the mid-twentieth century: the construction of the first large computers that were designed to be general-purpose machines. That is, rather than being useful merely for crunching numbers, the machines were designed to read inputs, store them temporarily while various operations were performed, retrieve additional information from memory, and use the results to produce new information for storage or to execute some task, such as producing a useful output. The goal was to manufacture a symbol-processing device with various

BOX 1.3

The Place of Theory in the Scientific Method

A theory is a general principle induced from a variety of observations that summarizes and explains a body of knowledge. That is, unlike its everyday use, it is more than a mere guess or a hypothesis about some specific observation. Rather, a theory has some scope that depends on its consistency with a large body of observations, such as the theories of motion and inertia, the relativity of space and time, the conservation of matter and energy, and biological evolution. A theory also can be used to predict observations in new situations. That is, theories go beyond mere description of data to include explanations that are the basis of predictions in new circumstances. If the predictions are correct, then the theory is maintained, and new generalizations are incorporated into the theory. If the predictions are incorrect, however, the theory must be reconsidered and perhaps changed or rejected entirely and replaced with a better description and explanation of natural phenomena.

The strength of the scientific method of inquiry is to develop, by deductive logic, hypotheses from a theory that are specific enough that they can be compared with data collected in an experiment. That is, theories are useful not only if they provide an explanation of behavior, but if they are capable of being disproved in the face of observational data (i.e., they are falsifiable, see Popper, 1959). The concept of falsifiability is crucial, as a theory is of no use if it can explain everything and never be proven wrong. For example, a conspiracy theory is difficult to eliminate, because the theorist could always say that the right evidence has not yet been collected (and often cannot be) to disprove it. The idea in science is akin to natural selection in determining the survival of the fittest. Hypotheses die out through competition in the field or in the laboratory. The goal of science is to develop cumulative knowledge about some area of importance, such that explanatory theories continually are refined or rejected as more observations are made. Science progresses much like Sherlock Holmes in solving a mystery—when the impossible is eliminated, we are left with the possible.

Sweeping theories of behavior were never goals of behaviorism (with some exceptions; e.g., see the review of Hull's learning theory in Hilgard & Bower, 1975), but such theories were needed when psychologists faced demands for applications of their science to important human problems. Important issues arising in the twentieth century include: (1) What is the best way to teach our children to read? (2) What is the best way to teach inexperienced people to use new technology, such as radar equipment, flight traffic controls, and instruments in cockpits or nuclear power plants? (3) How should such new technology be designed to make it easy to use while minimizing costly human errors? (4) How can we build computers and write programs to do intelligent things like solve problems, translate messages from one language to another, and provide advice in uncertain situations? Behaviorism offered some suggestions in these areas, but many scientists found it to be inadequate on both practical and theoretical grounds. For example, during World War II, the question was raised about how to design sights and guidance systems to improve accuracy of bombs and missiles. B. F. Skinner suggested using a trained pigeon in the nosecone of a missile that could control its direction by pecking at part of touch-sensitive display if the missile lurched off-target. Although his system might well have worked, it was rejected by the military as fantasy and science fiction conjured up by a crackpot professor. Animal conditioning also said little about the larger issues of how to train novices to use high-tech equipment creatively in uncertain situations.

Having general theories of human behavior serves several purposes. First, if the theories are valid, we have a way of summarizing and understanding some body of observations about human cognition and behavior. Second, theories allow us to generalize and predict behavior in new situations, in which no observations have previously been made. Third, theories provide a means of communicating ideas among researchers within and across disciplines, so that their short-hand descriptions reduce ambiguities in discussing research. Finally, theories allow us to carry out simulations of human behavior by intelligent machines that can do useful things for us in distant or difficult situations, such as underwater, in the centers of power plants, in outer space, inside the human body, and so on.

memory systems and computational abilities that could be programmed to do things that, if a human did them, we would label them as "intelligent." It should be no surprise that intelligent beings generally created intelligent machines in their own image, at least in terms of overall architecture (see Box 1.4).

BOX 1.4

A General Theory of Human Memory

One of the goals of cognitive psychology is to develop theories of mental structures and processes that summarize and explain existing data as well as make predictions about what should be observed in new situations. In the late 1960s, several researchers had decided that enough had been discovered to begin the task of developing a general theory of human memory. These theories borrowed concepts of information processing theory as realized in early computer systems. Perhaps the most influential of these theories was that of Atkinson and Shiffrin (1968; 1971).

Atkinson and Shiffrin expanded on William James's (1890) distinction between what he called primary memory and secondary memory. According to James, there is a difference between those thoughts that are immediately available to us and those that can be brought to mind only with some effort and uncertainty. Atkinson and Shiffrin called these two types of memories, short-term and long-term memory. To these they added sensory memories, of the type that Sperling (1960; see Box 1.2) had discovered for vision. Thus, there were three memory structures in their model: sensory memory, short-term memory, and long-term memory.

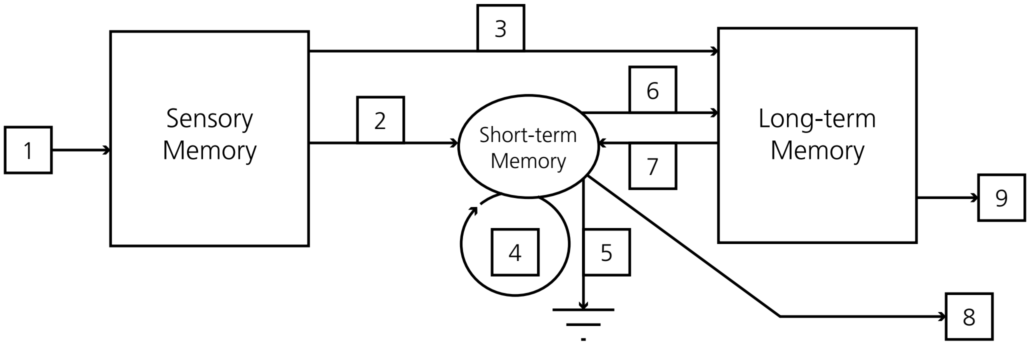
Sensory memories exist for all modalities, but they provide more information than we can possibly attend to at one time. Only some of the information available is selected for inclusion in short-term memory. Short-term memory has a limited capacity; it can handle only those few ideas or images that are actively maintained in conscious awareness. Long-term memory, on the other hand, is the enormous repository of everything we have ever learned, including specific details about our past as well as all general knowledge about things like language and mathematics.

To these three structures, Atkinson and Shiffrin added a number of processes for transforming information and shunting it among the memory systems. In this way, their model was analogous to a computer that has several types of memory structures to hold information temporarily or permanently and a set of software programs for controlling the contents of the memories and the operations performed on these contents. Thus, the memory structures in the Atkinson-Shiffrin model are analogous to the hardware components of a computer, and the proposed memory processes are analogous to its software. The structural and processing components of a revised version of their model are shown

A Proposed Model of Human Memory (after Atkinson & Shiffrin, 1968)

The structural components include sensory memories, short-term memory, and long-term memory. They differ in their properties as indicated in the following table.

	Capacity	Type of Code	Duration	Forgetting
Sensory	Large	Precategorized Sensations	1/2 to 2 secs	Decay or Overwriting
Short-term	Small	Subvocalizations Imagery	15 secs without Rehearsal	Replacement
Long-term	Unlimited	Semantics, Episodes, Procedures	Lifetime	Possibly none, retrieval failures due to Interference



The processing components include the following, as numbered in the above figure:

1. Sensation: the process by which physical stimuli are encoded into sensory messages that are sent to the brain
2. Attention: the process by which one or a few sensory inputs are selected for further processing by entering them into short-term memory
3. Automatic activation: the process by which some sensory signals activate corresponding codes in long-term memory without attention or awareness
4. Rehearsal: the process by which some codes are maintained in short-term memory by continuous processing, such as subvocalization or refreshing images
5. Forgetting from short-term memory: the loss of information through lack of rehearsal and spontaneous decay or overwriting by new inputs
6. Storage: the copying of new codes into long-term memory (learning)
7. Retrieval: the copying of old codes into short-term memory (remembering)
8. Controlled responses: the execution of some responses under control of conscious processes
9. Automatic responses: the execution of some responses without intention or awareness (e.g., a reflex)

All aspects of this version of the Atkinson-Shiffrin theory are based on research carried out over the last four decades of the twentieth century. The theory forms the basis for the consensus view of cognitive psychologists as we research new areas of human behavior and mental life. Although all cognitive psychologists have some disputes with the exact structure and terminology put forth here (for example, short-term memory has evolved into "working memory" to emphasize its complex processing capabilities beyond mere storage), the model is a good theoretical summary of human cognition. It summarizes much common jargon and beliefs that cognitive psychologists share in discussing their subject, and it forms a consolidating basis for what will follow in the rest of this textbook.

Of course, in order to program a computer to do something intelligent, we usually want to know what intelligent behavior is. This often requires that we understand what the most intelligent response would be in some situation, at least in terms of how we would react ourselves. Only then can the behavior be duplicated in computer codes that might well execute the process much more rapidly and accurately than humans can. What resulted from this enterprise was a kind of symbiosis based on computer simulations of human behavior. That is, in order to program a computer to solve a problem, we must understand and recreate problem-solving strategies used by people (i.e., a theory of human problem solving ability needs to be developed). At the same time, to complete the symbiotic relationship, effective programs and subroutines created by computer scientists can be used as models of human behavior. Of course, their usefulness in psychology depends on how well these computer models can explain and predict people's behaviors.

1.5.3 Cognitive Neuroscience

Another research area that has made important contributions to cognitive psychology is neuroscience. Biologists have long been studying how the nervous system works in animals and humans, and important advances in understanding neural processes have recently been made. Since cognition and behavior are controlled by the actions of nerve cells (neurons), it is of fundamental importance for psychologists to understand the basic structures and processes of the central nervous system. These include the study of normal as well as brain-damaged individuals. Head injuries, tumors, strokes, and other types of damage to the brain offer insights into normal brain function when we observe the loss of functions associated with damage to specific areas. There have also been tremendous advances in our ability to record neural activity in both the peripheral and central nervous systems of normal people. Existing methods can now yield fairly precise information about electrical and metabolic activities in the brains of alert, conscious individuals while performing various tasks. These measures can be used to indicate which cerebral areas are active in performing the tasks, as well as the sequence in which different brain areas coordinate their activities. The combination of results from brain-damaged individuals and observations of activity in normal brains gives a two-pronged approach to the problem of relating brain activity to observable behavior.

1.5.4 Cognitive Science

According to Howard Gardner (1982), 1956 is viewed as the first year of cognitive psychology because of three epoch-making events that took place in this year. The first event was the publication of the seminal paper by George Miller titled "The Magical Number Seven Plus or Minus Two", in which he proposed a common capacity limit for many memory and judgment behaviors. We will discuss his paper in more detail in Chapter 6. The second was the publication of the book titled "Syntactic Structures" by Noam Chomsky. His book revolutionized linguistics and created the new field called *psycholinguistics*. The third was the conference of computer scientists held at Dartmouth College, in which the term "artificial intelligence" was coined.

Today, we are witnessing the growth of a new scientific discipline called cognitive science, which pools data and theory from several sources. At the heart of this endeavor is laboratory science, in which theories are tested against the behavior of people in controlled situations. Psychologists' efforts have profited from converging operations in related fields, such as linguistics, computer science, anthropology, philosophy, and neuroscience, to develop increasingly complete theories of human mental processes. The challenge is to understand the very complex behaviors that are uniquely human, or sometimes present in an abbreviated form in other animals or artificially-intelligent devices, such as problem solving, the use of tools, the design of new technologies, and the development and use of language. The goal of research and theory in cognitive science is to understand all aspects of human behavior based on models of human mind-body systems. Success in this task will enable us to design new technologies in the fields of science, education, and entertainment that are able to extend human capabilities while compensating for human limitations.

Chapter Summary

Cognitive psychology is as old as people's abilities to think about where knowledge comes from and as new as the most modern methods of neuroscience and artificial intelligence. In the past people argued about whether knowledge is inborn, comes from experience, or is created anew in each person's thinking brain. In truth, we realize today that knowledge comes from many places, and almost all human behavior is a joint product of nature, nurture, and the power of human reason.

Any system as complicated as the human brain can best be studied using several different methods. Cognitive psychologists are proficient in testing information-processing models against human performance in strictly controlled laboratory experiments. In this way, proscribed parts of the entire cognitive system can be tested in relative isolation without the complications of trying to explain behavior in the immense and variable natural world. The problem of studying human behavior is greatly simplified by the strategy of divide and conquer. Such efforts can also lead to problems, however, in that any complex human behavior is the result of concerted contributions from a variety of neural substrates. In addition, textbooks, such as the one in your hands, can suffer from presenting "… a series of disconnected phenomena, a rag-tag collection of curiosities—what you might find at a psychologist's garage sale" (Rosenbaum, 2014, p. ix). Larger systems, such as the Atkinson-Shiffrin theory, result from attempts to put the pieces back together again, however premature such general theorizing might be given our current state of knowledge.

At the same time, psychologists appreciate the power of converging operations in applying different scholarly and laboratory disciplines to understanding the human mind and how it works. Tremendous insights into the design of intelligent systems have been gained from attempts to program computers to mimic and exceed human capacities for processing information. Similarly, the challenge of understanding how people come to learn and use language has produced contributions from laboratory experiments, computer speech production and comprehension systems, linguistic theory, and studies of the physiological processes occurring in normal and injured human brains. A new cognitive science is developing that combines these and other disciplines into a joint effort to gain an understanding of the structures and processes of the human brain, and how they come together to produce behavior, thoughts, feelings, and conscious awareness of the physical and social world.

Review Questions

- **Where does knowledge come from?**

  Knowledge traditionally has been ascribed to three different sources. Nativists argue that much of what we know is inborn or develops naturally as biological systems mature. Empiricists assert that knowledge results from experience with the outside world, including our social environment, and rationalists say that much of what we know we derive ourselves through mental effort and the power of human reason. There is at least some truth in all of these claims, as most human behavior results from multiple causes. There is room for explanation from many sources for the vast amount of knowledge and computational power that all of us carry around inside our heads.

- **Is it possible to study mental processes if we cannot observe or measure them directly?**

  The history of experimental psychology provides both classic and recent examples of how theory and experimentation go hand-in-hand to derive explanations of how the mind works. Over 100 years ago, Donders and Fechner demonstrated that we could measure mental processes, however indirectly, in a way that eliminated some theoretical explanations in favor of others. Similarly, Ebbinghaus used the scientific method to discover some of the basic properties of human learning and memory. Recent demonstrations of the power of theory to develop models of how the mind works include Sperling's demonstration of the existence of sensory memory and Sternberg's studies of the speed of comparisons in working memory. Theories and their rigorous tests in the laboratory have allowed us to build complicated information-processing systems, such as the Atkinson-Shiffrin theory, that go a long way toward explaining experimental data and providing direction for further research to correct and expand our theoretical understanding of mental life.

- **Is cognitive psychology the study of human behavior or the study of the human mind?**

  In truth, human behavior is the observation window into the mind that perceives and remembers information, and plans, controls, and executes behaviors. Therefore, behaviors are the data against which theories of the underlying mental operations that produce them can be tested. Cognitive psychology is thus a study of both behavior and the mental processes that give rise to it.

- **What roles, if any, do disciplines such as linguistics, computer science, and neuroscience have in modern cognitive psychology?**

  Linguistics is the study of language structure, and psycholinguistics is the study of linguistic behavior. Learning to speak and to read a natural language are two of the most important things that we learn in all our lives. Therefore, linguistics will always play a central role in developing theories of the kind of knowledge that children must acquire to master their native language and adults must have to communicate effectively.

Computer science is intimately related to cognitive psychology in that both research areas are centered on the design of intelligent systems, albeit natural versus artificial. Although some useful analogies can be made between software and mental processes and between hardware and mental structures, most advances in both fields are obtained at more abstract levels. Common problems are confronted in attempts to understand both human and artificial intelligence, such as in trying to define what we mean by intelligence, how language is used productively to communicate ideas, and how we can learn to navigate in a three-dimensional world filled with different static and moving objects. Solutions in one area frequently give rise to applications in the other, thus fostering a synergy across disciplines.

Finally, any theory of human behavior must be consistent with known facts of human physiology. The brain is an immensely complicated organ that is slowly yielding its secrets through applications of new techniques that measure activity in living, intact human brains and those that evaluate the performance of people with brain damage. Theories of human behavior increasingly incorporate neural-systems components in order to forge a closer approximation to the actual structures and processes of the human brain.

Key Terms