COGNITIVE METHODS

and Their Application to Clinical Research

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SELECTIVE ATTENTION TASKS IN COGNITIVE RESEARCH

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The goal of this chapter is to use research on selective attention within the field of cognitive psychology to provide a background that could guide researchers of clinical populations. The corpus of research on attention is huge but my policy nevertheless is to interpret the concept of attention broadly enough to make clear the rich interconnections between attention and other mental functions including perception, memory, and thought, and to point out the many options available if one is interested in studying attention.

Many essays on attention begin with a quote from the chapter on attention within William James' (1890) *Principles of Psychology*, in which he asserts, "Every one knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought." Although this statement is true, it seems equally telling that people do not often find similar quotes about how everyone knows what habit is, what memory is, what reasoning is, and so on. Perhaps more than most other aspects of the mind, there is a paradoxical difference between our ready folk knowledge of the concept of attention and

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the difficulty of understanding it, or even recognizing it, in clear and definite terms. For example, it is not as if, by looking at another person, one can consistently tell whether he or she is paying attention. In an episode of the cartoon strip *Dave* (by David Miller), our tongue-tied hero sits with his girlfriend, who is torturing him with a conversation about their relationship and is gazing intently at him while he silently muses, "How do I know that there is a god . . . and he's a guy? Because listening intently and zoning out look exactly the same!" On the whole, attention is known as a concept that is difficult to pin down and operationalize. I suspect that many a researcher has started a talk on some aspect of attention, only to be interrupted by a member of the audience who asks for a definition of what is meant by attention, perhaps mischievously expecting that the speaker will not be able to answer in a satisfactory manner. But life, and lectures, must go on despite the difficulty of defining attention.

The present chapter differs from most others in this book in that the topic is broader; attention is not a specific type of method as is, say, the Stroop effect, and it probably covers even more ground than do other relevant phenomena such as, say, autobiographical memory. Indeed, the deployment of attention affects almost everything humans do, and numerous methods have been developed to study it. The method must be shaped by the aspect of attention that is of interest and the starting assumptions that one is willing to make about how it operates. The floor plan for the present chapter consequently is as follows. First, I take stock of reasons why clinicians might be interested in seriously studying attention. Second, because a chapter cannot do justice to the broad topic of research on attention, some of the available book references are discussed. Third, a taxonomy of tasks that have been used to study attention are offered briefly, with a few examples and illustrations. Fourth, a key substantive question that can be addressed on the basis of such tasks—namely the question of what factors appear to cause attention or inattention—is discussed. Fifth, and finally, a more in-depth description of one line of attentional research, from the author's laboratory and collaborations, is presented to illustrate the methodological issues that must be taken into account in order to carry out a study of an aspect of attention.

WHY A CLINICIAN MIGHT STUDY ATTENTION

Why might a clinician or clinical researcher be interested in attention despite such difficulties? Perhaps because it is a key concept in understanding the human mind. It has been clear at least since James (1890), and almost certainly earlier, that there is a limit to how much information a human being can deal with at once, or within a limited period. I can think of at least three ways in which this human predicament is likely to be clinically relevant.

1. In abnormal individuals, there might be an abnormal attentional profile of diagnostic relevance. People with psychopathologies often attend to stimuli related to certain domains of clinically relevant interest (e.g., sex, violence, or emotional dependence) more than do normal individuals. Yiend and Mathews (see chap. 6, this volume) discuss this type of mechanism in detail. Conversely, it is theoretically possible that there could sometimes be a tendency to avoid such stimuli and therefore to focus attention on competing stimuli, or perhaps on no stimuli at all. In either case, an abnormal profile of attention might provide information about the topics of special concern to the patient, about the degree of severity of abnormality, and perhaps about the correct diagnosis. Yiend and Mathews offer numerous examples of different clinical populations (e.g., depressed versus anxious patients) responding differently in the same attention tasks.
2. An obsession with particular thoughts or types of thoughts can prevent attention from operating flexibly and normally. This kind of attentional abnormality can be very debilitating in its own right and warrants treatment. Of course, knowledge of research on attention is necessary for an effective treatment to be developed.
3. Some types of psychopathology (e.g., schizophrenia or attention-deficit/hyperactivity disorder) may physiologically cause cognitive impairment, including a debilitating deficit in the control of attention. Here, the treatments might differ from the case in which attentional deficits result indirectly, as a secondary consequence of obsessive thoughts.

EXTENSIVE SUMMARIES OF ATTENTION RESEARCH

In an important recent review of research in attention, Luck and Vecera (2002) stated, "The term *attention* has been used in the title or abstract of over 40,000 journal articles, books, and book chapters in the past 30 years. This greatly exceeds the 8,300 works that have used the term *emotion*, and it almost equals the 48,000 works that have used the term *memory*." Given the breadth of the topic of attention, it is best to start by describing a few resources that would allow the in-depth investigator to find out about a wider variety of experimental procedures and results than can be discussed in this chapter. Styles (1997) has written a short, general text on attention that is fairly accessible and Pashler (1998a) has written a longer but still-accessible one. A number of special, edited volumes on attention research also are worthwhile (e.g., Baddeley & Weiskrantz, 1994; Pashler, 1998b; Shapiro, 2001).

The book reporting proceedings from the regular *Attention and Performance* conference series has many useful entries, and the *Annual Review of Psychology* (Pashler, Johnston, & Ruthruff, 2000; Rensink, 2002) includes two recent summaries that are of relevance. Cowan (1995) summarized evidence of the interrelatedness of attention and memory. For historical insight regarding the development of the attention concept, one could read the chapter on attention by James (1890) and then the seminal book by Broadbent (1958). Shiffrin (1988) gives a comprehensive overview of aspects of attention research, including research on automatization of processes, that greatly increased the sophistication of researchers' understanding. Näätänen (1992) gives an in-depth summary of procedures that were used to examine the brain representation of attention, and that field has been growing rapidly (e.g., Braun, Koch, & Davis, 2001; Humphreys, Duncan, & Treisman, 1999; Parasuraman, 1998). Davies and Parasuraman (1982) and Hancock and Desmond (2001) give in-depth coverage of sustained attention, or vigilance, and practical aspects of it. There is enough overlap among these sources that it is not necessary to read all of them to gain a useful, working knowledge of research on attention. They do, however, reveal a range of theoretical perspectives and emphases as well as a great deal of empirical research.

MAJOR VARIETIES OF ATTENTION TASKS

There are various ways in which authors have classified the many different tasks that typically have been used to examine attention. Luck and Vecera (2002) provided a useful classification that distinguished between cuing paradigms, search paradigms, filtering paradigms, and dual-task paradigms and that classification will be followed here. Before that, however, a word on dependent measures is in order.

Dependent Measures in Attention Tasks

Within each category of task, some procedures measure the proportion of trials in which a correct response is given, or the difference that the direction of attention makes for the correctness of a response. Such procedures can involve very rapid presentations in order to make the task sufficiently difficult to discriminate between conditions or between individuals. Other procedures focus upon the reaction time to make a correct response. Ideally, both the reaction times and accuracy of responses must be taken into consideration in some way because there can be tradeoffs between the two. Specifically, some participants might answer more slowly so as to be sure to answer correctly, whereas others might take a greater risk of making incorrect or inaccurate responses in order to respond more quickly. This emphasis on accuracy versus speed falls along a continuum and can be modified with task instructions.

As a further complication, one can imagine tasks in which accuracy itself falls along a continuum. Such tasks are not very common in the laboratory but might be critical in real life, as for soldiers or police officers in a gun battle. Whereas either too slow or too inaccurate a firing upon a threatening attacker may mean death for the officer as a result of return fire, hitting the attacker just slightly off-target, that is, in an unintended anatomical location, still can have big consequences for either party but is not as risky for the officer as is missing the target completely. In a less life-threatening but still important example, a clinician has to respond to a statement by a patient within a relatively short time window but too hasty a response can throw the therapy onto the wrong track. People probably differ in their typical, overall tendency to be impulsive or reflective in responding in a particular situation.

Finally, in some tasks it is not just the correctness of responding that is at issue, but the particular response that is given. Sometimes the nature of erroneous responses is at issue (in error analysis) and other times there may be no correct answer or multiple possible correct answers, each of which has a different significance to the experimenter. All of these possibilities can be found in cuing, search, filtering, and dual-task procedures, although the emphasis is most often upon the pattern of proportion correct and reaction times across different conditions.

Cuing Paradigms

In cuing paradigms, as Luck and Vecera (2002, p. 240) put it, "a stimulus or an instruction is used to lead subjects to expect a specific source of inputs, and then the processing of this source of inputs is compared with the processing of other inputs." A well-known example is the procedure of Posner (1980) in which a participant is informed with a visual cue as to whether a target will appear on the left or right of visual fixation. The task is to respond with a buttonpress indicating which side of the screen the target is on, as quickly as possible. When a directional cue appears the cue usually (80% of the time) points to the correct location but on other trials (20% of the time) it is misleading, pointing to the incorrect location. On still other, control trials, there is no directional cue. For example, in some experiments the cue was a central arrow pointing left or right or a plus sign. This type of procedure produces an advantage for a correctly cued location and a disadvantage when attention is sent to the side opposite from the target. Investigators have drawn a distinction between *peripheral* or *exogenous* cues that appear at the location where the target probably will appear, which recruit attention to their locations rather involuntarily, and *central* or *endogenous* cues, such as the central arrow pointing to one side, which draw attention to the center but then allow the participant to move attention voluntarily in the direction in which the target is to be expected.

The value of cuing paradigms is that one can examine factors that recruit attention or allow attention to be shifted voluntarily, the speed and timing of these attention-shifting mechanisms, the difficulty of returning attention to a region that was recently attended, and other aspects of attention-shifting. Attention-shifting to a peripheral cue occurs automatically and, in fact, takes effort to suppress. Attention-shifting away from a central arrow toward the direction in which it points takes effort because the automatic tendency to direct attention to the arrow itself must be overcome. In this type of procedure one can usefully measure the response reaction time for trials with valid, invalid, and neutral cues and also eye movements to the cues. Given that the real-world application of attention often involves a shifting of attention to understand rapidly emerging threats and crises, cuing procedures can be quite informative. In clinical work, one could make a distinction between, say, an automatic aversion to threatening stimuli versus difficulty in using effortful processing to direct attention to threatening stimuli (see chap. 6, this volume). These mechanisms have different psychological implications. It is perhaps easier to combat a tendency that occurs with effort and voluntary processing than one that occurs automatically because the effortful processing is more visible to consciousness (e.g., Shiffrin, 1988).

Search Paradigms

In search paradigms, one item or several from a target set are to be found as quickly as possible within an array of items presented in the visual field (or, in principle at least, within a field of stimuli presented in any sensory modality or even across modalities). In a *memory search* procedure, there is just a single probe item to be examined but one searches through a memory representation to determine whether that probe was present within a previously learned or encountered set of items (Sternberg, 1966). In contrast, in a simple *visual search* procedure, there is only one item in memory, and it must be compared with a larger array of items in the visual field. Memory search and visual search also can be combined in the same experiment by having participants search for multiple possible targets, held in memory, within a multi-item array (e.g., Schneider & Shiffrin, 1977).

One benefit of search paradigms is that one can examine what factors influence the ability to use attention to find things in the environment or within a mental representation of a stimulus set. One also can examine the pattern of search times or accuracy as a function of how many items there are to be searched. For very rapid searches or searches in which items are processed in parallel, little time should be added to the reaction time for each additional item in the set to be searched. When searches must be made in a method in which only a small portion of the processing can be completed at once, say one item at a time, then each additional item in the set to be searched increases the reaction time substantially.

A key example is the visual search procedure used by Treisman and Gelade (1980). They distinguished between feature searches and conjunction searches. In an example of a feature search, a screen of dots might be presented, and one would have to press a button indicating if a red dot is present (among a field of blue dots). If a single red item is detected anywhere in the array, one can immediately ascertain that the target is present. The feature search might also involve, say, finding a triangle among circles. The reaction time for such a search does not increase much as a function of the number of objects in the display. In a conjunction search, one might be looking for a red circle among a set of items that includes at least two types of distractors: red triangles and blue circles. It is not enough to determine if the target features are present; one must carefully search to determine if they are present in the right combination. In this case, search time generally increases linearly as a function of the number of items in the display. Moreover, the slope of increase is twice as high when the target that one is searching for is absent from the display than when it is present. That is because one must search all items in a display to determine that a target is absent whereas, when a target is present, on average one finds it after searching through half of the items in the display. This type of procedure could be used to determine what the units of perception are. Clinically, we could speculate that certain objects of one's obsessions or concerns tend to be treated as features rather than conjunctions although to my knowledge there is no such research as yet.

Filtering Paradigms

In filtering paradigms, instructions given before a stimulus field indicate which part of the stimuli are to be attended and which others are to be ignored. One of the oldest examples of this type of paradigm is the selective-listening procedure in which competing spoken messages are presented to the two ears (Broadbent, 1958; Cherry, 1953). In Cherry's procedure, for example, one hears a message in one ear and a different message in the other ear and must quickly repeat (or *shadow*) everything that is said in one ear. It is clear that people can do a reasonably good job of processing only one coherent speech message at a time and that very little of the other message(s) is subsequently recalled, presumably because it could not be processed.

Filtering paradigms are useful because it is possible to learn the conditions under which distractions can or cannot be excluded from processing and the ways in which processing is impaired as a result. Learning all of this has considerable real-world application inasmuch as we live in a world with multiple concurrent stimuli and, much of the time, must exert effort to stay on task. Yiend and Mathews (see chap. 6, this volume) briefly mention early clinical work in which an emotional item is embedded within the ignored message in selective listening. To the extent that the subject's processing system is tuned to the issue of the emotional item, the item may tend to be noticed, resulting in a disruption of attention and revealing some of the subject's mental properties. An even older filtering procedure is the task by Stroop (1935/1992) discussed in previous chapters within this volume. When a color word is printed in a conflicting color of ink, people cannot name the color of the ink without massive interference from the printed color word, provided that they know how to read it. Also commonly used is the flankers task, in which the participant is to respond to a central target but not to distractors placed on the left and right of the target (see the review by Eriksen, 1995).

We have thus examined both auditory and visual filtering procedures. Although visual filtering studies traditionally have been easier to conduct with simple equipment, it is not clear that this is still the case with modern computers. In one way at least, auditory tests are especially useful: They allow ignored and attended stimuli to be presented at the same level of sensory acuity (because humans cannot close or redirect their ears). In contrast, ignored visual information tends to be perceived out of focus or peripherally, with less sensory acuity than the attended items, which can be focused with high acuity on the fovea and the closely surrounding regions of the retina. The uniform acuity found in audition makes it easier to avoid confounding sensory and attentional processes.

There are two ways in which a distractor can interfere with behavior. First, the control of the focus of attention may not be fine-grained enough to include the target and still exclude the distractors. Doing so depends on the precision of attention, the similarity of the features among target and distractors, and their spatial proximity. Second, some aspects of distractors may be processed automatically, without the need for attention. Nevertheless, this automatic processing may disrupt performance in one way or another. It may recruit attention away from processing of the target (as when a loud noise occurs in the unattended channel in selective listening) or it may contaminate the response-planning process (as in the Stroop effect). Variations on the filtering procedure are quite helpful in investigating the means whereby processing is disrupted.

A key type of evidence that ongoing processing has been disrupted is the orienting response (Sokolov, 1963), in which a shift of attention from one stimulus to another is accompanied by motor slowing and physiological signs such as heart-rate slowing, accompanied by privileged processing of the item that caused the orienting. Novel, abrupt stimuli tend to cause orienting, whereas repeated stimuli result in a habituation of orienting (see Cowan, 1995, for a review). Sokolov's theory stated that one builds a neural model of stimuli that are repeated, and there is evidence that this neural model can help a person to ignore the repeated stimuli and pay attention to something else (e.g., Cowan, 1995; Elliott & Cowan, 2001; Waters, McDonald, & Koresko, 1977). Thus, the switching of attention from one event to another is partly, but not entirely, under one's own voluntary control. If a very loud noise is unexpectedly heard, for example, attention will invariably shift from the ongoing activities to the noise. One can be internally conflicted, as when a student needs to pay attention to a boring lecture for the sake of a grade but finds it nearly impossible to do so, and attention often is a struggle between voluntary and involuntary processes. Of particular interest for clinical research, stimuli of special significance to the participant can cause continued orienting even when repeated (see Cowan, 1995).

Multiple-Task Paradigms

The final category of attentional paradigm described by Luck and Vecera (2002) was the dual-task paradigm, but we can talk more generally about multiple-task paradigms. When two or more tasks are to be accomplished at the same time, one can ask whether they all draw upon the same attentional processes or *resources*. To the extent that they do, improved performance in one task can be accomplished only at the expense of poorer performance in the other task or tasks. My own specialty in this regard is getting lost if driving to a rarely visited location while holding a discussion with a passenger, as several of my colleagues can attest (e.g., Monica Fabiani, personal communication, March 10, 2000). Broadbent (1957) described a prototypical dual-task procedure. Two different lists of three items were spoken simultaneously, with one list presented to the left ear and the other to the right ear, and then all six items were to be recalled. Recall was superior when the required order of recall was first one ear, and then the other, as opposed to an order in which the first, second, and third items in each ear were recalled in temporal order by alternating between left- and right-ear stimuli. The presumed reason is that sensory memory was used to hold the items that had not yet been recalled, and it was easiest to access one ear's representation at a time, without switching attention back and forth.

A particular dual task may have been groundbreaking in fostering the realization that human perception is fallible. As Boring (1957) has described, in Greenwich in 1796, an astronomer (Maskelyne) fired his assistant (Kinnebrook) because the two of them consistently produced results that were very different from one another. The task was one in which a metronome had to be used to time the movement of a star across hairlines in the telescope. Another forward-thinking astronomer, Bessel, from Königsberg, realized that the assistant may not have been at fault. Visiting various astronomers across Europe, he found that each one gave a different measurement but with an impressive amount of stability in judgment within an individual. Boring attributed the individual differences to the *law of prior entry*, which states that when two sensory impressions arrive concurrently, it is possible to allocate attention more to one or the other and that the attended sensory impression will seem to have arrived sooner than the initially unattended one. Differences in the style of attending to the telescope versus the metronome could have caused the astronomers to differ in their judgments.

Attention may have to be divided across time, across space, or both. It must be divided across time in the currently popular attentional blink procedure (Raymond, Shapiro, & Arnell, 1992; based on earlier, similar findings not using that nomenclature, by Broadbent & Broadbent, 1987; Reeves & Sperling, 1986; Weichselgartner & Sperling, 1987). In the attentional blink procedure, a stream of items is presented rapidly on the computer screen (e.g., 10 items per second), with one item replacing the next at the same spatial location. The participant must search for two targets, sometimes on different bases, and make two responses after the stream of characters ends. For example, the participant might be asked to search for the occurrence of two digits among letters, and then report the digits. The finding is that there is a period after the first target during which recognition of the second target is poor. If there are no items between the two targets, this *attentional blink* is not found. However, there is a period in which an occurrence of the second target will tend not to be noticed, which produces a scallop in the performance function for that target. Performance may be 50% down from its peak when there are 100 to 200 ms between targets and it returns to normal when there are about 500 to 600 ms between them.

One might worry that an attentional blink could occur because of an actual eye blink after the first target, but the data seem to rule out such an interpretation. For example, event-related brain potential recordings show that a second target that is not reported because of the attentional blink still elicits electrical components corresponding to sensory processing (P1 and N1 components) and semantic analysis (N400) but that a component corresponding to the updating of working memory (P3) is missing (Vogel, Luck, & Shapiro, 1998).

Another popular procedure in which attention is divided across time is the psychological refractory period procedure (e.g., see Ruthruff & Pashler, 2001). In that procedure, two stimuli requiring responses again are placed near one another with a variable interstimulus interval. However, here the dependent measure is not the accuracy of stimulus perception but, rather, the reaction times to the two stimuli. Again it is supposed that the allocation of attention to the first stimulus uses up some resource that may not yet be available again when the second stimulus arrives. The benefit of procedures in which attention is divided across time is that one can gain powerful indices of the time course of various types of processing that cannot be carried out for two stimuli at once.

In other procedures, attention must be divided over space instead of time. For example, in a dichotic listening experiment, such as the one by Broadbent (1957) described above, different left- and right-ear stimuli are presented at the same time and therefore have to be encoded concurrently. However, it has been assumed that we have a vivid but short-lived sensory memory that can outlast the actual stimuli (for reviews, see Cowan, 1988, 1995). It is therefore possible to complete the process of perceiving and identifying an item on the basis of its sensory memory. In essence, a simultaneous presentation of stimuli can be transformed by the participant into a sequential task in which items are processed, either directly or on the basis of the sensory memory trace, one by one. Therefore, concurrent presentation of stimuli may not yield such precise information about the time course of attentional processes. Researchers typically cannot tell which perceptual processes are delayed and then completed on the basis of a sensory memory or afterimage. This problem generally does not arise if stimuli are presented sequentially because each stimulus overwrites the sensory memory of previous ones.

In sequential presentations, one examines the consequences of pressuring the processing system in a temporal manner. The analogous possibility for simultaneous presentations is to examine the consequences of pressuring the processing system spatially, by presenting far more information than a participant possibly can deal with (even by offloading information to a short-lived sensory memory). That presumably is the situation leading to a phenomenon known as inattentional blindness (for reviews see Rensink, 2002; Simons, 2000). In this phenomenon, one finds that participants often are oblivious to very large changes in the environment, so long as an abrupt change within a single visual fixation is avoided. For example, a videotape with a visual scene of people at a table in a restaurant may cut to a very brief outdoor scene and then back to the restaurant scene, but water glasses appearing in the original scene may have disappeared and a pitcher of water may appear instead. Most participants do not notice such changes. Data and theorization in this area seem to suggest that people are able to keep in the focus of attention only a handful of independent aspects from an ongoing event. People are dependent on the external events themselves, and on logical coherence within the external scene, to perceive the stimulus bombardment that occurs at any one time.

Consistent with this suggestion of an attentional limitation, Cowan (2001) reviewed the limits on how many concurrent items can be held in the focus of attention at once. Across many different types of procedure, adult humans seem to be limited on average to about three or four independent items in the focus of attention at a time (although individual participants may yield estimates as low as two or as high as six). This limit may also be viewed as a fundamental working-memory limit, and so the relation between working memory and selective attention is a close one indeed (Cowan, 1995). Engle, Kane, and Tuholski (1999) explain how working-memory capacity on a variety of tests is related to the ability to control one's allocation and deployment of attention.

When one is confronted with a series of items one at a time, the typical finding is that people can remember and immediately repeat about seven items, give or take a few (Miller, 1956). However, Miller discussed the manner in which such immediate-memory estimates probably result from some amount of grouping together of items, or *chunking*, in memory. For example, it is difficult to recall nine random letters but easy to recall the nine letters FBI-CIA-IBM. In this example, for American readers at least, the nine letters have been transformed in memory into three well-known acronyms, each of which becomes a single chunk. Processes of covert rehearsal (e.g., Baddeley, 1986) may be useful in achieving such chunking transformations even when the stimuli do not contain already-known groups. That is probably why telephone numbers are presented as groups of three and four digits. Cowan (2001) found that, in a large variety of studies in which it is reasonable to assume that grouping and rehearsal processes have been prevented, the limit is three or four items in adults, much as in cases of concurrent stimulus presentation. Perhaps the largest current question is whether this is a central limit for stimuli presented in all modalities (presumably, a limit in the capacity of the focus of attention) or whether there are separate, albeit similar, limits for stimuli in different modalities or different types of perceptual code.

Although many of the multitask procedures have a heavy memory requirement, one also can find multitask procedures with no memory requirement, which is useful in distinguishing between memory and attention. For example, Pylyshyn and Storm (1988) developed a procedure in which a display of objects (e.g., dots) is presented and a certain number of the objects flash. They then stop flashing, and all of the objects begin to wander around the screen randomly and independently. When they stop, the required response is to indicate whether a particular object had been flashing at the beginning of the trial. Thus, this task requires multiobject tracking. It can be accomplished well by adults when there are, on average, four or fewer objects to be tracked, but certainly no more. Thus, attention must be divided between the target (previously flashing) objects throughout the trial.

A potential clinical benefit of multitask procedures is that one can examine differences in the quantity of what is attended. For example, an obsession could narrow the focus of attention as well as make the individual unable to shift the focus of attention. A narrowed attentional focus would show up in terms of fewer tasks or stimuli that could be perceived at the same time or recalled from a single stimulus array.

CAUSES OF ATTENTION AND INATTENTION AND CONSEQUENT CHOICES BETWEEN PARADIGMS

To determine which of the many attentional procedures is the right one to use for a particular experiment, one must first be explicit about which kinds of attentional mechanisms are of interest. One can point to two fundamentally different reasons why an individual might be attentive to some stimuli but inattentive to others, which can be called *processing limitations* and *processing motives*. In both cases, some types of information are said to be processed automatically, and other types of information are said to be processed only if sufficient attention of limited capacity is allocated. There also are situations in which processing limitations and processing motivations are combined. Processing limitations, processing motivation, automaticity, and the combination of processing limitations with motivations are discussed in turn below.

Processing Limitations

The first reason for attention and inattention, which can be found in the writings of William James (1890), is that there is a limit on how much information an individual is able to process at one time (i.e., a processing limitation). That type of mechanism, known as an attentional capacity limit, was one of the bases of the field of cognitive psychology as explained, for example, by Broadbent (1958) and Neisser (1967), and it remains a major topic of research. A practical situation that concerned Broadbent early on in the history of the field was the predicament of military pilots trying to hear instructions over the radio mixed in with instructions to other pilots. Another common example is the inability to process all conversations at once at a party, the widely discussed *cocktail party phenomenon*. Given the impossibility of processing everything in the environment, an individual must make some kind of strategic choice as to which stimuli are most important to process.

It is possible to adapt any of the types of attentional procedure to the study of processing limitations and, for that matter, to examine whether they are affected by clinical conditions or threatening situations that might drain attention away from the task. In a cuing procedure (e.g., the cue-validity procedure of Posner, 1980), one can study whether the attentional system is capable of exerting attention to make good use of endogenous cues (central arrows pointing to one side or another) to turn attention in a way that goes against the natural urge to focus on that central arrow itself. One might expect that a participant preoccupied with personal concerns would have fewer free resources to devote to the task and thus would do relatively poorly on endogenous cues. In a search procedure (e.g., the feature and conjunction search procedure of Treisman & Gelade, 1980), one can determine whether the increase in reaction time to find a particular feature conjunction, as a function of the display set size, is normal or slower than normal. In a filtering procedure (e.g., the selective-listening procedure of Cherry, 1953), one can examine how complex a stimulus stream can be processed and how well attention can be focused as a function of the degree of similarity between the messages to be attended versus ignored. Finally, in a multiple-task procedure (e.g., the multiobject tracking procedure of Pylyshyn & Storm, 1988) one can ask how many items can be kept in attention at once.

Processing Motivation

Even if the individual has enough of the necessary mental resources to process multiple stimuli, there may be cases in which he or she would prefer not to process certain stimuli because they are emotionally painful or because they would disrupt other mental processes, interfering with ongoing task performance or social interactions. This idea of motivated inattention can be traced back to Sigmund Freud. For example, Freud (1915/1990, p. 428) said, "Psychoanalysis has taught us that the essence of the process of repression lies, not in abrogating or annihilating the ideational representation of an instinct, but in withholding it from becoming conscious." If we accept that attention to an idea is the means by which it becomes part of conscious experience, then it follows that inattention can result from a motivation not to become aware of something. Anderson and Green (2001) showed that it is possible to simulate this process experimentally through instructions to inhibit the thoughts of words (e.g., "when you see *bear*, avoid thinking of *dish*"). In such instances, participants later find it more difficult to recall the second word in the pair than in conditions without any such inhibition instructions. Of course, as Yiend and Mathews (chap. 6, this volume) discuss, the opposite can occur and a person can be biased toward processing a certain type of emotion-laden stimulus, even if processing that stimulus reduces the person's feeling of well-being.

All of the types of procedures can, once again, be adapted to the study of processing motivation or bias. Cuing procedures (e.g., Posner, 1980) can be used to determine whether it is easier or more difficult to draw attention toward an object that matches a certain emotional or semantic bias than it is to draw attention toward a neutral object. Search procedures (e.g., Treisman & Gelade, 1980) can be used to determine whether one can spot an emotionally laden object among a crowd of objects (e.g., faces; see Yiend & Mathews [chap. 6, this volume]) more quickly than one can spot a neutral target object. Filtering procedures (e.g., Cherry, 1953) can be used to determine whether one can ignore an emotional element presented to the unattended channel. Finally, multiple-task procedures (e.g., the multiobject tracking procedure of Pylyshyn & Storm, 1988) could be used to determine if emotional objects could be tracked more easily than other objects, although this adaptation has not been tried.

In the area of attention, a plethora of procedures have overlapping aims and are relevant to highly overlapping issues. How, then, should one pick a procedure to use in a clinical experiment? A key point is that each procedure has many intricacies inasmuch as there are multiple strategies that participants can use to carry out the task. Therefore, an acceptable general method of picking a procedure would be as follows: (a) find a few experiments with results that one particularly likes and that seem to demonstrate a specific process in attention; (b) try to ensure that the procedure or procedures are not the center of an active debate concerning what fundamental processes are used to carry out those procedures; (c) get to know a tightly knit body of literature regarding that procedure; and (d) stick with the procedure for a while, changing just one thing at a time until a new point of interest can be established. This process seems better than hopping between procedures too quickly, given the investment of time and effort that is needed to learn valuable things from each procedure. Yiend and Mathews (see chap. 6, this volume) appear to illustrate this process in clinical research. Some potential pitfalls of a method are illustrated later in this chapter in a discussion of recent selective-listening studies with normal adults.

Now, however, the point about understanding how an attentional method works is explored with respect to one basic issue that distinguishes procedures from one another. Specifically, some procedures index automatic selection of an object from a multiobject field and others index effortful, attention-demanding processing. It is especially important to determine how to tell them apart.

Consequences of Automatic Versus Attention-Demanding Processing

Automaticity and Processing Limitation

Both the common conception of a processing limit and the concept of processing motives include the assumption that some processing takes place even without attention. This is termed *automatic processing*, which typically is not easily controlled and may occur even against the participant's wishes. Within the notion of a processing limit, for example, consider a seminal, selective-listening study by Cherry (1953) that influenced Broadbent (1958). Cherry presented different spoken messages to the two ears through headphones and required that the participant repeat concurrently, or *shadow*, one of the messages. This shadowing led to an almost total inability to recall anything that had been presented in the nonshadowed message. However, if the message changed in a basic physical quality (from a male voice to a female voice), this was invariably noticed. The voice quality must have been processed automatically at some level of the nervous system, even though the nonshadowed channel did not receive enough attention for processing of the message content.

The assumption of automatic processing of simple physical features of stimuli in selective listening is reinforced by the work of Johnston and Heinz (1978). They used selective-listening procedures in which two word lists, spoken concurrently, could differ in terms of voice quality or only in terms of the message topic. (There were also single-stream control conditions.) Participants could learn to listen to one list of spoken words while ignoring another. Depending on the experiment, the task was to respond to comprehension questions after the list, respond by shadowing the message, or search for particular target words in the list. In any case, there also were occasional flashes of light during the sentences, and the secondary task was to respond to the light flash with a buttonpress as quickly as possible, without interrupting the selective-listening task. The rationale behind that experimental design is that, the more attention-demanding the listening task is, the slower the responses to the light will be on average. These experiments showed that the reactions to the light flashes were much slower when they accompanied the task of selective listening on the basis of semantic differences than they were when they accompanied the task of selective listening on the basis of voice differences. The data suggested that listening on the basis of voice differences consumes little, if any, attention; the nontarget voice could be excluded from processing relatively automatically, without withdrawing attention from the tasks of interpreting the target message and waiting for the light flash. In contrast, the nontarget semantic content could be identified and excluded only at the expense of slower performance in the reaction-time task. Thus, only the physical features were processed automatically.

Although some types of automatic processing (such as the processing of basic physical features of the environment) may be intact from birth or may develop as an inevitable consequence of normal childhood development, other types of automatic processing develop through habit. For example, James (1890) discussed an instance in which he went upstairs to change into dinner clothes and, his thoughts being preoccupied, he accidentally changed into bedclothes instead. Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977) showed that habit leads to an automatization even of perceptual processes. They did this in a seminal, elaborate set of experiments in which they compared two types of search condition referred to as a consistent mapping and a varied mapping. The task was one in which a field of characters was to be searched for an item from a set of targets. For example, in one experiment (Schneider & Shiffrin, Experiment 2), a participant might have to search for the presence of either an E or an H among a visual array that included the letters F, B, H, and X (in which case the correct response would be to push the computer key indicating "yes" as quickly as possible because the H is present in the array). On each trial, the target set was given, followed by the array to be searched for the presence of any of the targets. The target set (items to be found) could include 1, 2, or 4 characters and, as well, the visual array to be searched could include 1, 2, or 4 characters. There never was more than one of the targets within a particular array. In the consistent mapping condition, target characters were drawn from the same set on every trial. For example, if the presence of an F would warrant a "yes" response on one trial, it would warrant a "yes" response whenever it occurred within that session. (It would occur in the array only if it also had been part of the target set on that trial.) In the varied mapping condition, in contrast, a particular character could serve as a target on one trial and as a distractor, or nontarget in the visual array, on another trial. For example, one might have to search for an H or S on trial n but, on trial n+x, either H or S or both could be present within an array for which one was to search instead for certain other letters. In that case, the correct answer on trial n+x would be "yes" only if those other, target letters were present, regardless of whether H or S were present (as distractors on this trial).

Practice succeeded in establishing an automatic perceptual process in the case of consistent mapping only. At first, reaction times were much slower for trials in which the memory set contained more items, and also for trials in which the array was larger. Presumably, searches had to take place a little bit at a time; searching processes could not cover the entire memory set or the entire visual array at once, at least not without interference between items. However, over many trials of consistent mapping, participants could learn to search arrays for a particular set of target characters. As a consequence, after a while it did not much matter how large the memory set was or how large the array was. In contrast, such learning never could take place in the varied mapping situation; the skill of searching for a new set of characters on each trial did not become automatized. Other experiments demonstrated the same thing by varying the duration of the array and measuring the proportion correct, which was reduced if the array was presented too quickly for the search process to be completed successfully.

In daily life, our considerable experience has divided items into different categories that can be used for automatic perceptual processing without specifically practicing for that purpose. For example, it is relatively easy to search for a digit among letters and relatively difficult to search for a letter among other letters or a digit among digits. The difficulty that can occur in searching for characters (e.g., a letter among other letters) occurs only if one is searching for an object that does not stand out on a physical basis. When one searches for basic physical features, they seem to pop out from the background and can be seen easily. For example, it is easy to search for a single red item among a field of items that are colored blue, or for a single triangle among circles. It is difficult to search when one needs to check the particular conjunction of features, such as searching for a single red circle in a field containing red triangles and blue circles, so that neither the color nor the shape is unique to the target items (Treisman & Gelade, 1980).

The automaticity of a perceptual process could play a role in performance in several ways: (a) If task-relevant items have come to be automatically perceived, the perception of these items can take place more efficiently. Automatization of the target set in the procedures of Shiffrin and Schneider exemplify that possibility. (b) If task-irrelevant distractors have come to be automatically perceived, and these distractors are clearly unlike the targets, this situation can prevent harmful attention to the distractors that otherwise would occur at the expense of the target processing. (c) In addition, though, if task-irrelevant distractors elicit the same response category as the targets, there may be some confusion that is *increased* after automaticity of the distractors because the response system is contaminated. There are examples of all of these possibilities in the research literature.

It has long been understood that when a process becomes automatic, it can be completed without attracting one's attention. That is one benefit of automaticity. For example, walking behavior has become relatively automatic so that one can walk and hold a conversation at the same time. Driving a car is also generally automatic except that an emergency on the road will interrupt the conversation. Recent research suggests that holding conversations through a cell phone, even one that does not have to be handheld, dangerously interferes with emergency coping within driving behavior (Strayer & Johnston, 2001).

Given that automatic behavior does not require one's attention, it often has been speculated that the memory system can be addressed and updated automatically, which results in unconscious perception and memory storage. Holender (1986) has reviewed a large number and range of studies purporting to demonstrate this automatic access and updating, and has cautioned that most of them are problematic in that one cannot be sure of the direction of participants' attention during testing.

Mechanisms Working Together

It is possible for both processing limitations and motivations, and their automatizations, to operate at the same time to control performance. Demonstrating this, Motley, Camden, and Baars (1982) examined slips of the tongue, which presumably reflect thoughts that were automatically formed and were converted to speech without being adequately monitored or suppressed. They set up a situation in which slips would occur more frequently than they do in daily life. In one example, after reading aloud numerous word pairs beginning with the letters f__ p__, as in *federal privilege, future payment,* and so on, participants were given a word pair with the opposite letter arrangement, p__ f__, such as *past fashion*. Participants often would incorrectly read this pair as *fast passion,* fitting the pattern of the previous pairs. Thus, the processing system was unable to prevent recently established automatic processes (the f__ p__ pattern) from dominating the response. The processing motivation also proved to be relevant. Participants who had been placed in a sexualized situation made more errors on sexual word pairs (e.g., *past fashion* misread as *fast passion*), whereas those placed under threat of shock made more errors on word pairs related to electricity (e.g., *worst cottage* misread as *cursed wattage*).

AN EXAMPLE OF A LINE OF RESEARCH ON CENTRAL ISSUES OF ATTENTION

One must consider various confounding and complicating factors in order to make progress in understanding the role of attention in any domain. One line of research illustrating these confounding and complicating factors examines whether attention filters out information after physical features have been processed (an early filter) or only after semantic features also have been processed (a later filter). Participants in our studies were to shadow the spoken message presented to one ear, a procedure that allows one to examine how well the attentional set is maintained. After Cherry (1953) found that people can recall very little of the information that occurs in an unattended channel in selective listening except for the basic physical features, Moray (1959) challenged this approach with the finding that people could sometimes notice and recall their own names having been presented in the unattended channel. (This, along with the difficulty of perceiving much else in an unattended channel, is the cocktail party phenomenon.) However, even though Moray's finding is commonly used in cognitive textbooks, it was only a pilot study that was never replicated. Moray tested 12 individuals and 4 of them noticed their names. Even these four might be accounted for on the grounds that each participant's name had to be spliced into the audiotape with the rest of the unattended message, which could have created subtle acoustic irregularities that could have recruited attention.

We thought of replicating Moray's experiment as a consequence of some experimental results on sensory memory. Cowan, Lichty, and Grove (1990) had participants read a novel silently or in a whisper while hearing meaningless syllables through headphones. There was no response to most of the syllables but, occasionally, the participant would receive a cue to stop reading and recall the last spoken syllable. This last syllable occurred 1, 5, or 10 s before the recall cue. Memory for unattended speech declined dramatically as a function of the retention interval. However, it also was found that the slightest redirection of attention to the spoken channel at the time of the speech presentation resulted in an enormous improvement in memory for speech, suggesting an early filter.

Wood and Cowan (1995a) replicated a condition from Cherry (1953): a change in the unattended message from forward speech to backward speech and then back to forward speech again 30 s later. Shadowing responses were tape-recorded to enable examination of the direction of attention. After the shadowing session, participants were quizzed about whether they had noticed anything unusual in the unattended channel and, if so, what it was. About half of the participants reported noticing something unusual. In those who did notice, the shadowing record showed pauses and errors mounting within the first 15 s of backward speech. Subjects who did not report anything unusual in the unattended channel showed no such shifting of attention. Thus, noticing the change in the channel that was supposed to be unattended was accompanied by a shift in attention. Wood and Cowan (1995b) used a similar procedure to reexamine whether people noticed their name in an unattended channel. We improved upon Moray's (1959) procedure by (a) using a larger number of participants, (b) carefully analyzing the shadowing response for pauses and errors that could reflect attention shifts, (c) using only subjects' first names in the recording and restricting the sample to subjects with monosyllabic first names mixed with other monosyllabic words to avoid acoustic differences, (d) using computer digitization techniques to eliminate any acoustic cues from splicing audiotapes to insert the names, and (e) using yoked pairs of participants who each received both names in the acoustic channel, so that each participant was tested on his or her own name and a control name. No participant ever notice the yoked control's name, whereas 33% of the participants noticed their own names, which replicated Moray's finding surprisingly well. Those who noticed their names showed a large shift of attention away from shadowing just after the name, which did not occur in the other participants.

The verdict from Wood and Cowan (1995a, 1995b) appeared to be that names in the unattended channel are automatically processed, though this processing clearly then recruited attention away from shadowing. A final study illustrates, however, how difficult it can be to determine what is automatic. Conway, Cowan, and Bunting (2001) asked *which* participants noticed the names in the unattended channels. One possibility was that those with better working memory would be able to shadow one channel while monitoring the other channel at the same time, and thus would notice their names. Alternatively, though, participants with better working-memory spans might be better at inhibiting distraction and therefore *less* likely to notice their names than would lower-span individuals.

The results strongly favored the inhibition view. Of participants in the highest quartile of working-memory span, only 20% noticed their names, whereas of participants in the lowest quartile, 65% noticed their names. This finding is rather consistent with an early-filter view. The supposedly unattended channel could not be monitored or perceived without a drop in shadowing performance. Low-span individuals apparently distributed attention across channels rather than focusing it more exclusively on the assigned task, the channel to be shadowed.

It is noteworthy that the interpretation based on Conway et al. (2001) is just the opposite from what one would think based on Wood and Cowan (1995b) and numerous related studies (Holender, 1986). This discrepancy between conclusions underscores the point that one cannot rely on a convergence of results from multiple studies if those studies share some hidden logical flaw. A single study that identifies the flaw is worth more.

Another lesson is the importance of assessing the processing abilities of the participants one wishes to study clinically. Suppose one is comparing anxious and normal individuals on an attention task. It could be important to make sure that these two groups are equated on working-memory abilities. One could imagine that part of the anxiety that some participants face is an indirect consequence of trying to manage scholastic work with a relatively low working-memory ability.

In a single laboratory, it may be preferable to stick with one good procedure for a long time, until the many possible bugs can be worked out, rather than to hop from one attractive procedure to another. At the same time, one must be aware that typically multiple procedures need to be interpreted. For example, the case of attending to one's name has been looked at in visual studies of the attentional blink (Shapiro, Caldwell, & Sorensen, 1997) and repetition blindness (Arnell, Shapiro, & Sorensen, 1999) and these studies still need to be reconciled with that of Conway et al. (2001). Perhaps the answer is that there are both early and late filtering mechanisms (Johnston & Heinz, 1978) or filtering in a leaky manner that lets some semantic processing proceed in an attenuated form (Cowan, 1988, 1995; Treisman, 1964). In any case, this presentation of research in its unfinished state illustrates how experimental procedures can be used, with caution, to explore the deployment of attention in various situations that relate to clinical experiences and outcomes.

REFERENCES

Anderson, M. C., & Green, C. (2001). Suppressing unwanted memories by executive control. *Nature, 410*, 366–369.

Arnell, K. M., Shapiro, K. L., & Sorensen, R. E. (1999). Reduced repetition blindness for one's own name. *Visual Cognition*, 6, 609–635.

Baddeley, A. D. (1986). *Working memory*. Oxford Psychology Series, No. 11. Oxford, England: Clarendon Press.

Baddeley, A. D., & Weiskrantz, L. (Eds.). (1994). *Attention: Selection, awareness, and control: A tribute to Donald Broadbent*. New York: Oxford University Press.

Boring, E. G. (1957). *A history of experimental psychology* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Braun, J., Koch, C., & Davis, J. L. (Eds.). (2001). *Visual attention and cortical circuits*. Cambridge, MA: MIT Press.

Broadbent, D. E. (1957). Immediate memory and simultaneous stimuli. *Quarterly Journal of Experimental Psychology*, 9, 1–11.

Broadbent, D. E. (1958). *Perception and communication*. New York: Pergamon Press.

Broadbent, D. E., & Broadbent, M. H. P. (1987). From detection to identification: Response to multiple targets in rapid serial visual presentation. *Perception & Psychophysics*, *42*, 105–113.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *The Journal of the Acoustical Society of America*, *25*, 975–979.

Conway, R. A., Cowan, N., & Bunting, M. F. (2001). The cocktail party phenomenon revisited: The importance of working memory capacity. *Psychonomic Bulletin & Review, 8*, 331–335.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin, 104*, 163–191.

Cowan, N. (1995). *Attention and memory: An integrated framework.* Oxford Psychology Series, No. 26. New York: Oxford University Press.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences, 24*, 87–185.

Cowan, N., Lichty, W., & Grove, T. R. (1990). Properties of memory for unattended spoken syllables. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 258–269.

Davies, D. R., & Parasuraman, R. (1982). *The psychology of vigilance.* New York: Academic Press.

Elliott, E. M., & Cowan, N. (2001). Habituation to auditory distractors in a cross-modal, color–word interference task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 27*, 654–667.

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 102–134). Cambridge, England: Cambridge University Press.

Eriksen, C. W. (1995). The flankers task and response competition: A useful tool for investigating a variety of cognitive problems. *Visual Cognition, 2*, 101–118.

Freud, S. (1990). The unconscious (C. M. Baines, Trans). In M. J. Adler (Ed.), *Great books of the western world* (Vol. 54, pp. 428–443). Chicago: Encyclopedia Britannica. (Original work published 1915)

Hancock, P. A., & Desmond, P. A. (Eds.). (2001). *Stress, workload, and fatigue.* Mahwah, NJ: Erlbaum.

Holender, D. (1986). Semantic activation without conscious identification in dichotic listening, parafoveal vision, and visual masking: A survey and appraisal. *Behavioral & Brain Sciences, 9*, 1–66.

Humphreys, G. W., Duncan, J., & Treisman, A. (Eds.). (1999). *Attention, space, and action: Studies in cognitive neuroscience.* New York: Oxford University Press.

James, W. (1890). *The principles of psychology.* New York: Holt.

Johnston, W. A., & Heinz, S. P. (1978). Flexibility and capacity demands of attention. *Journal of Experimental Psychology: General, 107*, 420–435.

Luck, S. J., & Vecera, S. P. (2002). Attention. In H. Pashler & S. Yantis (Eds.), *Steven's handbook of experimental psychology* (3rd ed., pp. 235–286). New York: Wiley.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81–97.

Moray, N. (1959). Attention in dichotic listening: Affective cues and the influence of instructions. *Quarterly Journal of Experimental Psychology, 11*, 56–60.

Motley, M. T., Camden, C. T., & Baars, B. J. (1982). Covert formulation and editing of anomalies in speech production: Evidence from experimentally elicited slips of the tongue. *Journal of Verbal Learning and Verbal Behavior, 21*, 578–594.

Näätänen, R. (1992). *Attention and brain function.* Hillsdale, NJ: Erlbaum.

Neisser, U. (1967). *Cognitive psychology.* New York: Appleton-Century-Crofts.

Parasuraman, R. (Ed.). (1998). *The attentive brain.* Cambridge, MA: MIT Press.

Pashler, H. E. (1998a). *The psychology of attention.* Cambridge, MA: MIT Press.

Pashler, H. (Ed.). (1998b). *Attention.* Hove, England: Psychology Press.

Pashler, H., Johnston, J. C., & Ruthruff, E. (2000). Attention and performance. *Annual Review of Psychology, 52*, 629–651.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3–25.

Pylyshyn, Z. W., & Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision, 3*, 179–197.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance, 18*, 849–860.

Reeves, A., & Sperling, G. (1986). Attention gating in short term visual memory. *Psychological Review, 93*, 180–206.

Rensink, R. A. (2002). Change detection. *Annual Review of Psychology, 53*, 245–277.

Ruthruff, E., & Pashler, H. E. (2001). Perceptual and central interference in dual-task performance. In K. Shapiro (Ed.), *The limits of attention: Temporal constraints in human information processing* (pp. 100–123). New York: Oxford University Press.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84*, 1–66.

Shapiro, K. (Ed.) (2001). *The limits of attention: Temporal constraints in human information processing.* New York: Oxford University Press.

Shapiro, K. L., Caldwell, J., & Sorensen, R. E. (1997). Personal names and the attentional blink: A visual "cocktail party" effect. *Journal of Experimental Psychology: Human Perception and Performance, 23*, 504–514.

Shiffrin, R. M. (1988). Attention. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), *Stevens' handbook of experimental psychology* (Vol. 2., pp. 739–811). New York: Wiley.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review, 84*, 127–190.

Simons, D. J. (2000). Attentional capture and inattentional blindness. *Trends in Cognitive Sciences, 4*, 147–155.

Sokolov, E. N. (1963). *Perception and the conditioned reflex.* New York: Pergamon Press.

Sternberg, S. (1966). High-speed scanning in human memory. *Science, 153,* 652–654.

Strayer, D. L., & Johnston, W. A. (2001). Driven to distraction: Dual-task studies of simulated driving and conversing on a cellular telephone. *Psychological Science, 12,* 462–466.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18,* 643–662. (Reprinted in 1992 in the *Journal of Experimental Psychology: General, 121,* 15–23.)

Styles, E. A. (1997). *The psychology of attention.* Hove, England: Psychology Press.

Treisman, A. M. (1964). Selective attention in man. *British Medical Bulletin, 20,* 12–16.

Treisman, A. M., & Gelade, G. (1980). A feature integration theory of attention. *Cognitive Psychology, 12,* 97–136.

Vogel, E. K., Luck, S. J., & Shapiro, K. L. (1998). Electrophysiological evidence for a postperceptual locus of suppression during the attentional blink. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1656–1674.

Waters, W. F., McDonald, D. G., & Koresko, R. L. (1977). Habituation of the orienting response: A gating mechanism subserving selective attention. *Psychophysiology, 14,* 228–236.

Weichselgartner, E., & Sperling, G. (1987). Dynamics of automatic and controlled visual attention. *Science, 238,* 778–780.

Wood, N., & Cowan, N. (1995a). The cocktail party phenomenon revisited: Attention and memory in the classic selective listening procedure of Cherry (1953). *Journal of Experimental Psychology: General, 124,* 243–262.

Wood, N., & Cowan, N. (1995b). The cocktail party phenomenon revisited: How frequent are attention shifts to one's name in an irrelevant auditory channel? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21,* 255–260.