only moderate amounts of driving experience. With practice, tasks become subjectively easier. In the context of capacity theories, improvement in performance with practice is assumed to reflect a reduction in the amount of resources needed to accomplish the task. At the extreme, a highly practiced task may become "automatic" in the sense that few, if any, limited cognitive resources are required to accomplish the task. For example, studies of visual search have shown that when observers search for the same target letters for thousands of trials, the number of distractor letters present in the display has no effect on response times, suggesting that the identification of the targets no longer requires the controlled allocation of limited processing resources. It follows that as the resource demands of a particular task decline, the ability to perform that task in combination with other tasks should improve, and this prediction is indeed supported by laboratory research. In the context of structural theories, practice is assumed to reflect an enhanced ability to coordinate critical processing operations. For example, practice may improve the ability to rapidly switch the response selector back and forth between tasks.

Charles L. Folk

See also Attention: Effect of Breakdown; Attention: Effect on Perception; Attention: Selective; Cell Phones and Driver Distraction; Change Detection

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Attention: Effect of Breakdown

Many encyclopedia entries and introductory chapters written about attentional selection start by noting that our environment is rather rich in sensory stimulation that cannot possibly be processed simultaneously and there has to be a mechanism (attentional selection) that deals with this bombardment of sensory stimulation by processing only the relevant information. This statement is valid, but what is the evidence for this implied limited capacity (i.e., the breakdown of attention)? Perhaps you have had the experience of walking into a crowded café trying to find an empty table while holding a tray with hot soup and a sandwich. After quite a bit of searching around, you finally find a table and sit down to enjoy your food. But just as you are about to bite into your sandwich, a friend of yours comes by your table asking why you've ignored her waving at you. This example illustrates a simple yet startling fact—even though we may feel as if we perceive everything around us, the perceptual reality is that we are only aware of a small subset of sensory events at any single moment in time. The failure of attention, illustrated with this example, reflects the fact that most of the sensory information available in the physical world is actually not processed, and therefore is not available for conscious perception. This lack of conscious access to the sensory information present in the physical world is termed *breakdown of attention.* Such apparent breakdown, or limited capacity, arises because there is too much distraction from all the possible sensory input that competes for conscious perception. This entry focuses on instances that demonstrate the need for attentional selection, give examples of breakdowns of attentional selection, and briefly considers the fate of the information that failed to reach conscious perception.

Behavioral Phenomena

One of the most striking examples of the breakdown in the attentional system, caused by sensory overload, was demonstrated by Daniel Simmons and his colleagues. The authors conducted a series of experiments that revolved around a simple scenario—a young man (one of the experimenters) approaches a passerby (unsuspecting participant in this experiment) asking for directions on how to get to one of the buildings on campus. In the middle of the conversation, however, two people carrying a door (experimental accomplices) walk in between the experimenter and the participant briefly obstructing the participant's view of the experimenter. During the time that the experimenter was invisible to the subject, another person trades places with the experimenter, so that once the door has passed, the participant is left talking to a new person! This experiment found that only 50% of the participants noticed that, after the interruption, the identity of the person they were conversing with was switched, even though the two experimenters were dissimilar in build, had different haircuts, had different pitched voices, and wore dissimilar clothing. This example is particularly potent because the experiment was conducted not in the contrived laboratory environment, but rather in our natural environment (i.e., outside) with innocent bystanders serving as participants. In addition, this experiment was not conducted in the middle of a hustle and bustle of, say, Times Square (an environment that we often think of as being conducive to sensory overload). This experiment demonstrates a striking breakdown of attention in our day-to-day environment, even under conditions when part of the stimulus was attended (few would argue that two people who are carrying a conversation with one another do not, at least on some level, pay attention to each other's identity). The breakdown of attention in this experiment could be attributed to competition from a multitude of sensory and mental events related and unrelated to the actual task at hand of giving directions—for example, remembering the campus layout, remembering landmarks on the way, hearing birds chirping in the background, or feeling faint pain from a blister on the left foot. All these cognitive tasks place enormous constraints on attentional selection, ultimately resulting in a failure of perception.

Such failures of perception are the rule rather than an exception. As such, we live in a limited world of what our attentional selection mechanisms have reconstructed for us. An insight into just how limited our perceptual world is without attentional selection is gained from examining perceptual experiences of patients with hemispatial neglect. This disorder is termed *hemispatial neglect* ("neglect") to reflect the failure to attend to information appearing on the contralesional left side.

Recipe for Breakdown—Competition and Attentional Load

What are the circumstances that lead to breakdown of attention? Robert Desimone and John Duncan proposed a biased competition model for selective attention suggesting that items presented in a multielement scene are not processed independently, but rather interact in a mutually suppressive way (i.e., each items competes for processing, increasing the odds of attentional failure). In other words, processing a single item within the scene will not be enough to tax capacity limitations, whereas multiple items within the scene will compete for sensory processing and will compete for attentional resources. Such suppressive interactions have been observed not only behaviorally but also with neurophysiological and neuroimaging techniques. For example, Sabine Kastner and her colleagues examined the consequence of suppressive interactions (i.e., when multiple sensory stimuli compete for processing) using functional magnetic resonance imaging (fMRI). The authors presented participants with a set of four colorful pictures that were either presented simultaneously (i.e., simultaneous condition) or one at a time (i.e., sequential condition) and participants were simply asked to passively view the presented items. fMRI blood-oxygenated-level-dependent response (BOLD) was recorded during presentation of sequential condition (summed over presentation of four items) and during the simultaneous condition. The overall fMRI response was much reduced in the simultaneous condition compared with the sequential condition. This finding demonstrates that stimuli presented in close spatial proximity do compete for attentional resources, thus inhibiting and interfering with one another. Such competition is eliminated, however, when items are presented one at a time.

In a recent investigation, Sarah Shomstein and Steven Yantis demonstrated that competitive interactions are not limited to a single modality. Rather, competition is observed when multiple stimuli, of any kind, vie for attentional resources. In this study, participants were presented with visual and auditory information simultaneously and were asked to pay attention to one or the other depending on instructions, and to occasionally shift their attentional focus from visual stimulation to auditory stimulation (and vice versa). Using fMRI, the authors demonstrated that overall activity in the corresponding sensory regions (i.e., auditory cortex and visual cortex) was decreased in presence of competing sensory information, similar to the simultaneous condition in the Kastner study described earlier. Moreover, even though the subject was not attending to the competing information, it was observed that when participants were paying attention to the visual stimuli, activity in the visual cortex increased and activity in the auditory cortex decreased. The opposite pattern was observed when auditory information was attended. These findings support several conclusions. First, early sensory cortical responses, as measured by the fMRI signal in auditory and visual cortices, are modulated by attention. Second, the "push–pull" effect of switching attention between vision and audition suggests a neural basis for behavioral evidence that focusing attention on auditory input (e.g., a cellular telephone conversation) can impair the detection of important visual events (e.g., what's happening on the road while driving an automobile). When attention must be directed to audition, the strength of early cortical representations in the visual system are compromised (and vice versa), leading to potentially significant behavioral impairments.

Another contributing factor to breakdown of attentional selection, bearing directly onto biased competition, is attentional load. According to the load hypothesis, originally proposed by Nilli Lavie, the extent to which distracting elements compete for resources is a function of how attentionally demanding the task is. In other words, under high perceptual load (e.g., reduced size or contrast of stimuli or number of stimuli), attentional capacity will be maximally taxed, thus resulting in increased competition, but under conditions of low perceptual load, there would be enough capacity to enable processing of all the available sensory input, reducing the need for competitive interactions.

The Fate of the Unattended

Although much recent research has been devoted to understanding the psychological and neural processes underlying attentional selection, researchers know little about the fate of the sensory information that is not selected. In other words, the question is what happens to all the information that is not processed, that is not available for conscious perception? Did the breakdown of attention result in total and utter failure of perception, or is the unattended sensory information available for perception and for behavior in some capacity? For example, when an observer selectively attends to some subset of the visual input, the degree to which the remaining, unattended input is represented remains largely unknown. That our current knowledge of such scenarios is so underspecified may be surprising given that understanding the nature and extent of processing of unattended information is one of the long-standing and seminal issues in perception. It is not particularly contentious that after the light hits the retina, or the air moved by a sound excites hair cells in the cochlea, some amount of processing is accomplished, regardless of whether the specific information is attended or not. What remains more uncertain, however, is the extent to which the unattended information influences behavior.

A strong claim made by some researchers is that little, if any, visual processing can occur in the absence of attention and that perception cannot proceed without attentional selection. Evidence supporting this account comes from inattentional blindness paradigms, pioneered by Arien Mack and Irvin Rock, in which task-irrelevant grouped items went unnoticed and did not influence the behavioral performance of the observers. In one well-known version of this paradigm, observers judge whether the horizontal or vertical arm of a briefly flashed cross was longer. On the fourth trial, an unexpected item—a word, a face, a shape, a texture—was presented simultaneously with the cross but at a different position on the screen (within the arms of the cross, but not at the cross section of the arms). When the cross was presented at fixation and the unexpected item was presented parafoveally (peripherally), about one quarter of the observers failed to perceive the presence of the unexpected object. Even more startling, when the cross was presented parafoveally and the unexpected item was presented at fixation (i.e., precise location of where the participant was gazing directly), nearly three quarters of observers failed to detect the unexpected item. These findings suggest that, in the absence of attention, information is not processed and therefore perception fails.

An equally strong but opposing account suggests that fundamental visual processes such as perceptual grouping and figure-ground segmentation can take place in the absence of attention. In one illustrative study, Cathleen Moore and Howard Egeth asked participants to judge which of two parallel lines, superimposed on a background matrix of black-and-white dots, was longer. The background dots, whose presence was orthogonal to the line-judgment task, were either randomly colored or were grouped to form the Müller-Lyer illusion (optical illusion that consists of two sets of arrow-like figures, one with both ends pointing in, and the other with both ends pointing out; when asked to judge which of the two lines is longer, viewers typically chose the inward pointing arrow—see Cultural Effects on Visual Perception, Figure 1). Because the length judgment was clearly influenced by whether the background dots gave rise to the illusion, the authors concluded that background dots, though not attended, were in fact perceptually processed and as such affected behavior. Further support for the view that unattended information influences behavior comes from a recent study by Ruth Kimchi and Irene Razpurker-Apfeld, in which subjects performed a change detection task on a small, centrally located black-and-white matrix, presented for a brief duration. The matrix-like target stimulus was embedded in the center of a background pattern, consisting of colored dots that grouped by similarity into either rows, columns, or simple shapes. On each trial, two successive displays were presented, and subjects judged whether the central target matrix remained the same or changed. In addition, within a trial, the organization of the background elements stayed the same or changed, independent of the status of the target matrix. Of greatest relevance was the finding that the grouping of the background, unattended stimuli influenced the detection of changes in the target matrix, leading to the conclusion that unattended background elements were perceived to an extent that was enough to influence task-relevant perceptual judgments.

Sarah Shomstein

See also Attention: Effect on Perception; Attention: Object-based; Attention: Physiological; Attention: Selective; Attention: Spatial; Attention and Consciousness; Visual Search

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Attention: Effect on Perception

Attention is the mechanism that allows us to select relevant information for processing from the vast