

CONTENTS

|                                                             |           |
|-------------------------------------------------------------|-----------|
| Preface                                                     | ix        |
| <b>1. Historical Overview of Research on Attention</b>      | <b>3</b>  |
| <i>The Philosophical Period</i>                             | 5         |
| <i>The Period From 1860 to 1909</i>                         | 7         |
| <i>The Period From 1910 to 1949</i>                         | 14        |
| <i>The Period From 1950 to 1974</i>                         | 17        |
| <i>The Period From 1975 to 1999</i>                         | 20        |
| <i>The Period From 2000 to 2020</i>                         | 23        |
| <i>Book Coverage</i>                                        | 23        |
| <i>Chapter Summary</i>                                      | 26        |
| <i>Key Points</i>                                           | 27        |
| <b>2. Information Processing and the Study of Attention</b> | <b>29</b> |
| <i>Human Information Processing</i>                         | 29        |
| <i>Behavioral Methods Used to Study Attention</i>           | 33        |
| <i>Cognitive Neuroscience</i>                               | 50        |
| <i>Chapter Summary</i>                                      | 59        |
| <i>Key Points</i>                                           | 59        |
| <b>3. Selective Attention in Audition and Vision</b>        | <b>61</b> |
| <i>The Function of Selective Attention</i>                  | 62        |
| <i>Auditory Selective Attention</i>                         | 64        |
| <i>Visual Selective Attention</i>                           | 74        |
| <i>Hemispheric Differences</i>                              | 86        |
| <i>Chapter Summary</i>                                      | 92        |
| <i>Key Points</i>                                           | 93        |

|                                                                                     |            |
|-------------------------------------------------------------------------------------|------------|
| <b>4. Orienting and Inhibiting Attention</b>                                        | <b>95</b>  |
| <i>Orienting</i>                                                                    | 96         |
| <i>Inhibition</i>                                                                   | 110        |
| <i>Visual Search</i>                                                                | 116        |
| <i>Chapter Summary</i>                                                              | 129        |
| <i>Key Points</i>                                                                   | 129        |
| <b>5. Attentional Control in Congruity and Negative Priming Tasks</b>               | <b>131</b> |
| <i>Compatibility Effects for Relevant Stimulus Information</i>                      | 133        |
| <i>Congruity Effects of Irrelevant Stimulus Information</i>                         | 134        |
| <i>Sequential and Global Percentage Effects</i>                                     | 143        |
| <i>Negative Priming</i>                                                             | 148        |
| <i>Chapter Summary</i>                                                              | 157        |
| <i>Key Points</i>                                                                   | 158        |
| <b>6. Change Detection and Cross-Modal Attention</b>                                | <b>159</b> |
| <i>Change Detection</i>                                                             | 160        |
| <i>Monitoring for Change in Oddball Tasks</i>                                       | 165        |
| <i>Tactile Attention</i>                                                            | 170        |
| <i>Cross-Modal Attention: Performance With Unimodal, Bimodal, and Trimodal Cues</i> | 172        |
| <i>Chapter Summary</i>                                                              | 184        |
| <i>Key Points</i>                                                                   | 184        |
| <b>7. Divided Attention and Multiple-Task Performance</b>                           | <b>187</b> |
| <i>Divided Attention</i>                                                            | 189        |
| <i>Multiple-Task Performance</i>                                                    | 192        |
| <i>Setting Goals and Intentions</i>                                                 | 197        |
| <i>Intentional Control and Multitasking</i>                                         | 204        |
| <i>Chapter Summary</i>                                                              | 218        |
| <i>Key Points</i>                                                                   | 218        |
| <b>8. Memory and Attention</b>                                                      | <b>221</b> |
| <i>Sensory Memory</i>                                                               | 224        |
| <i>Short-Term and Working Memory</i>                                                | 230        |
| <i>Memory Consolidation and Attention</i>                                           | 238        |
| <i>The Role of Attention in Encoding and Retrieval</i>                              | 245        |
| <i>Chapter Summary</i>                                                              | 253        |
| <i>Key Points</i>                                                                   | 253        |
| <b>9. Mental Workload and Situation Awareness</b>                                   | <b>255</b> |
| <i>Mental Workload</i>                                                              | 256        |
| <i>Situation Awareness</i>                                                          | 274        |
| <i>Chapter Summary</i>                                                              | 278        |
| <i>Key Points</i>                                                                   | 279        |

|                                                          |            |
|----------------------------------------------------------|------------|
| <b>10. Attention and Displays</b>                        | <b>281</b> |
| <i>Role of Selective and Divided Attention</i>           | 282        |
| <i>Mental Models</i>                                     | 283        |
| <i>Types of Displays</i>                                 | 293        |
| <i>Sustained Attention and Vigilance</i>                 | 302        |
| <i>Virtual Reality Environments</i>                      | 305        |
| <i>Chapter Summary</i>                                   | 307        |
| <i>Key Points</i>                                        | 307        |
| <b>11. Individual and Group Differences in Attention</b> | <b>309</b> |
| <i>Attention Across the Lifespan</i>                     | 310        |
| <i>Group Differences: Selected Examples</i>              | 331        |
| <i>Chapter Summary</i>                                   | 341        |
| <i>Key Points</i>                                        | 341        |
| <b>12. Social Attention and Team Performance</b>         | <b>343</b> |
| <i>Shared Attention</i>                                  | 344        |
| <i>Joint Representation and Social Priming</i>           | 353        |
| <i>Attention With Avatars</i>                            | 358        |
| <i>Affect and Emotion</i>                                | 363        |
| <i>Team Mental Models and Situation Awareness</i>        | 367        |
| <i>Valuation of Consumer Products</i>                    | 371        |
| <i>Chapter Summary</i>                                   | 373        |
| <i>Key Points</i>                                        | 373        |
| <b>Afterword</b>                                         | <b>375</b> |
| References                                               | 377        |
| Index                                                    | 459        |
| About the Authors                                        | 493        |



## 1

## Historical Overview of Research on Attention

The topic of *attention*—how people select information for perception, cognition, and action—is arguably the core of cognitive psychology. Interest in attention predates the founding of psychology as a discipline in 1879 and was prominent in the work of the earliest psychologists. Many of the most well-known and widely studied phenomena relate to attention, and attention was at the center of the “cognitive” revolution in the 1950s, which led to its current prominence. The topic of attention is embedded within all areas of psychology. Moreover, given the ever-increasing information demands on individuals in contemporary society, due to the expansion of media and technology, the subject of attention is more relevant now than ever.

In today’s physical, cyber, and social worlds, people are increasingly bombarded with various stimuli, only some of which are relevant to current goals. Just a few will affect our behavior, and even fewer will reach our consciousness. The information conveyed by the stimuli may not be consistent, and the multiple stimuli may each require a different action—actions that often are incompatible with each other. Think of driving in heavy traffic while operating the automobile’s entertainment system, following driving directions from a navigation system, and engaging in a conversation with one or more passengers. Alternatively, consider the task of flying an aircraft. The pilot must process information from numerous visual displays and the outside world while listening to and talking with air traffic controllers and other members of the flight crew, selecting and operating appropriate controls, and being prepared to detect

---

<https://doi.org/10.1037/0000317-001>

*Attention: Selection and Control in Human Information Processing*, by R. W. Proctor and K. P. L. Vu

Copyright © 2023 by the American Psychological Association. All rights reserved.

and identify emergency warning signals. Driving and flying thus require selection among competing stimuli, the concurrent performance of several subtasks, and the monitoring of the environment for changes. How people select among competing external and internal stimuli and control their thoughts and actions in a manner to achieve goals is of central concern in the study of attention.

The topic of attention is a major part of contemporary cognitive psychology and cognitive neuroscience, as well as of a variety of other areas in psychology and the interdisciplinary field of human factors engineering. Processes encompassed within the category of attention play critical roles in essentially all aspects of perception, cognition, and action, influencing the choices you make. For example, when performing a task such as remembering the name of someone you have met only once before, you must process the retrieval cue (the person's face or who they are with) and then shift to evaluating the possible alternative names for retrieval. In a more complex task, such as deciding which car to buy, attention must be directed to the different properties that the new car should have, and the most important goals (e.g., staying within budget) must be kept in mind. As these examples illustrate, the study of attention should be of interest to anyone who wants to learn more about human behavior and cognition and gain insight into how selective processes guide their thought and behavior.

As noted, because of its relevance to much of human experience, attention has been of importance to the field of psychology since its earliest days. This research was first summarized in the book *The Psychology of Attention* by Théodule Ribot (1890), in which he distinguished a spontaneous (i.e., automatic) mode of attention from a voluntary one. Spontaneous attention is most fundamental and is caused by emotional states, whereas voluntary attention is built on spontaneous attention through education and training. Voluntary attention was presumed to be accompanied by a feeling of effort because of the need to inhibit and direct attention.

Eighteen years later, two landmark texts devoted to the topic of attention were published: Edward B. Titchener's (1908/1973) *Lectures on the Elementary Psychology of Feeling and Attention* and Walter B. Pillsbury's (1908/1973) *Attention*. These texts put the study of attention in psychology on a firm footing. Titchener included several laws of psychology, among which the *law of prior entry* is the most well known. According to this law, "the stimulus for which we are predisposed requires less time than a like stimulus, for which we are unprepared, to produce its full conscious effect" (Titchener, 1908/1973, p. 251). In the book, Titchener described the discovery of attention as one of three major achievements of experimental psychology to that point, stating, "the doctrine of attention is the nerve of the whole psychological system" (p. 173).

Pillsbury (1908/1973) provided a similarly strong assessment of the importance of attention, asserting that effects of attention "extend to every part of the physical organism, and are among the most profound facts of mind" (p. 1). The quotes of Titchener and Pillsbury make apparent the central weight placed on attention in the early days of psychological science and also, in part, why

the topic of attention has continued to receive considerable research in this era: It relates to selection and control of perception, cognition, and action.

The history of research on attention can be broken up into six periods:

1. philosophic work preceding the founding of the field of psychology in the last half of the 1800s;
2. the period from the founding of psychology until 1909;
3. the period from 1910 until 1949, during which behaviorism flourished, and interest in attention waned to some extent;
4. the resurgence of widespread interest in attention during the period of the cognitive and engineering psychology revolutions from 1950 to 1974;
5. the experimental research on attention from 1974 to 1999; and
6. contemporary research with emphasis on cognitive control, multitasking, training, cognitive neuroscience, and applications dating from 2000 to the present.

In the sections that follow, we summarize the major research and theories of attention during each period. This historical context is essential to provide a foundation for the more detailed treatments of specific topics in subsequent chapters.

## THE PHILOSOPHICAL PERIOD

Interest in attention began in the field of philosophy before the founding of psychology as a scientific discipline. Because the topic of attention was originally discussed by philosophers, many ideas about the nature of attention held today can be traced back to the views held by them (Posner, 2017). Among the issues they considered was the role of attention in conscious awareness and thought and whether attention was directed voluntarily or involuntarily toward objects and events. The characterization of attention provided by each philosopher reflected that individual's larger metaphysical view of the nature of things and how we come to know the world. We briefly describe the treatments of attention provided by a few eminent philosophers.

The importance of empirical investigation was emphasized by Juan Luis Vives (1492–1540) in his book, *De Anima et Vita*, in 1538. He is most well known for his views on memory (Murray & Ross, 1982), in which attention played a significant role. According to Vives, the more closely one attends to stimuli, the better they will be retained. Learning consists of the formation of associations, and retrieval from memory occurs through automatic activation of associated ideas or intentional, effortful search.

The first extended treatment of attention was that of Nicolas Malebranche (1638–1715) in his book *The Search After Truth* (1674/1980; see Berlyne, 1974). Malebranche held that we have access to ideas, or mental representations of

the external world, but not direct access to the world itself. He considered attention to be necessary to prevent perception and ideas from becoming confused and to make some clearer by drawing attention to them.

The concept of *apperception*, introduced by Gottfried Leibniz (1765), refers to an act that is necessary for an individual to become conscious of a perceptual event. Events can be perceived unconsciously but will not enter conscious awareness without apperception. Leibniz emphasized a reflexive view of attention, in which attention is directed automatically to events and ideas that demand it (McRae, 1976). However, attention also has a voluntary and directed aspect (Leibniz, 1948/1985). Leibniz was a mathematician who discovered the differential calculus. Not surprisingly, he had the ambition of basing psychology and other sciences in mathematics (Klempe, 2021), a goal also of current quantitative modelers of attention.

From 1704 until his death in 1716, Leibniz corresponded with Christian Wolff (1679–1754) and had considerable influence on his thinking (Richards, 1980). Wolff published two books on psychology, *Psychologia Empirica* in 1738 and *Psychologia Rationalis* in 1740 (see English translations in Richards, 1980). He distinguished an empirical approach (introspection), which he argued would benefit from mathematical analyses, from a deductive, theoretical approach. Each book included a chapter with *attention* in the title (Richards, 1980). With regard to attention, Wolff (1740) also described several general properties that have been emphasized in subsequent textbooks (Hatfield, 1998, p. 5):

- The greater the attention, the smaller the part of the visual field to which it extends;
- with equally distributed attention, that part of a whole which otherwise is cognized most clearly will come to the fore; and
- conscious attention acts to combine spatial representations and temporal processes into ordered whole events in the part of the visual field to which it is directed.

Johann Herbart (1776–1841) agreed with Leibniz and Wolff that an event had to be apperceived to enter conscious awareness. However, he stressed that apperception involved relating newly perceived ideas to ones already contained in the mind (Herbart, 1824–1825). All new perceptual experience occurs in relation to prior perceptions. This apperceptive process occurs through associations among mental contents. Herbart also was the first person to apply mathematical modeling systematically to the study of psychology. The conceptual structure of his mathematical psychology was supplied by Immanuel Kant (1724–1804), specifically, Kant's view that knowledge of the observable world is a constructed mental representation (Leary, 1980). This view led Herbart to stress the study of the self as a dynamically changing representation composed of mental entities, mainly through introspections about experience. Whereas Kant was skeptical about the use of mathematics for understanding and predicting mental events, Herbart argued that a mathematical account could

be used to predict the existence, magnitude, and duration of mental events (Boudewijnse et al., 1999).

A popular view in the first part of the 19th century was that people are incapable of attending to more than one thing at once. However, William S. Hamilton (1788–1856) argued that the span of attention is more than one object. He proposed measuring its size by throwing marbles on the floor and determining how many of them could be apprehended at once: “If you throw a handful of marbles on the floor, you will find it difficult to view at once more than six, or seven at most, without confusion” (Hamilton, 1859, p. 254). Jevons (1871) followed up Hamilton’s idea for testing the span of apprehension and estimated it to be four items.

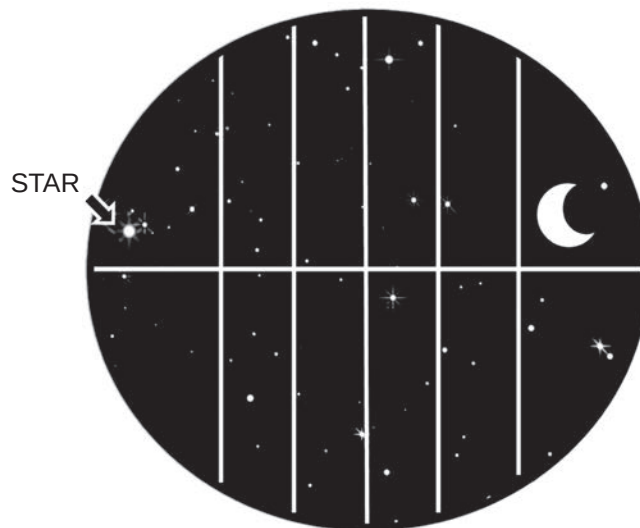
In summary, many philosophers and early psychologists gave attention a central role in perception and thinking. They introduced several issues that continue to be examined in contemporary research, such as the extent to which attention is directed automatically or intentionally. Although they conducted little experimental research themselves, their conceptual analyses of attention laid the foundation for the scientific study of attention in following years.

## THE PERIOD FROM 1860 TO 1909

The philosophical analyses of attention led to some predictions that could be tested experimentally, as in Hamilton’s work. Also, in the mid-1800s, psychophysical methods were being developed that allowed measurement of the relation between physical stimulus properties and the psychological perceptions of them (Fechner, 1966; Weber, 1846/1978). Thus, it was a small step to infer that attention can be investigated using an experimental approach.

### Speed of Mental Processes

The first laboratory devoted to psychological research was founded in 1879 by Wilhelm Wundt (1832–1920), who was responsible for introducing the study of attention to the field. As a laboratory assistant in physiology at Heidelberg, Germany, Wundt became interested in the issue of the astronomers’ *personal equation* (see Woodworth, 1938). This refers to systematic, individual differences between astronomers in their measures of the time for the transit of stars. Astronomers in the late 18th and early 19th centuries measured time by determining when the stars and planets crossed the meridian, using an “eye-and-ear” method (Sheehan, 2013). This measurement was made with a telescope that had an eyepiece equipped with a number of equidistant vertical wires (see Figure 1.1). The astronomer recorded the times at which a particular star crossed each of the wires by noting the distance of a star from one of the wires coinciding with two beats of a clock, heard immediately before and after the star crossed the wire. These times were averaged to find the time at which the star crossed the meridian. This method was generally accepted because it allowed comparison across different observatories.

**FIGURE 1.1. Depiction of a Star Crossing the Wires in the Field of View of a Meridian or Transit Telescope**

Nevil Maskelyne, then royal astronomer at the Royal Observatory Greenwich in England, noticed in 1795 that his assistant, David Kinnebrook, made measurements that were as much as 800 milliseconds (ms) longer than his own. Because this disparity continued into 1796, Maskelyne fired Kinnebrook for being incapable of making accurate observations. More than 20 years later, Friedrich Wilhelm Bessel (1784–1846), director of Prussian King Friedrich Wilhelm III's observatory at Königsberg, noted this incident. He then conducted a relatively controlled experiment in which he and a well-trained assistant made transit measurements on alternate nights for several nights using the eye-and-ear method for two sets of five stars. Their measurements showed an even greater difference between observers. This difference between observers is what became known as the personal equation, which Bessel indicated was “involuntary” because it could not be overcome by practice and training (Hoffmann, 2007). Since then, it has been noted that the eye-and-ear method involves several aspects of attention, the most obvious being switching attention between visual and auditory modalities.

Wundt was among those who became interested in the possible role of attention. Around 1860, he set up an apparatus to simulate this situation. As described by Blumenthal (1980),

Wundt suddenly realized that he was measuring the speed of a mental process, that for the first time, he thought, a self-conscious experimental psychology was taking place. *The time it takes to switch attention* [emphasis added] voluntarily from one stimulus to another had been measured—it varied around a tenth of a second. (p. 121)

This insight led Wundt to emphasize the voluntary control of attention.

The first demonstration that the speed of neural processing could be measured came from Herman von Helmholtz (1821–1894). By positioning an electrode at different places on a frog nerve-muscle preparation, Helmholtz was able to calculate the speed at which the nerve impulse was propagated as approximately 30 meters per second (Schmidgen, 2002). He applied the method similarly to humans by stimulating sensory areas on the skin at different distances from the brain and measuring the time to respond. The difference in times between the long and short distances was used to estimate the speed of neural processing, which was approximately 60 meters per second.

These findings led to more formal studies measuring the speed of mental processes in humans conducted by Franciscus C. Donders (1818–1889). De Jagger's (1865/1970) dissertation, conducted under Donders's supervision, provided the initial account of the experiments conducted in Donders's lab. The experiments focused on measuring the time required to identify a stimulus and select a motor response. In one set of experiments, participants were required to respond to a red light with the right hand and a white light with the left hand. The mean reaction time was 356 ms, which was 172 ms longer than a simple reaction (executing a single response when a stimulus is presented) to the same stimuli. De Jagger interpreted this time as the duration of the central processes involving stimulus discrimination and response initiation.

Donders (1868/1969) formalized the method used by De Jagger, known as the *subtractive method*, emphasizing specifically that the time for a particular process could be estimated by adding that process to a task and taking the difference in reaction time between the two tasks. He distinguished three types of reactions: *a* (simple reaction), *b* (choice reaction), and *c* (go or no-go reaction; responding to one stimulus but not another). These types of reactions allowed separate measures of the stimulus identification and decision processes that were assessed together by De Jagger. The difference between the *c* and *a* reactions was presumed to reflect the time for stimulus identification, and the difference between the *b* and *c* reactions was considered as the time for "expression of the will" (p. 424). Donders's assertion that the time for distinct mental processes can be measured and his method for modeling human information processing are precursors to contemporary methods that are described in Chapter 2 of this volume.

Reaction-time research, in general, and the study of action selection, in particular, flourished throughout the remainder of the 19th century (see Jastrow, 1890; D. K. Robinson, 2001). Other classic reaction-time experiments include those of Exner (1882), who noted that performance of simple reaction tasks was characterized by voluntary preparation that occurs before presentation of the stimulus, with the reaction being a reflexive response to the stimulus. L. Lange (1888) extended this work further by distinguishing between preparatory sets that focused on the sensory and motor stages of the task (D. K. Robinson, 2001). A motor set, which involved focusing attention on the response, produced fast, reflexive responses of the type described by Exner. In contrast, a perceptual set, which involved focusing attention on the stimulus,

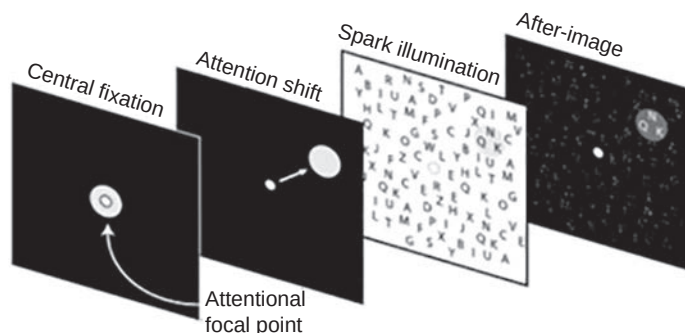
required apperception and an intentional act of will to initiate the response, resulting in slower responses.

An initial demonstration that choice-reaction time increases as a function of the number of possible stimulus–response alternatives—that is, as a function of uncertainty regarding which response will be required—was provided by Merkel (1885, described in Woodworth, 1938). In Merkel’s experiment, the Arabic numerals 1 through 5 were assigned to the left hand and the Roman numerals I through V to the right hand, in left-to-right order. Results showed that when the number of alternatives increased from two to 10 choices, mean reaction time increased from approximately 300 ms to a little over 600 ms. This relation, which indicates that the probabilities of occurrence of stimuli influence the time to respond to whichever one occurs, was rediscovered in the early 1950s by Hick (1952) and Hyman (1953). Their work resulted in the formulation of what is known as Hick’s law, or the Hick-Hyman law, which is described in detail in Chapter 2.

### Effects of Attention

The relation between attention and perception was one of the first topics to be studied in experimental psychology. At the end of the 19th century, Helmholtz (1894/1986) provided evidence suggesting that attention is essential for visual perception. Using himself as subject and pages of briefly visible printed letters as stimuli, he obtained evidence that attention could be directed in advance of the stimulus presentation to a particular region of the page, even though his eyes were kept fixed at a central point. As depicted in Figure 1.2, Helmholtz focused on an illuminated pinhole in the dark display (labeled *central fixation*) of a type of tachistoscope (a box used to briefly illuminate the display) and directed his attention to a particular peripheral location (labeled *attention shift*), after which the display was briefly illuminated by discharge of a spark (labeled

**FIGURE 1.2. Depiction of the Stimulus Display Helmholtz Used to Study Attention Shifts**



*Note.* From *Orienting of Attention* (p. 5), by R. D. Wright and J. M. Ward, 2008, Oxford University Press. Copyright 2008 by Oxford University Press. Reprinted with permission.

*spark illumination*), from which he could report the letters at the attended location. In his words, “With a subsequent discharge I could direct my perception to another section of the field, while always fixating on the pinhole, and then read a group of letters there” (p. 259).

Helmholtz also found that attention was limited: The letters in the largest part of the visual field, even in the vicinity of the fixation point, were not automatically perceived. Based on these observations, Helmholtz (1894/1986) concluded that attention can be covert and concentrated on a part of the visual field on which the eyes are not fixated.

The idea that attention was an inner activity that caused ideas to be present to differing degrees in consciousness was emphasized by Wundt (1880, 1907b). He distinguished between perception, which was the entry into what he called “the field of attention,” and apperception, which was responsible for entry into the inner focus. He assumed that the focus of attention could be narrow or wide, a view that has enjoyed popularity in contemporary research on attention (C. W. Eriksen & St. James, 1986). Cowan and Rachev (2018) noted similarities between Wundt’s “embedded system’s” view of attention and the contemporary working memory models of Cowan and others, described in Chapter 7. Wundt (1907a) identified three components of attention: increased clearness of ideas, muscle sensations in the same modality as the ideas, and emotions related to the ideas on which attention is focused. Wundt used the word *voluntarism* to describe his school of psychology, which emphasized volition, or the study of conscious decision and choice. He held that psychological processes could be understood only in terms of their goals or consequences and that apperception and attention are processes of active synthesis.

The conditions of an act of attention are found not only in the environment but also in the individual, as shown by demonstrations of the role of task set on performance. *Task set* refers to the readiness to carry out an instructed action in response to a given stimulus. One of the earliest investigations of task set was conducted by Oswald Külpe (1904), who used briefly displayed nonsense syllables of different colors as stimuli. The instructions were to determine the number of letters displayed, the colors and their positions, or the letters and their positions. Performance was best when the judgments that had to be made coincided with the task for which the observer had been set (Wilcocks, 1925). The attributes included different letters or colors of syllables in the display and their locations. Külpe’s results showed that the participants were able to report the chosen attribute more accurately when it was instructed in advance than when it was not.

A student of Külpe’s, Watt (1904/1906), related a similar effect, which he explained as an *Einstellung* (“task set”) that people create in constituting the instructed *Aufgabe* (“task”) before stimulus presentation. Ach (1905/1964) provided one of the best demonstrations of task set, presenting the numbers 6 and 2 as stimuli to participants. They yielded a response of 8, 4, or 12, depending on whether the instructed task was to add, subtract, or multiply the numbers.

Ach's results indicated that the same stimuli can yield different responses based on the task set.

The views of William James (1890/1950) on attention are probably the most well known of the early psychologists. His definition of attention is widely quoted:

It is the taking possession by the mind, in clear and vivid form, of one of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others. (pp. 403–404)

The emphasis on clearness is similar to that of Wundt, Titchener, and Pillsbury.

Researchers at the beginning of the 20th century debated how this increased clearness was obtained. Ernst Mach, Carl Stumpf, and others favored the view that this increase was direct, whereas Wundt, Külpe, and others held the view that the increase was accomplished indirectly by inhibiting the sensations that were not attended to (Pillsbury, 1908/1973). One difficulty with resolving the issue of how attention influences clearness is illustrated by an experiment conducted by Mach and Stumpf. They agreed that attention to a stimulus increases its perceived intensity, but whereas Mach thought that this effect of attention occurs for all stimuli, Stumpf thought that attention benefits only weak sensations. As described by Titchener (1908/1973), Mach and Stumpf listened to a harmonium together to determine whether attention to one of the clearly audible component tones in a chord increases its strength. Regrettably, Mach concluded that it did, but Stumpf concluded that it did not. Thus, their introspections did not allow them to agree on an answer to this question. The debate about whether attention increases the clearness of attended events or decreases the clearness of unattended events presaged the ongoing argument in psychology regarding whether, and how, attending is accomplished through excitatory and inhibitory mechanisms (e.g., Slagter et al., 2016; see also Chapter 5, this volume).

Although James considered clarity to be a central feature of attention, he is known for taking a functionalist view that emphasized the selective aspect of attention, as illustrated in the last sentence of the earlier quote from James. This functional, selective aspect of attention has been stressed in most research of the past 70 years (Pashler, 1998). Still, the issue of conscious awareness remains vital and is attracting increased interest (e.g., Simione et al., 2019).

James (1890/1950) suggested three categories for characterizing attention. The first is that attention can be directed to actual objects or mental representations of them. Also, attention can be linked to the present event or removed from it. Finally, attention can be automatically attracted to objects or spaces or voluntarily directed to them. James also indicated that attention makes people perceive, think, and remember better than they would without it. Although most studies of attention historically have been on perceiving and identifying stimuli, its influence on memory also was considered. Pillsbury (1908/1973) was explicit about the role of attention in memory, saying, "Retention is dependent on the degree of attention that was given at the moment of learning"

(p. 148). Note the similarity of this quote to Vives's view, cited earlier. Pillsbury also stressed the role of attention in retrieving information from memory.

Also, psychologists have been interested in the role of attention in selection and control of action. In his textbook on attention, Pillsbury (1908/1973) noted that all acts of attention are accompanied by some motor activation. Motor responses include both voluntary and involuntary orienting toward a source of stimulation, as well as other more overt actions. In agreement with Pillsbury, James (1890/1950) said, "Organic adjustment, then, and ideational preparation or preperception are concerned in all attentive acts" (p. 444). A similar view was advocated recently by Hommel et al. (2019), who promoted what they call a synthetic approach to attention that considers perceptual-motor interactions across the information-processing system.

Lotze (1852) and Harleß (1861) introduced the idea that the links between movements and their mental representations are bidirectional, thus allowing the representations to directly produce the movements. This idea came to be called *ideomotor action*, a term first coined by Carpenter (1852) to explain the effect of suggestion on muscular movement independent from conscious intent. Carpenter was interested mainly in explaining phenomena such as dowsing, in which a divining rod might be "pulled" to the earth by the presence of water under the ground, that were attributed to supernatural forces. His idea was that the individual's expectancies and thoughts affected the motor system and thus unintentionally caused the movements. James (1890/1950) agreed with Carpenter's views and was a strong advocate of the ideomotor theory of action. Margaret Washburn (1871–1930) also emphasized the motoric nature of attention, theorizing that associations between stimuli and motor responses become linked in mental images through attention to stimuli (Washburn, 1914). In more recent research, Greenwald (1970), Hommel (2019), Pfister (2019), and others have advocated ideomotor theories of action.

A common idea with respect to attention is that if a task requires attention, it will interfere with simultaneous performance of another task that also requires attention (Keele, 1973). Binet (1890) was one of the first individuals to suggest that attention could be understood in terms of interference. He found that mental addition interfered with a task of rhythmically squeezing a rubber ball a specified number of times. However, this interference did not occur when the timing and number of squeezes did not have to be monitored. In another demonstration of the link between action and attention, Welch (1898) found that a strong grip could not be maintained while performing demanding mental tasks.

In sum, around 1860, the philosophical approach dominated the study of psychology in general and attention in particular. During the period from 1860 to 1909, the study of attention was transformed, as was the field of psychology as a whole, to one of scientific inquiry with emphasis on experimental investigations. By 1909, many phenomena of concern to contemporary attention researchers had been discovered and investigated, and the study of attention was central to the field of psychology. However, the situation was one captured

by Ribot (1890) in the first sentence of his book: “Psychologists have given much study to the effects of attention, but very little to its mechanism” (p. 7). Unfortunately, emphasis on the study of attentional mechanisms was largely delayed until the middle of the 20th century.

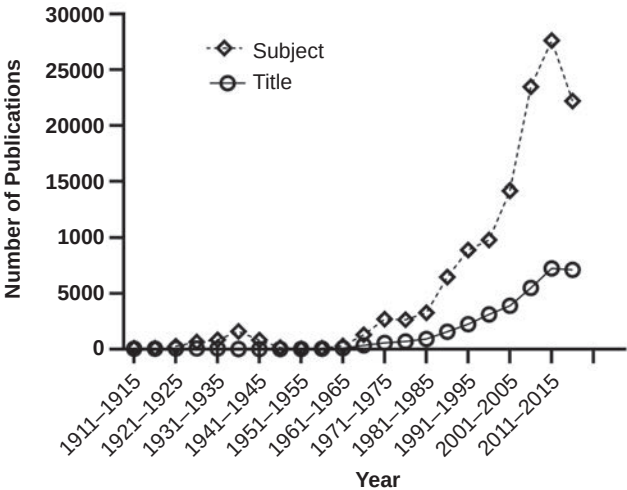
THE PERIOD FROM 1910 TO 1949

Lovie (1983) conducted a search of *Psychological Index* and *Psychological Abstracts* from 1911 to 1960 and found that the number of articles on the topic of attention exceeded 100 in all but the 1911–1920 decade. Figure 1.3 depicts results of a search of the PsycInfo database we conducted for the word *attention* in the title and subject categories. It illustrates the rise of interest in the topic of attention in contemporary psychology.

One often reads that research on attention essentially ceased between 1910 and 1949 (Keele, 1973; Moray, 1969; Neisser, 1976). However, although not evident from Figure 1.3 due to its scale, attention research never disappeared, as indicated by Lovie’s (1983) tallies of more than 100 articles on the topic being published in all but 1 decade before 1960. Not only was research on attention conducted continuously throughout the first half of the 20th century, but this research also provided a close link both to the work before 1910 and contemporary work. Lovie (1983) noted that research during this period pursued the ideas expressed in the work of Broadbent and others following the increased interest in attention in the 1950s.

Among the essential works on attention was that of Jersild (1927), who published a classic monograph, “Mental Set and Shift.” In it, he reported a

FIGURE 1.3. Research on Attention: Number of Publications as Indicated by a PsycInfo Search Conducted on December 15, 2021



series of experiments in which participants had to make judgments regarding each stimulus in a list as a function of whether a single task was to be performed or two tasks in alternating order. The major finding was that in many situations, the time to complete the list was longer for mixed lists than for pure lists of a single task. Although Jersild's study did not generate much interest for many years, since the mid-1990s, there has been a resurgence of interest in task-switching costs, making it one of the hottest areas of research on attention (e.g., Koch et al., 2018; see also Chapter 6, this volume).

Another significant contribution during this era is the discovery of the *psychological refractory period effect* by Telford (1931). He noted that numerous studies showed that stimulation of neurons was followed by a refractory phase during which the neurons were less sensitive to stimulation. Telford conducted an experiment to answer the question "Do voluntary responses, judgments and simple associative processes produce effects in the organism which serve as a barrier against immediate repetition, that can be identified with a refractory phase?" (p. 7). One of Telford's tasks required participants to make a simple reaction by pressing a key whenever a tone occurred. The interval between successive tones varied between 0.5, 1, 2, and 4 seconds. Responses were considerably slower when the stimulus followed the preceding one by a short interval than when the interval was longer. This finding, that reaction time to the second of two stimuli or tasks is increased when the interval between their onsets is short, was shown subsequently to be a pervasive phenomenon that occurred for choice reaction tasks as well. This psychological refractory period effect has been a constant source of research and theoretical speculation for the past 90 years (e.g., Klapp et al., 2019; Welford, 1952).

The same year as Telford, Bills (1931) reported a study on what would now be called *mind wandering*, or lapses of attention, but that he called "blocks." In a series of experiments, he had participants perform various tasks (e.g., color naming) as fast as possible for 7 to 10 minutes and, in a final experiment, an hour. Performance of all tasks showed blocks or pauses of varying durations in which no response occurred. The blocks tended to bunch together, suggesting a relatively rhythmic fluctuation of attention. The frequency of the blocks was about three per minute, but the frequency and length of the blocks were reduced by practice and increased by fatigue. Errors tended to coincide with the blocks, suggesting that their cause was linked to the low level of task engagement implied by the blocks.

One of the most well-known studies in the field of psychology was conducted by Stroop (1935/1992), who demonstrated that stimulus information that is irrelevant to the task can have a major impact on performance (the *Stroop effect*). He had participants name the ink colors for a list of 100 stimuli. In the crucial list, the stimuli spelled incongruent color words, and the participants were instructed to name the ink color while ignoring the color word (see Figure 1.4). Participants took an average of 110 seconds to name a list of this type, compared with 63 seconds to name the colors when presented in the form of solid squares. Thus, the naming time nearly doubled in the presence of conflicting

**FIGURE 1.4. A Monochrome Version of the Stroop Task**

|              |               |
|--------------|---------------|
| <b>BLACK</b> | <b>XXXXXX</b> |
| GRAY         | XXXXXX        |
| <b>WHITE</b> | <b>XXXXXX</b> |
| <b>GRAY</b>  | <b>XXXXXX</b> |
| BLACK        | XXXXXX        |
| <b>WHITE</b> | <b>XXXXXX</b> |

color words. Another finding of Stroop's was that the time to name the color words was unaffected by incongruent ink colors. The time to read 100 words for that list was 43 seconds, compared with 41 seconds for those words presented in black ink. Thus, the interference with color naming was asymmetric: Irrelevant words interfered with naming ink colors, but irrelevant ink colors did not interfere with naming color words.

The Stroop task provides one of the best methods for examining a variety of issues relevant to attention in young adults and more specialized populations of people. When the article was reprinted in 1992, MacLeod (1992) referred to the Stroop task as the "gold standard" of attentional measures and noted that citations of the article increased over the period of 1974 to 1990, from a low of 25 in 1974 to 80 in 1990. MacLeod's words, "The Stroop effect . . . continues to play a key role in the understanding of attention" (p. 12), are still true today.

Among the research conducted in the 1930s and 40s, that on preparatory set or mental set was among the most important (Gibson, 1941). Mowrer et al. (1940) established that preparatory set does not necessarily involve motor adjustments such as body posture and muscle tension. They reached this conclusion based on the finding that expectancy for one of two possible stimulus events was a critical factor influencing reaction time. They pointed out the consistency of their findings with those of Wundt (1880), who found that reaction time was longer when the participant did not know whether the stimulus would be visual, auditory, or tactual than when the sensory modality was known. Gibson (1941) provided a thorough, highly critical, review of the literature on set, noting, "The concept of set or attitude is a nearly universal one in psychological thinking despite the fact that the underlying meaning is indefinite, the terminology chaotic, and the usage by psychologists highly individualistic" (p. 781).

In the late 1940s, two influential works in cognitive neuroscience appeared. One was Hebb's (1949) book, *The Organization of Behavior: A Neuropsychological Theory*. In that book, Hebb pulled together research in neuroscience and psychology to provide a theory based on both. His theory was built around the concept of a *cell assembly*, a neural response in the brain corresponding to sensory information that activates specific motor responses. According to

Hebb, “Each assembly action may be aroused by a preceding assembly, by a sensory event, or—normally—by both. The central facilitation from one of these activities on the next is the prototype of ‘attention’” (p. xix). In other words, each assembly action can be primed by others. Hebb’s theory was one of the earliest connectionist models to try to relate brain and behavior. Even more pointedly, in criticizing much theorizing that did not include attention as a component, Hebb stated, “Since everyone knows that attention and set exist, we had better get the skeleton out of the closet and see what can be done with it” (p. 5). In essence, that is what the research described in this book is all about.

Moruzzi and Magoun (1949) conducted studies on cats that similarly showed the contribution of a brain region, the reticular formation, to arousal and alertness. The reticular formation is composed of many brain nuclei and projects into the forebrain, brainstem, and cerebellum. Moruzzi and Magoun stimulated various components of the reticular formation in sedated cats and found that electroencephalogram measures showed changes like those when the cat entered a waking state. Their study provided strong evidence that the reticular activating system mediates arousal by way of afferent pathways from the system to cortical and other brain areas.

In sum, although the proportion of psychological research devoted to the topic of attention was less during this period than in prior decades, many significant discoveries were made. Much of the recent research on attention has focused on developing theoretical accounts of the phenomenon of task-switching costs, the effects of irrelevant information in the Stroop and related tasks, and the psychological refractory period effect in dual-task performance, all of which were discovered during this time. Moreover, the insights of Hebb (1949), Moruzzi and Magoun (1949), and others spurred the analysis of brain networks underlying attention.

## **THE PERIOD FROM 1950 TO 1974**

The period from 1950 to 1974 saw a revival of interest in the characterization of human information processing. This revival is sometimes called the “cognitive revolution,” but we think that it is more accurately characterized as the information-processing revolution (Xiong & Proctor, 2018). The revolution was stimulated by developments in communication theory and by renewed interest in measuring and characterizing stages of information processing. Research on attention in this period is characterized by an interplay between application and theory. One of its founders, George A. Miller (2003), gives 1956, the year in which he published his classic article “The Magic Number Seven Plus or Minus Two,” as the inaugural year. However, he also specified that major advances had occurred in the prior years of the decade. This is true both for the view of the human as an information-processing system and the study of attention, for which seminal research in the modern era dates to the late 1940s (e.g., K. J. W. Craik, 1948, and Saltzman & Garner, 1948).

Although many areas of investigation contributed to the rise of the information-processing approach, research on attention and performance was at the forefront of advances, providing, among other things, the first formal processing model (Broadbent, 1958). It is customary to read that the approach relies on an analogy of humans to computers, but the fundamental idea is that humans are complex systems that can be analyzed in the same way as nonhuman systems (Posner, 1986; Proctor & Vu, 2006b).

The information-processing revolution was based on three pillars (Xiong & Proctor, 2018). The first of these, the systems concept, comes mainly from cybernetics (Wiener, 1950). Cybernetics provided the idea that everything ranging from neurophysiological mechanisms to societal activities can be modeled as structured control systems with feedforward and feedback loops. A second and closely related significant contributor was information theory (Shannon & Weaver, 1949), which provided a way to quantify entropy (uncertainty) and information and promoted theorizing in terms of information flow. The final pillar was statistical theory and the concept of null hypothesis testing, coupled with advances in experimental design, which afforded the means for making scientific inferences from the results of controlled experiments using small group designs (Fisher, 1937). Statistical theory also provided the basis for conceptualizing human decision making in other situations (Peterson et al., 1954). An additional influence was the advent of artificial intelligence and the possibility of simulating human cognition (Hovland, 1960). All these contributions came together in the early 1950s to provide the basis for most research on cognition in general and attention in particular since that time.

Experiments on the maintenance of vigilance, or sustained attention, that exemplified the interplay between theory and application were reported by Mackworth (1950/1961). This research originated in concerns about the performance of World War II radar operators in detecting infrequently occurring signals. It has continued to generate interest because of its relevance to industrial monitoring tasks and theoretical issues in attention. Mackworth introduced a “clock” test in which a pointer moved in steps of 12 minutes of arc per second, but 12 times in 20 seconds, it made a double jump of 24 minutes. The participant was to report the double jumps by pressing a key whenever one occurred. The proportion of double jumps detected decreased across the first half hour or so of the vigil. Research on the nature of this *vigilance decrement* and the factors that affect its magnitude has been conducted continuously since Mackworth’s influential study (e.g., Neigel et al., 2020).

Cherry (1953) produced one of the groundbreaking works on attention. He studied the problem of auditory selective attention or, as he called it, the *cocktail-party phenomenon*. He was concerned with the issues of how we can select one voice to attend to among several and what information is remembered from the unattended messages. Cherry used a procedure called dichotic listening in which he presented different messages to each ear through headphones. Participants were to repeat aloud, or shadow, one of the two messages while ignoring the other. This was a relatively easy task for them to do. Moreover, when

subsequently asked questions about the unattended message, participants were unable to describe anything about it except physical characteristics, such as the gender of the speaker.

Broadbent (1958) conducted an experiment that produced converging results with those of Cherry (1953). He presented participants with a set of three digits one after the other to one ear and another set at the same time to the other ear, with instructions to recall as many digits as possible. Participants tended to recall all the digits presented to one ear before trying to recall the digits presented to the other ear. To account for findings such as his and Cherry's, Broadbent developed the first complete model of attention, called filter theory (see Chapter 3, this volume). He proposed that the nervous system acts as a single-communication channel of limited capacity. According to filter theory, information is held in a preattentive temporary store, and only sensory events that have some physical feature in common (e.g., spatial location) are selected to pass into the limited capacity processing system. Broadbent's filter theory implies that the meaning of unattended messages is not identified. He also proposed that an amount of time that is not negligible is required to shift the filter from one channel of events to another.

Later studies showed that the unattended message could be processed beyond the physical level, in at least some cases (Treisman, 1960). To explain the finding that the meaning of an unattended message can influence performance, Treisman (1960) reformulated filter theory into filter-attenuation theory. According to this theory, early selection by filtering still precedes stimulus identification, but attenuated signals may be sufficient to allow identification if the stimulus has a low identification threshold, such as a person's name or an expected event. Deutsch and Deutsch (1963) took an alternative approach, proposing that unattended stimuli are always identified and that the bottleneck occurs in later processing. This view is called late-selection theory, in contrast to the filter and filter-attenuation theories, which are called early-selection theories. The issue posed by the distinction between the early- and late-selection theories is whether meaning is fully analyzed. This issue continues to be debated; for example, Weissman et al. (2018) evaluated conditions under which selection seems to be early versus late.

In the early 1970s, there was a shift from studying attention with auditory tasks to visual tasks. A view that regards attention as a limited-capacity resource that can be directed toward various processes became popular. Kahneman's (1973) model is the most well known of these unitary-capacity, or resource, theories. According to the theory, attention is a resource that can be divided up among distinct tasks in different amounts. The available supply of this resource varies as a function of arousal and task demands, and allocation strategies determine the tasks and processes to which the resource is devoted when the demand exceeds the supply. Posner and Boies (1971) distinguished two attentional components in addition to processing capacity, alertness and selectivity, and demonstrated how the separate effects of these components could be isolated in behavioral experiments.

In the early 1970s, the first controlled experiments that used psychophysiological techniques to study attention were conducted on humans (e.g., Hillyard et al., 1973). These experiments used methods that allow brain activity relating to the processing of a stimulus, called *event-related potentials*, to be measured from electrodes placed on the scalp. The difference between event-related potential patterns obtained under different conditions, such as when a person is attending to a stimulus versus when the person is not, can provide evidence about the nature of the neural mechanisms underlying the processing of specific stimuli.

Techniques were also developed to perform single-cell recordings in alert monkeys. Wurtz and Goldberg (1972) provided evidence that neurons in the superior colliculus (a midbrain area involved in sensory integration) are involved in a shift of visual attention to the location of a critical region of the visual field before the onset of eye movements. Tanji and Evarts (1976) offered similar evidence that an instruction signal as to whether a forthcoming movement would be a push or pull of a lever led to anticipatory activity in the motor cortex while the monkey was waiting for a signal to trigger the movement.

The research during this period yielded considerable information about the mechanisms of attention, specifically those involved in auditory attention. The most notable development was the introduction of detailed information-processing models of attention and performance, beginning with Broadbent's (1958) filter theory. The realization that such models can be developed and tested paved the way for many advances in our understanding of attention.

## THE PERIOD FROM 1975 TO 1999

Research on attention flourished during the last quarter of the 20th century. This is evident in Figure 1.3, which shows that the number of articles with *attention* in the title increased from approximately 700 in the period ending in 1980 to more than 3,000 for the period ending in 2000. Researchers continued to conduct behavioral (and psychophysiological) research directed toward many of the tasks, issues, and phenomena of the previous period, but the range of research expanded.

Many studies showed that it is easier to perform two tasks together when they use different stimulus or response modalities than when they use the same modalities. Performance is also better when one task is verbal and the other is visuospatial than when they are the same type. On the basis of these findings, Navon and Gopher (1979) proposed that attention is better viewed as multiple resources. Wickens (1980) extended the multiple-resource view by proposing that different attentional resources exist for distinct sensory modalities, coding modes, and response modalities. Multiple-resource theory captures the fact that multiple-task performance typically is better when the tasks use different input–output modes than when they use the same modes. Although

useful for application guidelines, the concept of multiple resources is limited as a theory of attention because its flexibility allows new resources to be added to fit any finding showing the specificity of interference (Navon, 1984).

Another distinction that became prominent is between space-based and object-based approaches to attention. In the *space-based* approach, a widely used metaphor for visual attention is a spotlight that is presumed to direct attention to everything in its field (e.g., Posner, 1980). The attentional spotlight can presumably be dissociated from the direction of gaze (a view for which Helmholtz, 1894/1968, provided evidence many years earlier). Studies showed that when a location is cued as likely to contain a target stimulus but then a probe stimulus is presented at another location, a spatial gradient surrounds the attended location such that items nearer to the focus of attention are processed more efficiently than those farther away from it (LaBerge, 1983). Evidence suggested that the attentional spotlight can be moved to a location either voluntarily or involuntarily (attention is captured by an abrupt stimulus onset).

Treisman and Gelade (1980) developed a highly influential variant of spotlight theory called feature integration theory to explain the results from visual search studies, in which participants detect whether a target is present among distractors. Feature integration theory assumes that basic features of stimuli are encoded into feature maps in parallel across the visual field at a preattentive stage. Search for a target distinguished from distractors by a single feature can be based on processing occurring during this preattentive stage. The second stage involves focusing attention on a specific location and combining the features at that location into an object. Searching for a target distinguished from distractors by a conjunction of features requires attention, and search performance decreases as the number of distractors increases.

*Object-based* models of attention view objects as the primary units on which attention operates. The primary reason for proposing such models is that numerous findings suggest a processing cost when attention must be directed toward two different objects, even when spatial factors are controlled (Duncan, 1984).

Priming studies were also popular during this period. In such studies, a prime stimulus precedes a target stimulus to which the participant is to respond; the prime can be the same as or different from some aspect of the target. When it is the same as or a close associate of the target stimulus, the prime facilitates responding to the target. For example, Meyer et al. (1975) found that the time to say the name of a visual word (e.g., BUTTER) or classify it as a word (vs. nonword) was less when it was preceded by an associated word (e.g., BREAD). Posner and Snyder (1975) and Neely (1977) varied the onsets between a prime stimulus and the target stimulus and provided evidence for two types of priming effects, one that is rapid and automatic and the other that is slower and intentional. Neely found that a category prime (e.g., Bird) facilitated processing of a word from that category at short intervals, without a cost for processing words not from the category. At longer intervals, though, the category benefit was accompanied by a cost for stimuli from a nonprimed category.

A phenomenon called *negative priming* was introduced, for which responding to a stimulus is slower when that stimulus had to be ignored on the prior trial (e.g., it was the word of Stroop color stimulus). This phenomenon was originally attributed to inhibitory processes from the prime trial affecting the probe trial, but the specific cause of negative priming remains unresolved (Labossière & Leboe-McGowan, 2018).

Another view that gained some adherents is that of *selection-for-action*. According to this view, first advocated by Neumann (1987) and Allport (1987), attentional limitations should not be attributed to a limited capacity resource or mechanism. Instead, the limitations are byproducts of the need to coordinate action and ensure that the correct stimulus information is controlling the intended responses. An application of this approach is the executive-process interactive control model presented by Meyer and Kieras (1997a, 1997b), which attempts to account for limitations in multiple-task performance in terms of strategic factors rather than structural capacity limitations. The view is represented more recently in Hommel et al.'s (2019) synthetic approach, which suggests that the emphasis should be on selection processes relevant to behavior and the systems that implement them.

During this period of research, a focus was on gathering neuropsychological evidence pertaining to the brain mechanisms that underlie attention. Cognitive neuroscience, of which studies of attention are a major part, made great strides due to the continued development of neuroimaging technologies. These include the measurement of event-related brain potentials with scalp electrodes, positron emission tomography, and functional magnetic resonance imaging. These techniques, described in Chapter 2, allow the activity of different brain regions during the performance of a variety of tasks to be examined (e.g., Leonards et al., 2000). Likewise, *spatial neglect*—a reduced ability to attend to and respond to stimuli on the side opposite a cerebral lesion (typically right hemisphere lesion and left visual field neglect)—provided evidence regarding the brain mechanisms underlying visual attention (Heilman & Valenstein, 1979; Heilman, Watson, & Valenstein, 1985). Among the most influential articles in the area of attention was Posner and Petersen's (1990) "Attentional Systems of the Brain," which distinguished three separate but interrelated subsystems of the attentional system. One subsystem is concerned with orienting to sensory events, another to detecting events to which conscious processing may be directed, and the third to maintaining an alert state. Posner and Petersen's depictions of each subsystem were based on a variety of neuroscience data from animals and humans.

Significant advances were also made toward expanding the theories and methods of attention to address a range of applied problems. Applications of research on attention are many, but two major areas can be identified. The first concerns ergonomics in its broadest sense, ranging from human-machine interactions to improvement of work environments. Examples of this work include *mental workload* (the measurement of the mental demands placed

on a person; Gopher, 1994) and *situation awareness* (a person's understanding of the situation in which they are involved; Endsley, 1995b), for both of which measurement became increasingly sophisticated during the period (see Chapter 9). The second major area of application is clinical neuropsychology, which benefited substantially from adopting cognitive models and methods to describe and investigate damaged systems in neurological patients (see Chapter 3).

## THE PERIOD FROM 2000 TO 2020

Research on attention continued to grow during the first 2 decades of the 21st century. One need only note from Figure 1.3 that the number of articles with *attention* in the title from 2000 to 2020 approximately equals the total number of articles before that time. We will not describe the research from this era in much detail because it will be covered throughout the remainder of the book. However, the following are some highlights.

A popular view is that attention has three distinct functions—alerting, orienting, and executive control—that are implemented in distinct neural systems (Fan & Posner, 2004). Work on executive control based on sequential effects in tasks for which some irrelevant aspect of stimulation can correspond or not with relevant information became a central focus of investigation. Botvinick et al.'s (2001) conflict resolution model initiated much of this interest. Bidirectional relations between perception and action came to the forefront, as in the theory of event coding (Hommel et al., 2001). Another widely investigated topic is the influence of action video game play on attention and performance; a meta-analysis concluded that playing action video games enhances top-down attention and spatial cognition (Bediou et al., 2018). Research on the neural bases of attention has continued to grow, as has research on the role of attention in social interactions. Findings of attention research have been applied to online education, social media, driving, and other human interactions with technology (see Box 1.1).

## BOOK COVERAGE

In this chapter, we touched on many of the topics that subsequent chapters cover in detail. By necessity, we cannot address all topics on attention. For this book, we selected topics and studies that illustrate how research on attention is conducted and advances. Part of what we want students and researchers to learn is how research and theory coevolve. Consequently, we present evidence to support alternative views and only state definitive conclusions where they seem warranted. As you will see, the data show a lot of agreement about the fundamental phenomena and the factors that influence them, and the issues

BOX 1.1 | HUMAN FACTORS AND ERGONOMICS

Human factors and ergonomics (HFE) is a “scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and other methods to design in order to optimize human well-being and overall system performance” (International Ergonomics Association, n.d., para. 1). HFE grew out of World War II, when human error was a leading cause of aviation and naval accidents (Proctor & Van Zandt, 2018). Many researchers studied factors that impacted human performance, including attentional factors in perception, cognition, and action. By understanding human information processing, researchers were able to design products and systems to increase performance and safety. Chapter 1 provides an overview of the history of research on attention, and this box is intended to highlight how “old issues” relating to attention are directly applicable to “new issues” associated with the design of modern products and systems. Thus, history repeats. Table B1.1 highlights historical trends in attention research and shows how similar issues resurface years later.

TABLE B1.1. Applications of Attentional Theories and Phenomena

| Theory                                                                                                          | Phenomena                                                                                                                                                                                     | Applications                                                                                                                                                                                                                                                                           |
|-----------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Philosophical Work                                                                                              |                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                        |
| Vives: Notion that the more closely one attends to stimuli, the better they will be retained.                   | Depth of processing: The deeper you process information at encoding, the better retention.                                                                                                    | Study strategies that relate new information to prior knowledge and other contexts result in better learning and retention of that material.                                                                                                                                           |
| Hamilton: Notion that more than one object or event can be attended at the same time, but with less efficiency. | Cost of concurrence: Just having to keep track of two tasks, even though 100% of attention is devoted to one of the tasks results in poorer performance than performing that same task alone. | Driving modes on smart-phones: Driving modes prevent distraction during driving (e.g., alerts from text messages, emails, apps). Even if one is not actively responding to the alerts generated from the phone, the possibility of getting an alert can influence driving performance. |
| Founding of Psychology (1860 to 1909)                                                                           |                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                        |
| Wundt: Notion that it takes time to switch attention.                                                           | Task-switching cost: It takes longer to respond to stimuli on task-switch than task-repeat trials.                                                                                            | Multitasking: Multitasking performance is poorer than single task performance in most situations.                                                                                                                                                                                      |
| Pillsbury: Retention is dependent on the degree of attention given to the material at the moment of learning.   | Encoding specificity: Retention is better when the recall environment matches the learning environment.                                                                                       | Transfer appropriate training: Training should focus on directing learners to code information in a manner consistent with how they will retrieve it.                                                                                                                                  |

BOX 1.1 | HUMAN FACTORS AND ERGONOMICS (Continued)

TABLE B1.1. Applications of Attentional Theories and Phenomena (Continued)

| Theory                                                                                                                  | Phenomena                                                                                                                                                                                            | Applications                                                                                                                                                                                                      |
|-------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Period of 1910 to 1949                                                                                                  |                                                                                                                                                                                                      |                                                                                                                                                                                                                   |
| Jersild: The time to switch between tasks is typically longer than the time to repeat the same task.                    | Task switching effect: Slowing of response to a second task if it follows performance of another task rather than the same task.                                                                     | Multitasking: There is a cost of multitasking, even though performance can become more efficient with practice.                                                                                                   |
| Stroop: Stimulus information that is related but irrelevant to the defined task can have a major impact on performance. | Stroop effect: Irrelevant color words interfere with relevant task of naming ink colors.                                                                                                             | Brain training: Practice at the Stroop task is used in a variety of games intended to promote attentional and cognitive control.                                                                                  |
| Information-Processing Revolution (1950–1974)                                                                           |                                                                                                                                                                                                      |                                                                                                                                                                                                                   |
| Mackworth: It is difficult to sustain attention.                                                                        | Vigilance decrement: Decreased ability to detect infrequent events over time.                                                                                                                        | Automation monitoring: Automation monitoring is similar to performing a vigilance task, making the human a bad “back up” for detecting automation failures.                                                       |
| Broadbent: The nervous system acts as a single-communication channel of limited capacity.                               | Cocktail-party effect: Attended conversation is processed and understood; unattended conversation cannot be recalled. But attention can be given to unattended conversation if it is highly salient. | Online learning: Students who multitask during class show poorer performance on retention tests. Moreover, students who sit in view of other students multitasking with other media also show poorer performance. |

are about the best ways to explain the underlying mechanisms of these phenomena. As researchers learn more about a topic and have additional data to inform their theories, the issues become more refined, and debates arise. Ongoing debates do not mean a lack of progress; they are part of the scientific process. Although the resolution of issues may sometimes occur relatively quickly, more often, many decades are required to arrive at a consensus.

One point on which researchers agree is that “attention” is an overarching concept for which there are subcategories based on distinct mechanisms. Some

have called for the abandonment of the term “attention” because of the broad range of topics it encompasses (Hommel et al., 2019). However, there is considerable family resemblance (Medin et al., 1987; Wittgenstein, 1953) among the subcategories of attention, relating to selection and control at all stages of information processing, which we argue warrants viewing attention as an encompassing category. The widespread research conducted under the umbrella of attention suggests that most researchers agree with us. In terms of practical implications of the research on attention, we show how this work is relevant to multitasking in everyday environments such as driving and remote learning, monitoring automation, cognitive “brain” training, and behavioral interventions for developmental disorders of attention. In the remainder of the book, you will see that much has been learned about the topics considered under “attention” and how they apply to everyday life, although, as noted earlier, there is still more to learn.

## CHAPTER SUMMARY

In this text, we take a scientific approach to the study of attention. That means that the emphasis is on empirical testing, most often in controlled laboratory environments (Proctor & Capaldi, 2006). This testing allows claims to be evaluated in terms of what Strevens (2020) called the *iron rule of explanation*, to which he attributes scientific progress:

1. Strive to settle all arguments by empirical testing.
2. To conduct an empirical test to decide between a pair of hypotheses, perform an experiment or measurement, one of whose possible outcomes can be explained by one hypothesis (and accompanying cohort) but not the other. (p. 96)

Implications of this approach are that details of research are crucial and that alternative theories have to be taken into consideration.

In this context, it is essential to distinguish facts, phenomena, and theories—which we emphasize in the Chapter Summary section of each chapter. Because the concept of attention is multifaceted, the distinctions between these classifications in some cases are somewhat fuzzy. In this chapter, we have introduced facts, phenomena, and theories regarding attention, into which we will delve in more detail in the remaining chapters. This chapter thus provides a base on which understanding of the science of attention and its applications can build in the subsequent chapters. Several facts, phenomena, and theories are summarized here, and many more will be explained and highlighted throughout the book in the Key Points sections at the end of each chapter. There is typically agreement on the facts and phenomena but less agreement on theories because they involve interpretation of the facts and phenomena.

We have tried to make it apparent in this chapter that contemporary research on attention owes a considerable debt to the work on attention conducted since

the earliest days of the field of psychology. Forty years ago, Posner (1982) made this point eloquently, stating:

One can see emerging from psychological research in the area of attention a cumulative development of theoretical concepts that rely on principles, some over 100 years old, that are now elaborated in ways that were essentially unavailable to earlier researchers. (p. 168)

He also noted,

The cumulative nature of work on attention is not widely appreciated, in part because of a failure to recognize that the methods used in current studies arose in empirical findings of the past and also because attention is a concept that can be studied at many levels. (p. 168)

Among the findings Posner referred to are that each mental operation requires a measurable period (Donders, 1868/1969), two events occurring close together in time are processed sequentially (Wundt, 1912), internal events can have facilitatory or inhibitory properties (Pavlov, 1960), and reflexive orienting to stimuli may occur (Sokolov, 1963).

In the Introduction to his collection of readings, *The Psychology of Attention*, Posner (2017) again posed the question of progress and once more answered it affirmatively:

Is there a cumulative development of work on attention? Can we argue that recent work answers issues raised earlier, even in the distant past? Based on my reading I think the answer is yes, despite many changes in language and method. (p. 2)

We hope that this chapter will help you appreciate the history of research on attention in its own right, as well as for the foundation it provides for ongoing investigations into this central aspect of human perception, cognition, and action that we describe in the remainder of this book.

## KEY POINTS

- **Fact:** Attention is a topic that has attracted considerable interest over many centuries.
- **Fact:** Empirical investigations of attention began in the last half of the 19th century and introduced reaction-time procedures to study attention that are still used today.
- **Fact:** Attention was a focus of experimental psychology through the first part of the 20th century.
- **Fact:** Much research shifted to a behavioral emphasis in the first half of the 20th century, with the study of attention continuing but in a secondary role.

- **Fact:** Attention research has flourished since the middle of the 20th century due to the development of theories and models that characterize human information processing in detail and the progress of technologies that allow examination of neural correlates of attention.
- **Fact:** Perhaps more than any other aspect of cognitive psychology, attention research has benefited from an interplay between basic and applied studies.
- **Fact:** Selection and control are key factors in all aspects of human information processing—perception, cognition, and action, and their interactions—at the individual and social levels.
- **Phenomenon:** Many phenomena introduced here, such as the Stroop effect, the psychological refractory period effect, and the cocktail-party effect, will resurface throughout the book.
- **Theory:** Many theories of attention have been proposed and tested over the years, resulting in a refinement in the understanding of attention.
- **Fact:** The interplay between theory and data from controlled experiments is essential to the progress that has been made in the way that attention is understood.