PART IV

Attention and Action Processes

CHAPTER 10

Selective Attention

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A basic characteristic of human perception is its selectiveness. At any given moment, we perceive only a fraction of the myriad of stimuli reaching our sense organs. For example, while reading these lines, you ignore the pressure of the chair on your thighs and the humming of the refrigerator. In the words of Garner (1974, p.23), "the human organism exists in an environment containing many different sources of information. It is patently impossible for the organism to process all these sources, because it has a limited information capacity, and the amount of information available is always much greater than the limited capacity." We experience these limitations on our processing capacity every day. Suppose two people are talking at once. It is easy to selectively attend to one of them. However, it is very difficult to listen to both at once. At best, you will have to switch attention back and forth from speech stream to speech stream, missing chunks of one while attending to the other.

Because our information processing capacity is limited (e.g., Broadbent, 1958; Neisser, 1967), we attend to some stimuli in our environment while ignoring others. As a result, we perceive the former while the latter gets lost. An issue that has kept researchers busy for decades concerns the fate of unattended stimuli: To what extent are they processed? Do we register only their elementary perceptual features such as their location, color, or shape, or do we also compute their meaning? The first part of this chapter is devoted to examining the current status of what has become known as the early versus late selection debate.

Another important question concerns the factors that determine which stimuli are selected at a given time. A core premise of most leading models of visual search is that selection is guided by both stimulus-driven and goal-directed factors (e.g., Bundesen, 2005; Treisman & Sato, 1990; Wolfe, 2007). For instance, according to the biased competition model (e.g, Desimone & Duncan, 1995) object representations compete for neural representation in our brains. Items that are highly salient enjoy a competitive advantage relative to low-salience items, but the goals of the observer bias this competitive process, thereby ensuring that low-salience objects that are highly relevant to the task at hand are also represented across the visual hierarchy. However, claims that attention selection might be guided exclusively by how salient an object is, irrespective of the observers' intentions or, alternatively, only by the goals adopted by the observers, have ignited a heated debate that has generated considerable research in the past 20 years and are reviewed in the second section of this chapter.

For goal-driven processing of relevant information to be at all possible, representations of certain object characteristics, which meet the observer's goal, must be activated within long-term memory and maintained during the task. This formulation of goal-directed attention highlights the close relationship between attention and working memory (e.g., Awh, Vogel, & Oh, 2006; Cowan, 1995). In the third section of this chapter, we provide a selective review of the growing behavioral literature demonstrating interactions between memory of spatial locations, features and objects and the deployment of attention and of neuroscientific findings showing that the neural structures associated with working memory and attention often overlap (see also Nairne & Neath, this volume).

The last issue covered by this chapter focuses on the relationship between attention and conscious awareness (see also Banks & Farber, this volume). Although cognitive

psychologists have long been interested in the unconscious mind, and in particular in establishing how deeply information that is not consciously perceived can be processed (e.g., see Kouider & Dehaene, 2007 for a recent review), more recent research has shifted toward the study of conscious awareness. In particular, since Crick and Koch (1990) launched the search of the neural correlates of consciousness, a large number of studies have contrasted conscious and unconscious processing in order to elucidate what specific mechanisms characterize conscious perception. Within this framework, they have often used attentional manipulations in order to exclude parts of the visual field from conscious awareness, implying that there might be a causal relationship between attention and awareness. Here, we review the findings pertaining to the question of whether attention to an object is necessary and sufficient for conscious perception of this object to arise.

A single chapter cannot completely cover the broad and active field of attention, and we chose to focus on only four of the issues that we deem to be particularly central in the current study of attention. Readers interested in pursuing other aspects of attention may also consult a recent *Annual Review of Psychology* on attention (Chun, Golomb, Turk-Browne, 2011).

EARLY VERSUS LATE SELECTION

Broadbent (1958; see also Neisser, 1967) proposed a filter theory that laid the foundations of early perceptual selection theory. He suggested that there is a bottleneck in the sequence of processing stages involved in perception. Whereas physical properties such as color or spatial position can be extracted in parallel with no capacity limitations, further perceptual analysis (e.g., identification) can be performed only on selected information. Thus, unattended stimuli, which are filtered out as a result of attentional selection, are not fully perceived.

Subsequent research was soon to call filter theory into question, giving rise to the late-selection approach. One striking example is the finding by Moray (1959) that when a message in the unattended ear is preceded by the subject's own name, the likelihood of reporting the unattended message is increased. This result suggests that the unattended message had not been entirely excluded from further analysis. Thus, according to the late-selection view (e.g., Deutsch & Deutsch, 1963; Duncan, 1980; Shiffrin & Schneider, 1977), perceptual processing operates in parallel and selection occurs after perceptual processing is complete (e.g., after identification), with capacity limitations arising only from later, response-related processes.

Renewed Support for Early Selection

Neurophysiological Studies

A spate of physiological studies, mainly during the 1990s, has provided renewed support for early selection. In a pioneering single-cell recording study, Moran and Desimone (1985; see also Reynolds, Chelazzi, & Desimone, 1999) recorded from neurons in area V4 of the monkey brain and showed that their activity could be modulated by attention. The monkey was trained to attend to one of two objects presented simultaneously within the same receptive field of a V4 neuron. When the monkey attended to the ineffective stimulus, the neuron's response was weak, even though the effective stimulus—which evoked a strong response by the neuron when presented alone—was also present in the cell's receptive field.

Evidence for attentional effects in early visual areas was also obtained using various noninvasive techniques on humans. Although there was initially much debate regarding the earliest region in which spatial attention can modulate neural activity (e.g., Posner & Gilbert, 1999 for a review), several functional magnetic imaging (fMRI) studies (e.g., Gandhi, Heeger, & Boynton, 1999) have demonstrated such modulation in area V1 (as well as in other retinotopic visual areas). Failures to find striate modulations during spatially directed attention (e.g., Mangun, Hopfinger, Kussmaul, Fletcher, & Heinze, 1997) have been accounted for by the hypothesis that the target must compete with nearby distractors in order for spatial attention to engage primary visual cortex (e.g., Worden & Schneider, 1996).

However, as there are both feed-forward and feedback processing within the cortical hierarchy, finding attentional modulation in anatomically early areas does not necessarily entail that such modulation occurs early in time. Thus, fMRI studies may be less appropriate for investigating the early versus late selection issue than tools that provide better temporal resolution, such as event-related potential (ERP) recordings. This point is nicely illustrated by a study by Martinez et al. (2001) who used fMRI to localize attention-related changes in neural activity within V1 as well as within other retinotopic visual areas, while recordings of ERPs traced the time course of these changes. These authors were able to show that stimulus-locked V1 activity shows an early peak (50–90 ms post-stimulus) and a later peak (160–260 ms), with only the latter being affected by spatial attention. In addition, they showed that extrastriate regions (V3, V4) show attentional modulation during a time window that occurs between the two phases of striate activation. These findings suggest that

attentional modulation of V1 activity observed using fMRI indeed reflects feedback to V1 from higher areas. They also indicate that the earliest modulation of neural activity by attention nonetheless occurs during the first flow of information through extrastriate regions, that is, before stimulus-related information reach inferotemporal cortex (IT), where identification is likely to occur.

However, it is not clear how one should interpret early attentional effects on neural activity, because such modulation is typically partial: Neural activity is not eliminated for unattended objects, which suggests that these are processed at least to some extent. In particular, it is difficult to determine whether such partial activation is sufficient for identification. Thus, it remains important to consider behavioral research bearing on the early versus late selection issue.

Behavioral Studies

Lachter, Forster, and Ruthruff (2004) reviewed the literature on stimulus identification and concluded that there was no convincing evidence that identification is possible without attention. They focused on verbal material presented visually. They pointed out that the numerous demonstrations that *irrelevant* stimuli can be identified do not necessarily entail that *unattended* stimuli can be identified. In the usual flanker task, a central letter is presented at fixation and is flanked by two other letters, on the left and right. The task is to identify the central letter, pressing one button if it is an A or H, and another if it is an S or C. Typically, the flankers are completely unpredictive of the target (and it is in this sense that the flankers are said to be task irrelevant). When the flankers are assigned the same response as the target, reaction times are typically faster than when the flankers are assigned to the alternative response (i.e., H A H would yield faster reaction times than S A S).

Although the preceding result suggests that irrelevant material can be identified, does it also mean that unattended material can be identified? Lachter et al. (2004) suggest not. They draw an important distinction between *leakage* and *slippage* of attention. Broadbent's (1958) theory holds that an early filter prevents unwanted information from achieving further processing. If information leaks through the filter, allowing stimulus identification, then the theory is in error and needs to be revised. However, under appropriate circumstances, it is possible for attention to be voluntarily switched from one stimulus to another, or for the switch to occur involuntarily.

Consider, for example, the role of stimulus duration. In the basic flanker task, suppose that the stimuli were presented for 200 ms. That duration is long enough for subjects to move attention from the target to one of the flankers, so that both target and flanker are attended. A shorter display followed by a mask would be required to eliminate that problem. The critical theoretical question, then, is whether one can find evidence for leakage (thus disconfirming filter theory) when opportunities for slippage have been eliminated, or at least drastically curtailed.

Yantis and Johnston (1990) used the flanker paradigm in conditions designed to minimize slippage, namely by using a precue that informed the subjects of the upcoming target's location with 100% validity. However, they also took steps to prevent leakage: for instance, they used circular configurations in order to equate the extent to which the target and distractors suffered from lateral inhibition. When they did so the compatibility effects virtually disappeared.

As Lachter et al.'s (2004) goal was to test Broadbent's filter theory, they set out to determine whether leakage is at all possible when the opportunity for slippage is tightly controlled. Therefore, they used optimal conditions for minimizing slippage and maximizing leakage. To explore the possible identification of unattended stimuli, they used the repetition priming paradigm because robust priming effects from very brief presentations of masked primes are frequently observed. For instance, (e.g., Forster & Veres, 1998), when subjects are shown a target letter string and asked to make a lexical decision (e.g., *converge* should be judged to be a word, *convenge* a nonword), the basic finding is that this decision is speeded if the same letter string (even when printed in different cases) is presented as a masked prime. This benefit appears to require identification of the prime, and is not occurring at the letter level. Indeed, repetition priming is much stronger for words than for nonwords. Also, the effect differs for stimuli that differ only slightly: CONVERGE can be primed by *converge* but not by the very similar looking nonword *convenge*.

In Experiment 1 of Lachter et al. (2004), each trial began with two rows of hash signs, followed by a very brief (55 ms) exposure of a lowercase prime (e.g., *agent*) presented in either the top or the bottom position. The other position contained hash signs. Then, the target, which was an uppercase letter string (e.g., AGENT or ABENT) appeared in the lower position, while the other position was filled with a symbol string. To maximize the possibility of finding leakage, if it exists, they presented the prime close to the location of the target. To minimize slippage, the target always appeared in the same known location. The prime affected responses only when it appeared at the

same location as the target, a pattern that was replicated in several other experiments. Thus, Lachter et al. (2004) failed to show any evidence of priming from unattended words.

Although these results convincingly suggest that early selection occurs with verbal stimuli, one interesting line of research suggests that there may be some special classes of stimuli that can be identified without attention. For instance, Rousselet, Fabre-Thorpe, and Thorpe (2002; see also Drewes, Trommershäuser, & Gegenfurtner, 2011) suggested that the rapid identification of animals can be accomplished in the absence of focal attention. Subjects had to indicate if an animal target was present in a brief (20 ms) display, which contained either one or two scenes presented at the same eccentricity to the left or right of fixation. Regardless of display size (one or two), there was a single animal picture present on half the trials. Median reaction times were virtually identical on the one- and two-scene trials.

Another approach to the study of processing of complex natural scenes also suggests that high level categorization may be accomplished without focal attention. For example, Li, VanRullen, Koch, and Perona (2002) used a dual-task paradigm; the basic idea was that if natural scene categorization demands attention, then there should be a significant decrease in performance under the dual task condition. In one study, subjects had to determine if the scene contained an animal (which could be a mammal, a bird, a fish, etc.). There were two tasks. In one attentionally demanding task, five small randomly rotated letters (Ts and Ls) were presented briefly near fixation and then masked. Subjects had to indicate whether one letter differed from the others. In the second task, subjects had to determine whether a natural scene presented briefly at a random location in the periphery (and then masked) contained an animal. To assess whether there is something special about natural scene categorization, subjects also served in a control peripheral task reliably shown by prior research to be attentionally demanding. The critical comparison was between the single-task conditions and the dual-task condition (in which subjects were required to respond to both the central and the peripheral stimuli).

The results were quite striking. Performance on the peripheral task, when it was attentionally demanding (i.e., in the control condition), was drastically reduced in the dual task compared with the single task condition. However, when subjects had to detect animals in natural scenes in the periphery, their performances were essentially just as good in the dual- and single-task conditions. The authors took this result to indicate that, "...rapid visual categorization of novel natural scenes requires very little or no focal attention" (p. 9599).

A Feature-Based Approach to Scene Perception Without Attention

Do the foregoing studies actually indicate that high-level categorization does not require attention? There are several bases for doubt. Note first that the Li et al. (2002) paper is titled "Rapid Scene Categorization in the *Near* Absence of Attention" (italics added). It is difficult to know if no attention at all is required as there may have been undetected slippage.

On more theoretical grounds, Evans and Treisman (2005) have argued that, in the scene-categorization tasks, subjects may have detected rapidly and in parallel disjunctive sets of unbound features. The presence of these features may have enabled subjects to discriminate scenes that did and did not contain the target item, but without subjects actually fully identifying the objects. They tested this hypothesis by designing a paradigm that would enable them to determine what information subjects have about the targets they detect and, in particular, whether performance is better than would be predicted from unbound feature information.

In a rapid serial visual presentation (RSVP) stream, subjects had to report the presence of a target scene (containing an animal, for half the subjects or a vehicle for the other half). Additionally, if they detected a target, they had to specify what animal or vehicle they saw and to localize it. Some of the pictures contained humans as distractors. Several results were consistent with the hypothesis that animal detection could be based on parallel detection of disjunctive features without attentional binding. The human distractors (which are more confusable with animals than with vehicles) had a more detrimental effect in the animal-target condition than in the vehicle-target condition. Also, subjects often correctly detected a target but were unable to correctly localize it. Perhaps most important, a careful analysis of the subject's verbal responses makes it clear that they were often able to identify the superordinate category of the stimulus (e.g., mammal) without being able to identify the particular animal. Consistent with these findings, Levin, Takarae, Miner, and Keil (2001) studied visual search for animals among man-made artifacts, and they found that performance was almost as good when the images of individual objects were jumbled as when they were intact.

In the same vein, Scharff, Palmer, and Moore (in press) used an extension of the simultaneous-successive paradigm developed by Shiffrin and Gardner (1972) to

explore whether scene categorization is possible without attention. Each display contained a target drawn from one of two target categories (e.g., bear or cougar) and three nontarget pictures of other animals. Thus, the task required more than mere detection. The critical manipulation was the timing of the displays. In the simultaneous condition, all four stimuli appeared at the same time and remained on the screen for 100 ms. In the sequential condition, they were divided into two subsets that appeared one after the other, for 100 ms each. Thus, in both conditions, any given scene was visible for 100 ms. If identification can be carried out without capacity limitations, then subjects should be able to identify the target equally well in the sequential and in the simultaneous conditions. However, if there is a limited capacity, performance should be better if subjects can focus first on just a subset of two items and then move on to another set of two items. The data strongly supported the limited capacity prediction. Other work makes it clear that, when simple featural discriminations are involved, the results are well accommodated by an unlimited capacity model (e.g., Kleiss & Lane, 1986).

In summary, it would appear that Broadbent (1958) was largely correct in his claim that simple features can be detected in parallel and without attention, but that higher-order processing, such as full identification of an object's semantic category, requires attention.

Load Theory: A Failed Resolution?

This conclusion seems to be at odds with the basic tenets of Lavie's load theory (e.g., Lavie, 1995; Lavie & Tsal, 1994). Lavie suggested that her theory resolves the long-standing early- versus late-selection debate. She elaborated on a distinction initially made by Kahneman and Treisman (1984). These authors had noted that, although the early-selection approach initially gained the lion's share of empirical support, later studies favored the late-selection view. Kahneman and Treisman had attributed this dichotomy to a change in paradigm that took place in the field of attention starting from the late 1970s. Specifically, early studies used the "filtering paradigm," in which subjects are typically overloaded with relevant and irrelevant stimuli and required to perform a complex task. Later studies used the "selective set paradigm" in which subjects are typically presented with few stimuli and required to perform a simple task. Thus, based on the observation that the conditions prevailing in the two types of study are very different, Kahneman and Treisman had cautioned against any generalization across these paradigms.

Lavie pushed this line of thought further by proposing that perceptual load determines the locus of attentional selection. She suggested that "perception has limited capacity (as in early-selection views) but processes all stimuli in an automatic mandatory fashion (as in late-selection views) until it runs out of capacity. This led to the predictions that high perceptual load that engages full capacity in relevant processing would leave no spare capacity for perception of task-irrelevant stimuli. In situations of low perceptual load, however, any capacity not taken up in perception of task-relevant stimuli would involuntarily 'spill over' to the perception of task-irrelevant distractors" (Lavie, 2005, p.75). Thus, according to the theory, perception of irrelevant distractors can be prevented (early selection) when the processing of task-relevant stimuli involves high perceptual load, whereas the same distractors are perceived in tasks involving low perceptual load (late selection), even when the observer attempts to ignore them.

Empirical support for the load theory has been typically obtained using variants of the flanker task. In these studies, the target appears at a fixed location or in one of several locations known to be equally likely to contain the target. The critical distractor appears at a different, "irrelevant" location. Perceptual load is manipulated, and flanker effects (also known as response-compatibility effects) are used to determine whether the irrelevant distractor has been identified. Lavie does not offer a precise theoretical definition of perceptual load, and the operational definitions that she and others have employed rely mostly on intuition. In most instances (e.g., Lavie, 1995, Exp.1), perceptual load is manipulated by varying the number of distractors in the "relevant set," that is, in the locations in which the target may appear: the low-load condition involves only one possible location, whereas the high-load condition involves a large set size. The typical finding is that the irrelevant distractor affects performance—usually by inducing response-compatibility effects—when perceptual load is low and not when it is high.

Recent research, however, has seriously undermined the basic tenets of load theory. These studies have contradicted three central predictions of the theory: (1) that distractor interference is maximal under low-load conditions; (2) that distractor interference is minimal under high-load conditions and (3) that allocation of attention to the irrelevant stimulus is entirely automatic whenever the perceptual demands of the relevant stimulus do not use all available resources.

Distractor Interference Can Be Eliminated Under Low-Load Conditions

Several authors have suggested that slippage is more likely to occur in the low-load than in the high-load condition in

Lavie's experiments (e.g., Lachter et al., 2004). In other words, attentional resources accrue to the critical distractor not because there is spare capacity that inevitably leaks to irrelevant parts of the display until it is fully used, but because of other factors that are confounded with what Lavie takes to be a load manipulation. This alternative account predicts that if slippage is prevented in the low-load condition without increasing perceptual load in any way, distractor interference effects should be eliminated, thereby disconfirming the theory. There have been several reports supporting this alternative account.

Eltiti, Wallace, and Fox (2005) suggested that the critical distractor is allocated attention only because it is similar to the target: Specifically, it has a task-relevant shape (which allows it to produce response-compatibility effects) and is abruptly onset as the target is. Folk, Remington and Johnston (1992; see also Gibson & Kelsey, 1998) showed that an irrelevant distractor captures attention only if it matches the observer's attentional set. Relying on this finding, Eltiti et al. (2005) suggested that in Lavie's experiments, the critical distractor is less likely to capture attention when it is presented with several other onsets (i.e., in the high-load condition) than when it is the only onset competing with the target (i.e., in the low-load condition). To test this alternative account, they manipulated the presentation conditions of the target and critical distractor, each of them being presented either as an onset or as an offset. Crucially, all trials were low-load trials. Lavie's findings were replicated (i.e., interference effects are found) only when the critical distractor shared the target's presentation format but not when it did not (when the target was onset and the target was offset and vice-versa).

Johnson, McGrath, and McNeil (2002; see also Paquet & Craig, 1997) used cues to focus attention and eliminated the flanker effect in the valid-cue low-load condition. That is, in Lachter et al.'s terms, when slippage is prevented by tightly focusing attention using a precue, leakage does not occur despite the fact that, according to the theory, there are unused attentional resources (see Yantis & Johnston, 1990, for similar findings).

### Distractor Interference Can Occur Under High-Load Condition

There have also been reports showing that results diagnostic of late selection can prevail under high-load conditions. Tsal and Benoni (2010; Benoni & Tsal, 2010) suggested that an alternative interpretation of the load effect is that the distractor is similarly processed in both displays, yet its interference in large displays is diluted by the presence of the neutral letters. The authors separated the effects of load

and dilution by introducing dilution displays. For instance, Tsal and Benoni (2010, Experiment 3, see Figure 10.1) was a replication of Lavie's (1995, Experiment 1); in the low-load condition, the target was the unique X, whereas, in the high-load condition (which was also a high-dilution condition), the X target appeared among five heterogeneous letters. As usual, in both cases, the critical distractor appeared at an irrelevant location. Tsal and Benoni added an important twist: In the high-load condition, the letters were heterogeneously colored. The critical condition they added was the low-load high-dilution condition in which the display was identical to that of the high-load condition, but the target's color was known in advance to the observers, thereby bringing load to a low level. Distractor interference was observed with low load only when dilution was also low: it disappeared in the low-load high-dilution condition. Thus, again, distractor interference could be eliminated in a low-load condition, thereby providing evidence against Lavie's theory.

More strikingly, however, the comparison between the high- and low-load conditions when dilution was equally high allowed one to assess the dilution-free effect of load: Across four similar experiments presented by Tsal and Benoni (2010), increasing load actually increased distractor interference. Thus, not only do these findings show that dilution accounts for the effects misattributed to load, but they also show that when load is measured in the absence of the dilution confound, it has effects that go in the opposite direction of those predicted by load theory (see Wilson, Muroi & MacLeod, 2011 for similar findings).

Allocation of Attention to the Irrelevant Stimulus Is Not Automatic

An important aspect of the load theory is that allocation of attention to the irrelevant stimulus is entirely automatic whenever the perceptual demands of the relevant stimulus do not use all available resources. In other words the theory stipulates that attentional allocation is a stimulus-driven process, exclusively determined by the perceptual demands imposed by the relevant stimulus. This aspect of the theory is important because it is what differentiates the load account from earlier traditional theories of attentional selection. For instance, the zoom-lens theory (e.g., Eriksen & Yeh, 1985) stipulates that a peripheral distractor affects behavior if attention is widely distributed and is excluded from processing if attention is narrowly focused. Yet, according to the zoom-lens theory, known task demands rather than trial-by-trial stimulus characteristics determine the size of the attentional focus, such that attentional allocation is viewed as a goal-directed process.
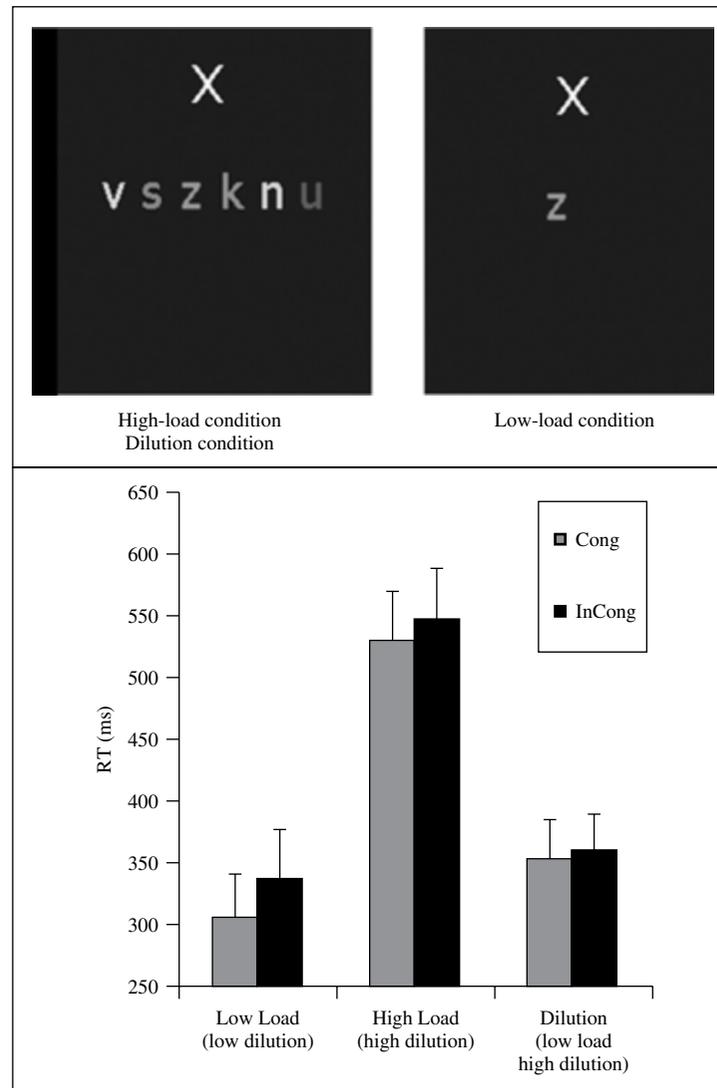
Upper Panel. Low-load, dilution and high-load conditions in Tsal and Benoni's (2010, Exp.3) study. In this example, the distractor (X) was incompatible with the target (Z). *Lower Panel.* Mean reaction times for congruent- and incongruent-distractor conditions in all three conditions.

Figure 10.1 Tsal and Benoni's "dilution" alternative to load theory

Thus, as long as perceptual load is confounded with the expectation of a certain level of perceptual load, a simple zoom lens account can explain the typical perceptual load results pattern: when the task is expected to be easy, subjects adopt a wide attentional window and interference is observed, whereas when the task is expected to be difficult, subjects adopt a narrow attentional focus and no interference is observed.

In fact, several findings argue against the notion that stimulus-driven factors determine attentional selection. Two studies tested the effects of mixing rather than blocking conditions of perceptual load. If stimulus-driven

factors indeed determine attentional selection, then whether conditions of perceptual load (high and low) are blocked or mixed within blocks should not modulate the influence of load manipulation. Yet, the opposite pattern of results was observed.

For instance, in Theeuwes, Kramer, and Belopolsky's (2004) study, the target was either an X or an N among either Os (low-load condition) or heterogeneous letters (high-load condition). They replicated the traditional perceptual load effect with a blocked design, but they found distractor interference to emerge in both low- and high-load conditions when these were mixed. Thus, the

interaction between the distractor effect and load that is the core prediction of load theory was eliminated when subjects could not prepare to a known level of task difficulty (see Murray & Jones, 2002, for compatible findings).

These findings clearly suggest that advance knowledge of perceptual load level rather than perceptual load per se, modulates the distribution of attention. This modulation appears to be mediated by the spread of attentional focus. That is, in line with a traditional zoom-lens account, anticipated task demands determine whether attention is narrowly focused or widely distributed across the visual field.

Testing Load Theory Versus Using the Load Manipulation

Lavie's load theory has been heavily cited in the nearly 20 years that followed its first publication (Lavie & Tsal, 1994; Lavie, 1995). It may, therefore, be surprising that it fares so poorly when tested against alternative accounts. In this regard, however, it may be important to realize that, although perceptual load has been manipulated in many experiments, only a few studies actually tested the predictions of the theory. Most of the authors who manipulated perceptual load assumed load theory to be correct. That is, they assumed that a given task requires attention if it is affected by perceptual load and does not require attention if it is not affected by perceptual load. Therefore, the findings resulting from such studies do not provide support for the load theory because whether the task under study is automatic or resource demanding cannot be stated a priori; the answer to this question is the end product of the investigation.

An illustration can make this point clearer. Whether threat-related stimuli can be processed without attention is the focus of ongoing debate (see Pessoa, 2005 for a review). Several studies have manipulated perceptual load and measured the extent to which perception of an irrelevant threat-related distractor is affected by the manipulation (e.g., Bishop, Jenkins & Lawrence, 2007; Pessoa, Kastner & Ungerleider, 2002). The rationale of this type of study is that if perceptual load has no effect, then one may conclude that perception of threat is automatic, whereas the opposite outcome would suggest that perception of threat requires attention. The fact that the effect of perceptual load is open-ended in such studies clearly shows that they cannot be viewed as tests of the perceptual load hypothesis. Indeed, any outcome can be accommodated within the theory by stipulating that perception of threat is or is not automatic.

Accordingly, some authors claimed that "because task-irrelevant spiders . . . elicited an enhanced response in spider-fearful individuals even under high perceptual load, the present findings provide evidence for the processing of task-irrelevant but potent emotional pictures independently of attention" (Norberg, Peira & Wiens, 2010, p. 1157), whereas others arrived at the opposite conclusion: "when all attentional resources were consumed by another task, responses to faces were eliminated . . . Therefore, it does not appear that faces emotional expressions are a 'privileged' category of objects immune to the effects of attention" (Pessoa et al., 2002, p. 40).

Early Versus Late Selection: Conclusions

After more than 50 years of debate, it seems that we have come a full circle: the current state of the literature clearly favors the early-selection account suggested by Broadbent (1958). Although load manipulations appear to offer a convenient tool to probe the extent to which a given process requires attention, mounting evidence against the theory (e.g., Lachter et al, 2004; Tsal & Benoni, 2010; Wilson et al., 2011; Theeuwes et al., 2004; Paquet & Craig, 1997; Johnson et al., 2002; Eltiti et al., 2005) invites caution when drawing conclusions based on the outcomes of load manipulations; the attentional effects inferred from these outcomes are likely, instead, to reflect effects related to differences in distractor's dilution, expected task difficulty, and more.

SOURCES OF ATTENTIONAL CONTROL

If you look for your brown socks in a drawer full of black items, you will find them quickly, no matter how full the drawer is. However, if your child inadvertently left his red ball inside your drawer will it attract your attention and delay the moment at which you will spot you brown socks? The extent to which attentional selection is controlled by the observer's intentions (goal-directed or top-down control of attention) or by the properties of the stimulus in the environment (stimulus-driven or bottom-up control of attention) remains a highly controversial issue (e.g., see reviews Burnham, 2007; Rauschenberger, 2003; Theeuwes, 2010;). On the one hand, some researchers (e.g., Theeuwes, 2010) have been claiming that, within a spatially defined window of attention, the most salient object is always granted attentional priority mandatorily and irrespective of the observer's goals. Thus, you will not be able to avoid attending to your child's ball first because

it is physically more salient than your brown socks; you will have to redirect your attention to find what you were looking for. At the other end the spectrum, an increasingly popular account (e.g., Anderson & Folk, 2010; Folk et al., 1992) postulates that salient information can be ignored when it does not match the attentional set of the observer. Accordingly, your child's red ball will not grab your attention at all because it has none of the characteristics that you are purposefully using to direct your search. By contrast, you are likely to direct your attention to it if the ball is also brown. Thus, the debate around the sources of attentional control revolves mainly around the following question: When you distribute your attention across a display to find an item with a certain defining property (brown socks), what kind of stimulus may cause you to involuntarily shift your attention to its location before (a) an object that is physically more salient than your target item (a red ball among the socks) or (b) an object that resembles what you are looking for but happens not to be the target (a brown ball)?

It should be noted that the use of bottom-up and top-down terminology to describe stimulus-driven and goal-directed processes has generated much confusion. Indeed, it suggests that stimulus-driven influences on attentional selection rely exclusively on the initial volley of information from lower to higher regions of the brain cortex, which Lamme and colleagues (e.g., Lamme, 2003) have described as the fast feed-forward sweep, whereas goal-directed influences would result from reentrant processing. These are assumptions that are not supported by electrophysiological evidence (e.g., Rauschenberger, 2010). Thus, in this chapter we always refer to stimulus-driven and goal-directed factors.

The Salience-Based View

What has come to be called the salience-based view is mostly identified with the work of Jan Theeuwes (e.g., 1991; 1992; 2010). He suggests that, when observers search the environment for a predetermined target, their attention is first deployed to the items in the visual field in order of decreasing saliency irrespective of their relevance to the task at hand, with goal-directed control coming into effect only later in processing. This view has typically relied on the additional singleton paradigm: Participants search for a single diamond among circles (e.g., Theeuwes, 1992, see Figure 10.2) and have to report the orientation of the line inside the unique circle (i.e., shape singleton). On half of the trials, one of the nontarget stimuli is red (color singleton), whereas the others are green. The presence of the color singleton typically increases response time to the relevant shape singleton, but only when color contrast is stronger than shape contrast.

It has been claimed (e.g., Folk & Remington, 1998) that such delay does not necessarily entail a shift of spatial attention to the location of the salient distractor but might instead result from filtering costs (e.g., Kahneman, Treisman & Burkell, 1983); increased competition between the target distractor would simply take longer to resolve with attention being nonetheless directed to the target first. However, evidence collected with additional measures of attentional capture make this possibility unlikely. For instance, Theeuwes, Atchley, and Kramer (2000) measured compatibility effects. Participants had to report the orientation of the letter inside the unique target shape, and the irrelevant distractor with a salient color contained a letter that elicited either the same response or the opposite response. The rationale was that letter compatibility
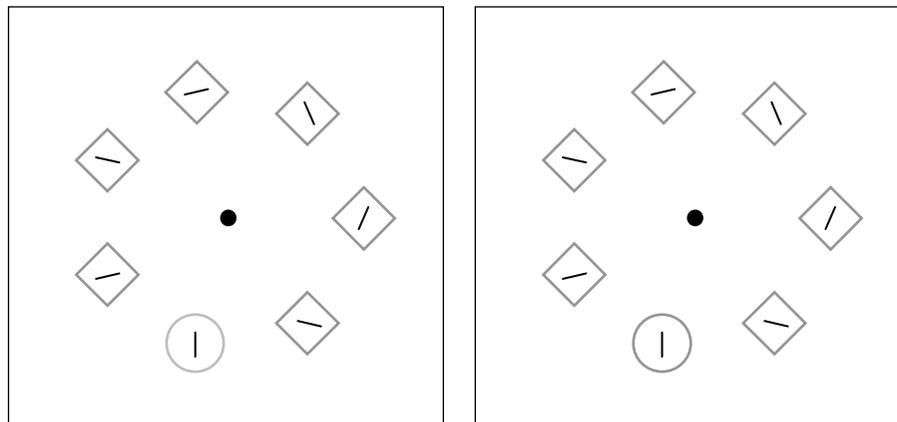
Subjects searched for a circle surrounded by diamonds of the same color, with (left panel) or without (right panel) a diamond distractor with a different, unique color.

Figure 10.2   Sample displays in Theeuwes's (1992, Experiment 1) study

should have an effect only if attention is spatially shifted to the location-irrelevant salient distractor, because identifying the letter requires focal attention, and such was indeed the observed pattern of results.

In addition, inhibition of return (IoR) to the location of the irrelevant salient singleton has been reported (e.g., Theeuwes & Godjin, 2002). Immediately after a spatial location is cued, a stimulus that appears near that location is responded to faster than stimuli at other locations (e.g., Posner, Snyder, & Davidson, 1980). However, after attention is removed from the cued location, it is more difficult to reallocate one's attention at the cued location than to other locations. This effect has been labeled inhibition of return (IoR; Posner & Cohen, 1984; see Klein, 2000 for a review). Inhibition of return occurs following a stimulus-driven shift of spatial attention, but it is not observed following voluntary shifts of attention. Thus, finding IoR is taken as an indication that an involuntary shift of attention has occurred. Accordingly, Theeuwes and Godjin's (2002) finding that IoR is tied to the location of an irrelevant salient singleton supports the notion that this irrelevant indeed captured attention to its location.

Finally, several studies have used a dot-probe procedure to investigate the spatial distribution of attention during a typical additional singleton task (e.g., Kim & Cave, 1995; Lamy, Tsal & Egeth, 2003). The rationale is that, if the irrelevant singleton elicits a shift of spatial attention to its location, then a small probe flashed shortly after the display has disappeared should be responded to faster when it appears near the salient distractor than at other locations. Yet, after some time (typically 150 ms), responses should be faster at the location of the target because there has been enough time to redirect attention to it. This is the pattern of results that was found and it supports the notion of spatial capture against the filtering cost alternative account.

The Contingent Capture Hypothesis

The competing view, promoted by Folk and colleagues, stipulates that perceptual salience does not affect attentional priority in a purely automatic and uncontrolled fashion and that selection always depends on the goals held by the observer at any given time (e.g., Folk, Leber, & Egeth, 2002; Lamy & Egeth, 2003;). This view, known as the contingent capture hypothesis, has mainly relied on the modified spatial cueing paradigm. In the classic study (Folk et al., 1992; see Figure 10.3), the search display consisted of either a color singleton (a red item among whites ones) or an onset singleton (the only element in the display). Preceding the target display by 150 ms, a cue display

was presented that consisted of either a color cue (in which one location was surrounded by red dots and the other three locations were surrounded by white dots) or an onset cue (in which one location was surrounded by an abrupt onset of white dots and the remaining locations remained empty). The locations of the cue and target were uncorrelated. All conditions were factorially combined and the target type remained constant within block of trials.

Attentional capture was measured as the performance benefit on trials in which the target appeared at the same location as the cue rather than at a different location. To-be-ignored cues captured attention only when their unique property matched that of the singleton for which observers were searching. These results suggest that the attentional set determines selection priority: "With a control setting established, an event exhibiting the critical properties will involuntarily summon attention, regardless of whether the event is actually relevant to task performance. Stimuli not exhibiting these properties will not involuntarily summon attention" (p. 1041, Folk et al, 1992).

Pitfalls in Investigating Attentional Capture

It is important to realize that the debate has focused on the notion of attentional capture, in ways that are unsuited to investigating the relative contributions of stimulus-driven and goal-directed factors. Indeed, the aim has most often been to determine which item receives attention first: the most salient item *or* the item that has the best match with the observer's target in the search. Proponents of the purely stimulus-driven view have typically manipulated only salience of the irrelevant distractor relative to that of the target but not the match between the distractor and the attentional set (e.g., Theeuwes, 1992; Yeh & Liao, 2008), whereas proponents of the contingent-capture view have manipulated only the match between the salient distractor and the attentional set but not its salience (e.g., Bacon & Egeth, 1994; Folk et al., 1992; Lamy & Egeth, 2003). Yet, because capture only indexes the net difference between the relative contributions of the two types of factor to attentional priority within certain experimental conditions, neither failure to observe capture by a salient distractor nor findings of attentional capture despite adoption of an attentional set can unveil the mechanisms that affect attentional priority.

The dichotomized nature of the debate has obscured what a more objective review of the literature seems to confirm: As originally claimed by leading models of visual search, both stimulus-driven and goal-directed factors contribute to attentional priority setting. Yet, along the way,
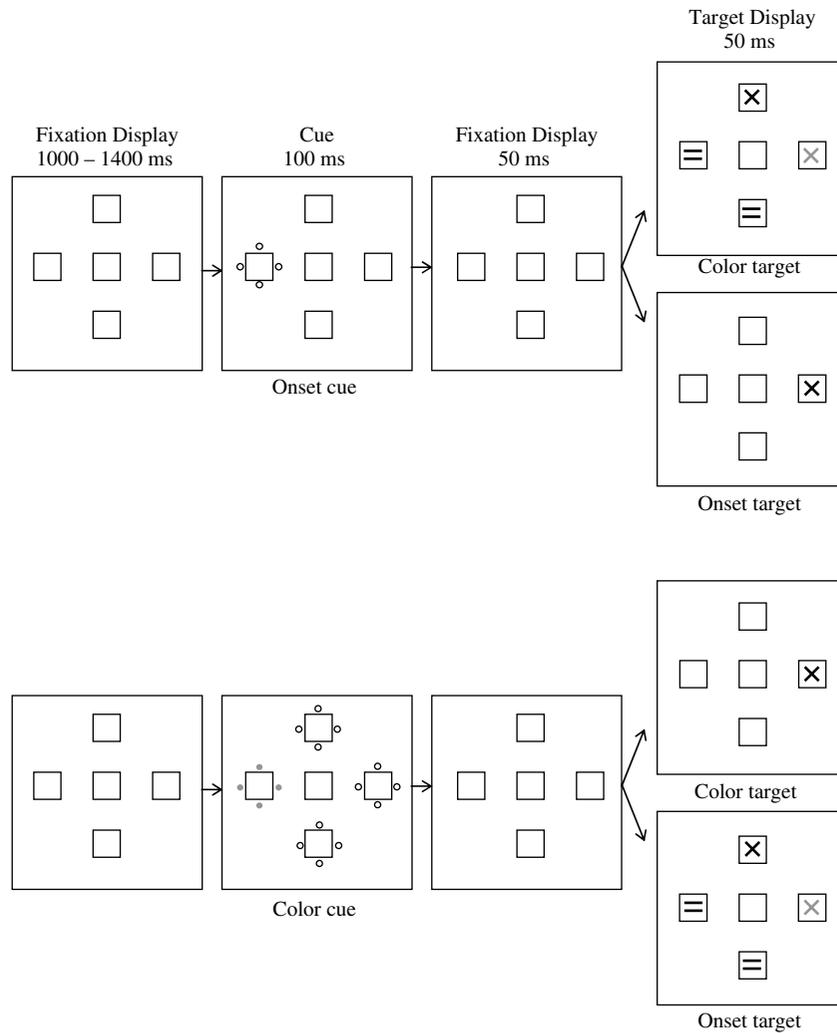
Upper panel: onset cue condition. *Lower panel*: color cue condition. In this example, the target location was invalidly cued.

Figure 10.3   Sample displays and sequence of events in Folk et al.'s (1992) study

the controversy around attentional capture has yielded a wealth of findings that have provided important insights into the mechanisms underlying attentional selection.

Current Issues in Research on Sources of Attentional Control

Hidden Attentional Control Settings

Operational definitions of stimulus-driven salience are straightforward or, at least, widely agreed on: A distractor can be made salient by increasing local contrast at its location (e.g., by boosting its luminance relative to the other items and background or by increasing display density) or by endowing it with a unique dynamic property (e.g., by making it appear abruptly while other items are

gradually onset). However, how an attentional set can be defined has proved to be more elusive.

Consider the simple case in which the observer is required to search for a red target. A distractor within the attentional set would have to be red but to differ from the target by a known property; otherwise, attentional capture cannot be avoided, by definition. For instance, in Folk et al.'s experiments (e.g., 1992), the target was either an "=" or an "x" red sign within a box, whereas the salient distractor that matched the attentional setting was a group of red dots surrounding the box and appearing before the target. Thus, the target could be distinguished from the distractor both by its shape and by the time of its occurrence (it always appeared before the target). The very notion of attentional capture by a distractor possessing

the task-relevant property implies that attentional control settings operate according to an inclusive rule (orient attention to stimuli that share a task-relevant feature with the target), rather than according to an exclusive rule (do not orient attention to stimuli that do not share a task-relevant feature with the target). Indeed, a red distractor captures attention because it shares the color red with the target and despite the fact that it differs from it in many known aspects.

A distractor outside the attentional set would be a green distractor, for instance. However, consider the findings presented by Folk et al. (1992). When the target was defined as the unique red item among white ones, a unique green distractor captured attention but an abrupt onset distractor did not. On the one hand, these findings indicate that a salient distractor that does not match the observer's attentional setting (the green distractor) captured attention, thus, apparently, arguing against the contingent capture hypothesis. On the other hand, an abrupt onset that was salient enough to capture attention when subjects searched for an onset target failed to do so when subjects searched for a color singleton, thus supporting the idea that attentional capture is contingent on attentional settings. The authors concluded that observers could adopt a set for either "dynamic discontinuities" or "static discontinuities." That is, although the subjects were explicitly required to search for a red target, the set they are thought to have adopted was different and they searched for a static discontinuity. According to this rationale, the green distractor captured attention because it also qualified as a static discontinuity.

A similar and influential proposal was put forward by Bacon and Egeth (1994). They suggested that the finding that an item with a unique color delays the deployment of attention to a target with a unique shape (e.g., Theeuwes, 1992) results from the subjects' adopting "singleton detection mode." These authors suggested that because the target is always reliably a circle and unique on a given dimension, two search strategies are available: singleton detection mode, in which attention is directed to the location with the largest local feature contrast, and feature search mode, which entails directing attention to items possessing the target feature. If subjects use singleton detection mode, both relevant and irrelevant singletons could capture attention, depending on which exhibits the greatest local feature contrast. To test this hypothesis, Bacon and Egeth (1994) designed conditions in which singleton detection mode was inappropriate for performing the task. The disruption caused by the unique distractor disappeared. They concluded that irrelevant singletons

may or may not cause distraction during parallel search for a known target, depending on the search strategy (or attentional set) employed.

The main problem with this type of rationale is that the conditions that promote the use of one attentional set at the expense of another remain largely unspecified. For instance, in a later study using a very similar procedure (Folk and Remington, 1998), a green singleton did not capture attention in search for a red singleton. This finding suggests that under similar conditions, subjects sometimes adopt a set for static continuities (Folk et al., 1992) and sometimes a set for a specific color. The only data on which one relies to determine which set is adopted is the data that reveals whether the nominally irrelevant object captured attention. Obviously, there is a serious risk of circularity when the attentional set is inferred from the data. Thus, while it suffices to show that under certain circumstances, manipulation of the attentional set overrides attentional capture by a salient distractor to conclude that capture is not purely stimulus driven, invoking a hidden set to explain capture by nominally irrelevant salient distractors endangers the contingent capture hypothesis with unfalsifiability. In fact, as is explained in the next section, intertrial priming sometimes provides an alternative account for effects attributed to hidden attentional sets.

Intertrial Priming as an Alternative Account for the Role of Attentional Set?

The role of implicit intertrial memory in visual search is increasingly acknowledged (e.g., dimension priming, Found & Müller, 1996; feature and location priming of pop-out, Maljkovic & Nakayama, 1994, 1996; singleton priming, Lamy, Bar-Anan, & Egeth, 2008). Crucially, several authors have suggested intertrial priming as an alternative account for effects traditionally attributed to the operation of goal-directed attentional control settings (e.g., Lamy, Bar-Anan, Egeth, & Carmel, 2006; Lamy & Zoaris, 2009; Maljkovic & Nakayama, 1994).

For instance, Bravo and Nakayama (1992) showed that performance on search for a unique target differs when the target's unique property is known (blocked condition) than when it changes unpredictably from trial to trial (mixed condition). When subjects search for the unique color and the target is randomly either a red item among green ones or a green item among red ones, search is slower than when the target and distractor do not change colors throughout the experimental block. These authors concluded that search is guided by the known unique property in the

former case, whereas it is based on detection of the highest local contrast in the latter.

Maljkovic and Nakayama (1994) overturned this conclusion by proposing that the dramatic RT advantage observed in the blocked relative to the mixed condition results from intertrial repetition effects rather than from the benefit of knowing the target feature. In support of this claim, they showed that in the mixed condition, performance is enhanced if the target happens to have the same unique feature on consecutive trials, an effect that is called "priming of pop-out" (henceforth, PoP). In the same vein, Pinto, Olivers, & Theeuwes (2005) suggested that PoP accounts for the larger distractor interference typically observed when the target unique feature is not known (Theeuwes, 1991) versus known (Theeuwes, 1992). Thus, according to these authors, attention cannot be guided by advance knowledge of the target feature in parallel search. However, later studies have demonstrated that PoP accounts for part but not all the effects of feature-based attentional guidance (e.g., Lamy et al., 2006; Lamy & Yashar, 2008; Leonard & Egeth, 2008).

On a slightly different note, intertrial priming has also been put forward as an alternative to the notion that observers adopt a default singleton detection mode when the target is reliably a unique item on a given dimension. This claim is based on the finding that a unique item is detected faster when the target on the previous trial was also a unique item (e.g., Lamy, Bar-Anan, et al., 2006, Lamy et al., 2008) and takes longer to detect when a unique item was ignored on the previous trial (e.g., Lamy & Zoaris, 2009; Zehetleitner, Proulx, & Muller, 2009). Thus, what appears to be a search mode for singletons in fact appears to reflect, at least in part, carry-over effects that make it more difficult to ignore a singleton when a singleton was attended on the previous trial.

To conclude, intertrial priming effects have been shown to mimic effects of goal-directed factors and sometimes to mask the influence of stimulus-driven factors. Yet, although it will be important to take them into account in future research, the current literature does not suggest that they entirely account for effects attributed to guidance of attention by a known target feature.

The Time Courses of Goal-Directed and Stimulus-Driven Guidance

The time it takes for salience-based factors and attentional settings to become effective in guiding attention is critical to the controversy surrounding attentional capture. Indeed, it is obvious that selection is not always stimulus driven: Ultimately, we are able to select those objects and events

that are relevant for our behavior. The question at issue is whether preknowledge of a target property can bias the initial processing of a scene in favor of objects that possess the desired property.

It has been long known that endogenous (or goal-directed) cues take more time to become fully effective than do exogenous (or stimulus-driven) cues (e.g., Müller & Rabbitt, 1989; see Egeth & Yantis, 1997, for a review). Thus, it is important to distinguish between studies that explore feature-based attentional guidance by using a trial-by-trial cueing procedure and studies in which the target feature is defined over a block of trials. In the former case, the attentional set starts unfolding as soon as the cue appears, and whether it is effective crucially depends on how much time is allowed to process it before the search can begin. In the latter case, an attentional set can be established offline and it is fully developed when the search display comes on. Such set-ups are best suited to test the ability of attentional sets to guide initial shifts of attention.

Yet, Theeuwes et al. (2000) have shown that even when the target feature is known over a block of trials, attention can be directed to the target only after it has been shifted to the most salient item in the display. Theeuwes et al. (2000) relied on the observation that, in the paradigm from which most of the support for the contingent capture hypothesis is drawn (e.g. Folk et al., 1992), there is typically a delay of 150 ms between the presentation of the cue display and that of the search display (see Figure 10.3). Theeuwes et al. (2000) suggested that attention is captured by the irrelevant singleton cue early on, but disengagement of attention from the cue is relatively fast when the cue does not share the target defining property and relatively slow when the cue shares the target defining property. By this explanation, the 150-ms cue-to-target SOA masks initial capture by the irrelevant salient distractor.

To test this hypothesis, Theeuwes et al. (2000) had subjects search for a shape singleton while ignoring a color singleton presented at different stimulus onset asynchronies (SOAs; from 50 to 400 ms) prior to the search display. Although the distractor failed to summon attention at SOAs of 150–200 ms, it significantly disrupted search at earlier SOAs (50 and 100 ms, but also, unexpectedly, at the latest SOA of 400 ms). These findings nicely fit the predictions of the fast disengagement account (see Lamy & Egeth, 2003 for similar findings).

However, the conclusions from this study have been challenged by later experiments. For example, Chen and Mordkoff (2007) showed that in search for a color target an onset distractor that preceded the target by only 35 ms failed to capture attention, whereas a color cue (that

matched the attentional set) effectively drew attention to its location (but see Theeuwes, 2010 for an alternative account). In addition, Lamy (2005) showed that temporal expectations rather than fast disengagement account for subjects' ability to overcome attentional capture. She showed that it is easier to override attentional capture with fixed than with variable distractor-to-target SOAs (i.e., when the interval of time during which an attentional shift toward the salient distractor must be withheld is predictable versus unpredictable).

Finally, the findings from a myriad of recent experiments using scalp-recorded event-related brain potentials (ERPs) methodology clearly favor the notion that the first shift of attention can be determined by attentional set and, therefore, argues against the fast disengagement hypothesis. ERPs provide a continuous measure of brain activity and as such, they allow one to track the time course of the different perceptual processes that unfold from the onset of the search display. In particular, the N2pc component (an enhanced negativity over posterior scalp electrodes contralateral to the side of an attended stimulus) is thought to be a temporal marker for the allocation of attention in visual space, and has, therefore, been extensively used to distinguish between the two conflicting hypotheses.

On the one hand, several studies have shown that with Theeuwes' additional paradigm, the N2pc was elicited by the most salient item in the display (e.g., Hickey, McDonald & Theeuwes, 2006; Hickey, van Zoest & Theeuwes, 2010), thus paralleling the pattern of results obtained on RT data; these findings show that the RT delay associated with the presence of a salient distractor indeed indicates that spatial attention is initially captured by this distractor. However, such studies are not suited to investigate the fast disengagement hypothesis, because fast disengagement does not occur in the additional singleton paradigm. The critical question is whether a spatial shift of attention followed by fast disengagement indeed takes place for a salient distractor outside the attentional set during the distractor-to-target interval that typically prevails in experiments supporting the contingent-capture hypothesis.

Empirical evidence demonstrates that this is not the case. When a target competes with a more salient object that does not match the attentional set, the target elicits the first shift of attention with no evidence for prior fast disengagement from the distractor (e.g., Ansorge, Kiss, Worschech & Eimer, 2011; Leblanc, Prime & Jolicoeur, 2008; Lien, Ruthruff, Goodin, & Remington, 2008; Wykowska & Schubo, 2010).

The conclusion from these findings rests on the premise that N2pc indexes spatial shifts of attention. If instead it indexes enduring attentional processing at the location to which attention shifted or attentional engagement (as suggested by Theeuwes, 2010), that is, a processing stage akin to the "engage" component (Rafal & Posner, 1987), then absence of N2pc may not imply that the distractor singleton failed to capture attention. However, as Folk and Remington (2010) rightly noted, "if the allocation of attention to a cue is so brief that it produces no discernable behavioral or physiological effects, then it becomes functionally impossible to disconfirm the theory, and calls into serious question the usefulness of the construct." Thus, unless separate indices for attentional shifts followed by fast disengagement and engagement of attention are eventually identified, the current evidence argues against the fast disengagement hypothesis.

What Conditions Prevent Attentional Capture by Irrelevant Objects?

As the foregoing review suggests, goal-directed factors can bias attentional priority setting and prevent attentional capture by salient irrelevant objects. However, if such objects are made salient enough, attentional control breaks down (e.g., Lamy, 2005; Yeh & Liao, 2008). For instance, Lamy (2005) found that in search for a color singleton, a white irrelevant abrupt onset flashed against a black background can be ignored when it is drawn with a 1-pixel stroke but clearly captures attention when it is drawn with a 3-pixel stroke.

Leber (2010) suggested that, even when the salience of a potentially distracting object remains constant, the ability to resist capture might fluctuate from one moment to the next. Consistent with this claim, he showed that the momentary degree of distraction, indexed by the magnitude of distractor interference during search, could be predicted by pretrial activity in middle frontal gyrus of the brain measured during functional magnetic resonance imaging (fMRI). It is also possible that such ability to maintain an attentional set may vary from one individual to another.

However, efficiency of selection can be considerably boosted when attention focusing is optimal. Several studies have shown that attentional capture by irrelevant salient items can be completely prevented when the attention is narrowly focused. For instance, Yantis and Jonides (1990) showed that when a central cue allows attention to be focused in advance on the location of an impending target, an abrupt onset has no effect, whereas it produces strong capture when the cue appears simultaneously with the target display and attention is, therefore, still distributed

across the display (see Belopolsky, Zwaan, Theeuwes, & Kramer, 2007 for related findings).

Based on these results, Theeuwes (e.g., 2010) has claimed that attentional capture is limited to situations in which attention is spatially diffused. He has stretched the argument to suggest that whenever search is not strictly parallel, the size of the attentional window is reduced to smaller portions of the visual field, and failure to observe capture in such conditions can be explained by the fact that the distractor may lie outside the attentional window (Theeuwes, 2004). However, later studies have tested two direct predictions that follow from Theeuwes' hypothesis and have found them to fail. One prediction is that distractors that are more salient than the target should always capture attention in strictly parallel search; yet, there are contrary findings (e.g., Lamy, Carmel, Egeth, & Leber, 2006; Leber & Egeth, 2006). On the other hand, attentional capture by salient irrelevant objects should not occur in highly serial search; yet such capture has been reported (e.g., Lamy & Zoaris, 2009).

Focusing attention on a location known to contain the target thus prevents capture better than does successive focusing of attention on candidate locations in serial search. Two differences between these situations may be relevant. On the one hand, attention is more narrowly focused by a precue than during serial search. On the other hand, the need for selection is eliminated in the former case but not in the latter.

A series of experiments by Folk and colleagues (Folk et al., 2002; Folk, Ester & Troemel, 2009; see also Lamy, Leber & Egeth, 2004) suggests that optimal focusing of attention is not the critical factor that prevents capture. For instance, in Folk et al.'s (2002) study, observers searched for a red letter in a rapid serial visual presentation (RSVP) stream at fixation. A red peripheral cue that was distant from fixation by no less than 5° captured attention, whereas a green distractor did not. Folk et al. (2009) showed that capture by the peripheral distractor possessing the target color was completely eliminated when a central distractor engaged attention on the stream. Thus, the current state of the literature suggests that attentional engagement, but not attentional focusing, can totally prevent capture by salient objects, even when these objects share the target's task-relevant property.

Sources of Attentional Control: Conclusions

The foregoing review suggests that, although stimulus-driven and goal-directed factors are both powerful determinants of attentional priority, other factors such as intertrial priming and temporal expectations, which had been initially neglected, strongly affect what objects in the visual field receive attention.

ATTENTION AND WORKING MEMORY

Although researchers have traditionally focused on how attention determines which information flows into these higher stages, less scrutiny has been devoted to understanding how information flows in the opposite direction. That is, what higher-stage mechanism is responsible for controlling attention, and precisely how does this mechanism implement control? Abundant evidence, reviewed in previous sections, shows that attention can be controlled in a goal-directed fashion (e.g., Folk et al., 1992), but efforts to generate a more detailed characterization of the mechanism governing control have only recently begun to gather steam. Thus far, these efforts have suggested a key role for working memory in mediating attentional control, partly fueled by Desimone and Duncan's (1995) biased competition model (see also Miller & Cohen, 2001). In this section, we consider three central themes: (a) overlap in neural substrates linked to working memory and attention, (b) behavioral evidence for interactions between memory for spatial location and the deployment of spatial attention, and (c) behavioral evidence for object and feature memory guiding nonspatial attention. Like others who have preceded us, we define working memory as a mechanism that internally maintains task-relevant stimulus representations in the absence of available sensory input (e.g., Baddeley, 1986; 2003).

Common Neural Substrates

Perhaps the most conspicuous commonality between working memory and attention is their shared neural substrates. We review evidence for neural overlap in both early-to-mid level visual processing regions and in higher-level frontoparietal cortex (see Awh & Jonides, 1998).

Visual Processing Regions

Attention has been shown to modulate the stimulus-evoked neural response to visual stimuli through virtually all sensory processing regions, including areas V1 through V4 in both humans and monkeys (Luck, Chelazzi, Hillyard & Desimone, 1997); motion-selective MT/MST (O'Craven, Rosen, Kwong, Treisman, & Savoy 1997); monkey IT (Chelazzi, Miller, Duncan & Desimone, 1993) and human lateral occipital complex (Murray & Wojciulik,

2003); face-selective fusiform gyrus and scene-selective parahippocampal cortex in humans (O'Craven, Downing & Kanwisher, 1999).

Similarly, neural activity due to working memory maintenance has been observed in these same regions. In a seminal study by Fuster & Jervey (1981), macaques were trained to perform a delayed match-to-sample task, in which a colored geometric symbol was presented briefly and followed up to 32 sec later by a test array containing the same symbol among distractor symbols. Recordings from single units in IT revealed an enhanced firing rate in these neurons, which was sustained across the retention period. These results thus demonstrated direct working memory modulation of sensory regions, in the absence of ongoing visual stimulation. Using fMRI, O'Craven & Kanwisher (2000) asked their participants to close their eyes and imagine either faces or houses, and results showed sustained activity in fusiform gyrus during visual imagery for faces and in parahippocampal gyrus during imagery for houses. More recently, Harrison and Tong (2009) used multivoxel pattern classification to analyze spatial patterns of fMRI activity separately in areas V1 through V4 and were able to reliably predict the orientation of gratings that were maintained during working memory delays in the absence of visual stimulation. Further, Serences, Ester, Vogel, and Awh (2009) classified orientation-selective fMRI patterns of activity during both stimulus viewing and memory delays, finding the patterns to be highly similar. Taken together, the findings reviewed here clearly show that the effects of both attention and working memory target the same stimulus-processing regions.

Overlap in Higher Brain Regions

In addition to the aforementioned regions, substantial overlap is also apparent in frontal and parietal brain regions. One subregion of dorsolateral prefrontal cortex (PFC), frontal eye field (FEF), is thought to coordinate goal-directed spatial attention (Corbetta & Shulman, 2002). Several brain-imaging studies using positron emission tomography (PET) and fMRI have reported spatial working memory delay activity in human FEF (e.g., Curtis, 2006) and in nearby superior frontal sulcus (Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998). Most recently, studies incorporating both attention and working memory tasks within subjects have found common activation for these tasks in dorsolateral PFC, including FEF (Offen, Gardner, Schluppek & Heeger, 2010).

Intraparietal sulcus (IPS) has also been designated as a key source of attentional control (Corbetta & Shulman,

2002). Recent fMRI studies of visual working memory have provided especially strong evidence for participation of IPS, reporting modulation of activity to be dependent on working memory load (Todd & Marois, 2004; Xu & Chun, 2006). Research using event-related potentials (ERPs) provides converging evidence (Awh, Anllo-Vento, & Hillyard, 2000; Drew & Vogel, 2008). Results from a component referred to as the contralateral delay activity (CDA; Vogel & Machizawa, 2004) have been particularly informative. Like the fMRI results from Todd and Marois (2004), the CDA, which is thought to originate in the intraparietal sulcus, shows a load-dependent effect for visual objects stored during working memory delays (Vogel & Machizawa, 2004). More recently, Drew and Vogel (2008) implemented a multiple object tracking task, requiring sustained attention to a subset of moving objects in the display (Pylyshyn & Storm, 1988). Results showed a CDA component that increased with the number of objects tracked by observers. Additional evidence for a dual role of IPS comes from two studies by Heeger and colleagues. Silver, Ress, and Heeger (2005) demonstrated that two distinct subregions of IPS are organized topographically but are sensitive only to visual stimulation that is attended. They subsequently showed these same subregions to exhibit sustained activity over working memory delays (Schluppeck, Curtis, Glimcher & Heeger, 2006). Across these studies, the fMRI and ERP results suggest substantial overlap in the neural manifestations of attention and working memory, across spatial and temporal indices.

Do the Contents of Working Memory Set Attentional Control?

Establishing that attention and working memory utilize the same physical hardware answers key questions about the functional architecture of these two processes. However, converging methods are required to more fully characterize how the processes interact with one another. What are the behavioral ramifications of two systems that are so intimately related? Just over 100 years ago, Pillsbury proposed that "searching for anything consists ordinarily of nothing more than walking about the place where the object is supposed to be, with the idea of the object kept prominently in mind, and thereby standing ready to facilitate the entrance of the perception when it offers itself." He goes on to say that "one of the important conditions of attention to an object is to have in mind at the time it is received an image of the object" (Pillsbury, 1908, p. 36). That is, he predicts that the contents of working memory necessarily determine how attention is oriented to objects.

Only within the last 10–12 years have researchers begun to carefully test this prediction with empirical data. In this section we discuss whether and how the contents of working memory guide spatial and nonspatial attention.

Does Spatial Working Memory Determine Attention to Locations?

Awh, Jonides, and Reuter-Lorenz (1998) provided some of the earliest evidence supporting memory-driven allocation of spatial attention. In one experiment, participants were asked to store a letter, presented briefly at a random location of approximately $5°$ eccentricity, for a 5,000 ms retention interval. They would later be asked to judge whether a memory probe item appeared in the same or a different location. The task was challenging (overall accuracy of 77%), as different-location probes appeared between $0.7°$ to $2.7°$ away from the memory stimulus location. To examine the effects of working memory on attention, the experimenters also briefly presented a choice RT stimulus during the retention interval, for which observers had to discriminate whether this stimulus was one of two false-font stimuli. Critically, the location of this stimulus either matched or did not match the location of the memory stimulus. Results showed significantly faster RTs to choice stimuli occupying the memory stimulus location compared to different locations, demonstrating that the location stored in spatial working memory resulted in the attentional prioritization of that location (see Awh & Jonides, 2001 for related findings).

An additional line of evidence comes from studies of saccade trajectories. One classic finding within the attention literature is that saccadic eye movements deviate away from locations that were recently attended (Sheliga, Riggio & Rizzolatti, 1995), which is interpreted as key evidence for the premotor theory of attention, which holds that covert spatial attention is mediated by the same neural mechanisms controlling eye movements (Rizzolatti, Riggio, Dascola & Umilta, 1987). Theeuwes, Olivers, and Chizk (2005) hypothesized that, if the contents of working memory influence spatial attention in a similar fashion, then saccades should deviate away from locations held in working memory. They asked observers to memorize a gray dot that was briefly presented in one of the four display quadrants (approximately $5°$ above or below and $5°$ left or right of fixation). During the retention interval, an arrow instructed the participants to move their eyes to a new fixation location about $7°$ above or below the initial fixation. Results showed that when the vertical position of the memory item was between the initial and postsaccade fixation locations (e.g., in the upper left quadrant

on trials with an upwards saccade), eye movements deviated approximately $0.25°$ away from the memory location. Theeuwes et al. (2005) interpreted these results in the framework of the premotor theory, drawing important parallels between spatial working memory and attention.

Does Nonspatial Working Memory Determine Attention to Features and Objects?

Pashler and Shiu (1999) tested Pillsbury's hypothesis as it relates to object processing. They presented observers with a word or phrase describing an object (e.g., elephant) and asked the observers to form a clear mental image of the object. Next, an RSVP stream began, containing a series of line drawings with a target digit embedded among them. Critically, a line drawing that matched the imaged object was presented on each trial, either two frames before or two frames after the target digit. Pashler and Shiu reasoned that if the imaged object influenced attentional selection, the corresponding line drawing would trigger an attentional blink when it appeared prior to the target. Results confirmed this prediction, as target identification accuracy was impaired in the two-frames-before condition. However, it must be noted that the task was decidedly not a working memory task; in fact, in a second experiment, observers were given extra encouragement to drop the imaged object from memory, yet the same results were obtained. Thus, it is possible that the attentional blink was due to some other phenomenon, such as priming.

A subsequent study by Downing (2000) did employ a working memory task. In one experiment, observers performed a delayed match to sample on a face stimulus, with a retention interval of approximately 3 sec. During this interval, two additional faces briefly flanked fixation, one of which matched the item in memory, and a probe discrimination task followed about 200 ms later. Results showed that probe RT was reliably faster when the probe appeared in the location that had just been occupied by the matching face flanker, suggesting that attention had been shifted to the matching flanker. Much like the results of Pashler and Shiu (1999), Downing's data might have been the result of priming, and not working memory. However, in another experiment, Downing added a control condition in which the initial item was not required to be stored in memory. Here, the facilitation effect reversed; participants' probe RTs were now actually slower at the location of the matching flanker item. Downing concluded that the contents of actively maintained working memory were responsible for shifting attention to matching information. Nevertheless, one important limitation in the study is that observers may have deliberately attended the

memory-matching flankers to refresh their working memory representations.

What if the memory item is irrelevant during the RT task? Downing and Dodds (2004) devised a paradigm that removed the observers' incentive to deliberately attend to memory-matching information. They showed participants two sample objects (drawn from a set of novel shapes), and specified that one object would be the "search target" and the other the "memory target." During the retention interval, a three-object search array appeared, in which a speeded present/absent judgment was registered. The memory target was presented within the search array on half of the trials, now as an irrelevant distractor. Results showed that search performance was not impaired, but was rather sometimes improved by the presence of the memory target as a distractor item. This suggests that attention is not automatically drawn to objects matching the contents of working memory and that the working memory representation may be actively inhibited when it could potentially distract observers from the current task (see Woodman & Luck, 2007 for similar conclusions).

Although the studies by Downing and Dodds (2004) and Woodman and Luck (2007) controlled for some limitations of the earlier work, more recent studies that were also carefully controlled have indeed reported memory-driven capture (Olivers, Meijer, & Theeuwes, 2006; Soto, Heinke, Humphreys, & Blanco, 2005). Olivers et al. (2006) proposed that objects in working memory are more prone to interfere with visual search when they cannot be verbalized. To test this hypothesis, the researchers presented a "more verbal" condition, in which memory items were from verbally distinct categories (e.g., red, green, blue), and a "more visual" condition, in which memory items were not easily separated into distinct verbal categories (e.g., various shades of red). Reliable memory-driven capture was found, but only in the "more visual" condition. The reader may note that the "more visual" memory task was more difficult than the "more verbal" one, suggesting that the difference in results may have been due to task difficulty (see Olivers, 2009, for further discussion of this issue).

To summarize this section, evidence showing that nonspatial contents of working memory guiding attention is mixed. Reconciliation may lie in the nature of the memory task, and continued work has focused on this (see Olivers, 2009).

ATTENTION AND CONSCIOUSNESS

Introspection suggests a causal relationship between attention and conscious awareness. When we attend to a portion of the visual field, the objects in that region appear to be thrust into our awareness. When we shift our attention away, the vivid experience of seeing these objects seems to dissolve. Consistent with this idea, the metaphors used to describe attention and consciousness often hint to a close link between the two concepts. For instance, attention has been compared to a spotlight that enhances visual information within the circumscribed region on which it falls (e.g., LaBerge, 1983) and according to the global workspace theory (Baars, 1988), consciousness is a bright spot "cast by a spotlight on the stage of a dark theater" (Baars, 1998, p. 56). The selective function that is common to attention and consciousness and is underscored by such metaphors has led some authors to posit that "a visual stimulus is consciously perceived when information in visual pathways is selected by attention and passed onto working memory" (Prinz, 2000). According to this view, attention is necessary for perceptual representations to become conscious (e.g., O'Regan & Noe, 2001).

Associations Between Attention and Conscious Perception

Phenomena such as inattentional blindness (IB), change blindness (CB), and the attentional blink (AB) offer striking demonstrations of close link between attention and conscious perception. *Inattentional blindness* refers to a situation in which people fail to notice stimuli appearing in full view when they are absorbed with an attentionally demanding task (Mack & Rock, 1998). In a typical experiment (see Figure 10.4), observers have to perform a difficult perceptual discrimination on the only item that appears on the screen (the target), for several trials. On the first few trials, nothing unexpected occurs; only the target is present. On the critical trial, however, an additional item appears simultaneously with the target. The crux of the IB paradigm is that observers do not expect it; thus, this trial is referred to as "the inattention trial." Immediately after this unexpected object disappears and before the next trial begins, observers are asked whether they have noticed anything on the previous trial other than the target. Typically, a substantial proportion of the participants report no awareness of the additional item. The number of "noticers" rises considerably when, later in the experiment, the additional item is again presented and observers are asked whether they noticed its presence. Because the observers now know that an additional item might appear, this trial is referred to as "the divided attention trial." Thus, when attention is completely removed from an item, we fail to consciously perceive it. Yet, even when the main
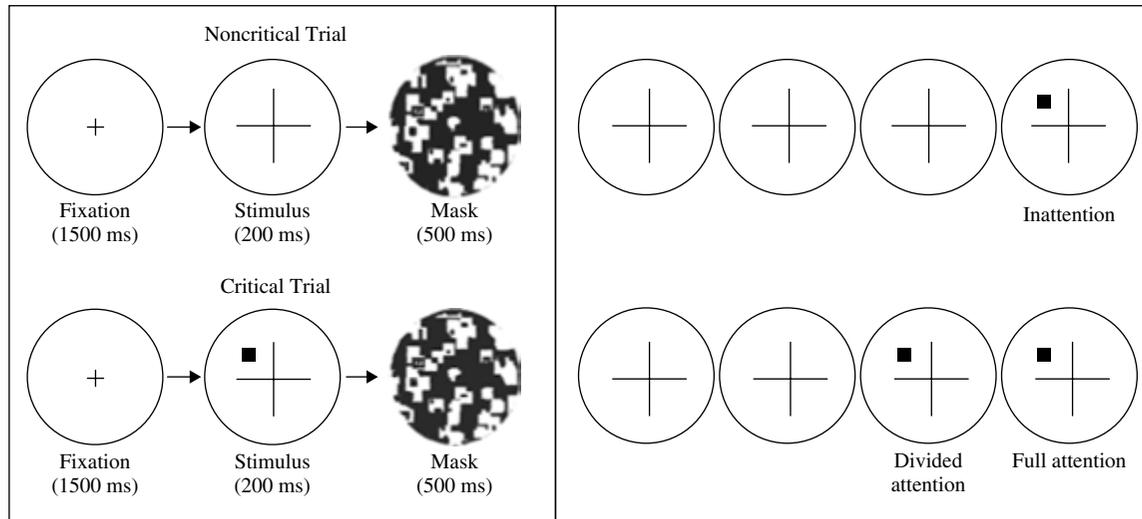
Subjects are required to make a fine discrimination concerning the cross. *Left panel*: Trial types: critical trial (peripheral stimulus present) and noncritical trial (peripheral stimulus absent). *Right panel*: Trials sequence. After each critical trial, subjects are asked whether they noticed anything in the display except for the cross.

Figure 10.4   Typical Inattentional Blindness experiment (e.g., Rock et al., 1992)

task requirements remain unchanged (difficult attention-consuming discrimination), the mere knowledge that an additional item might appear suffices for some attention to be allocated to it and for inattentional blindness to break down.

Change-blindness experiments show that despite erroneous intuitions to the contrary (Levin, Momen, Drivdahl, Simons, 2000), observers can be strikingly inept at detecting even large changes in their visual environment when these occur simultaneously with a brief visual disruption (see Simons & Ambinder, 2005, for a review). For instance, in the flicker paradigm (Rensink, O'Regan & Clark, 1997), an original and a changed scene separated in time by a blank screen alternate continually until observers detect the change. The blank screen creates a luminance change everywhere in the scene, thus masking the signal produced by the change. Even though observers actively search for the change, it typically takes them several alternations to detect it. Focused attention at the location of the change appears to be necessary and sufficient for conscious detection of the change (e.g., Becker, Pashler, & Anstis, 2000). For instance, cueing the relevant item before the potential change eliminates change blindness (Becker et al., 2000), changes to regions of main interest in the scene are less likely to be missed (Rensink et al., 1997) and so are irrelevant yet perceptually salient objects (Scholl, 2000).

The *attentional blink* demonstrates limitations that arise when processing sequentially presented stimuli (Broadbent & Broadbent, 1987; Raymond, Shapiro & Arnell, 1992). Subjects view with a rapid serial visual presentation (RSVP) stream of stimuli and have to respond to two targets embedded in the stream. When the lag between these targets ranges between 100 and 500 ms, conscious detection of the second target (T2), given that the first target (T1) was correctly reported, is severely impaired relative to a control condition in which the first target is ignored. Findings showing that increasing T2 perceptual salience attenuates the blink (e.g., Keil & Ihssen, 2004) suggest that AB reflects attentional gating of visual information reaching awareness.

The pathological condition referred to as *unilateral neglect* also provides strong support for a causal role of attention in visual awareness. Unilateral neglect is caused by damage to the posterior parietal cortex, which is associated with a disruption in attentional processing and failure to perceive objects in the scene opposite the lesion (see Bartolomeo, 2007, for a review): The patients appear to be subjectively blind to them. The most widely accepted interpretation of unilateral neglect is that it results from a failure to orient attention to the contralesional visual field. Support for this claim comes from findings showing that when patients are presented with a stimulus in each visual field, the resulting blindness to the stimulus in the contralesional field is reduced by the presentation of a spatial cue in the neglected field. Thus, unilateral neglect also appears to be an instance of blindness caused by inattention.

Alternative Views on the Relationship Between Attention and Conscious Perception

Although these findings appear to indicate that attention is necessary and sufficient for conscious awareness to arise, this idea has been challenged. There are two main competing views. On the one hand, Dehaene and colleagues (e.g., Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006) agree that conscious perception cannot occur without attention but also claim that attention is not sufficient: They argue that for a stimulus to reach awareness, its physical energy must also exceed a certain threshold. Specifically, they suggest that processing of a stimulus with subthreshold "bottom-up strength" can be enhanced by attention allocation, but this stimulus remains inaccessible to conscious awareness (subliminal processing).

On the other hand, Koch and colleagues (e.g., Koch & Tsuchiya, 2007; van Boxtel, Tsuchiya, & Koch, 2010) deny that attention is either necessary or sufficient for conscious perception. In successive reviews of the extant findings, they have gathered evidence that they view as instances of attention without awareness or of awareness without attention.

A somewhat hybrid view has been put forward by Lamme (e.g., 2003) who relies on the distinction between phenomenal awareness and access awareness initially proposed by Baars (e.g., Baars, 1988). Lamme claims that attention is necessary only for conscious report (access awareness), but not for the short-lived and vulnerable experience of seeing (phenomenal awareness) that does not easily lend itself to conscious report.

In the remainder of this section, we reevaluate the findings held to support that attention is not sufficient for awareness and for the more controversial claim that attention is not necessary for awareness. We focus on behavioral studies and leave aside evidence from brain imaging and electrophysiological studies: Because these methods are correlational, they are less suitable to address the questions of necessity and sufficiency.

Operational Definitions of Conscious Perception

The question of what measure should be used to determine whether a subject is aware or unaware of a stimulus has been the focus of intense debate (e.g., Cheesman & Merikle, 1984; Eriksen, 1960; Holender, 1986; Snodgrass, Bernat, & Shevrin, 2004). With subjective measures, awareness is assessed on the basis of the subjects' self-reports of their conscious experiences. The subjects are typically required to press a key when they are perceptually aware of a given target, but they are asked not

to guess when making this judgment. Alternatively, they may be required to rate the visibility of the target on a multiple-point scale (e.g., Sergent & Dehaene, 2004). According to this approach, only the subjects themselves have access to their inner states through introspection, and their subjective report is the only valid marker of their conscious experience. With objective measures, awareness is assessed based on the observers' forced-choice decisions regarding different stimulus states. The subjects have to respond on each trial, even when they report not seeing the stimuli and they just guess. Perception is said to be unconscious when the observer's forced-choice performance falls to chance (e.g., Marcel, 1983). According to this approach, subjective reports are likely to be contaminated by response biases. Thus, for ambiguous signals, some subjects may be ready to report having seen the critical stimulus, whereas others may be reluctant to do so, although their conscious experience of the stimulus may, in fact, be similar. On the downside, however, objective measures of awareness do not reflect the phenomenological experience of being visually aware and may seriously underestimate the influence of information perceived without awareness.

Articulated within the framework of Signal Detection Theory (SDT, Green & Swets, 1966), these distinctions imply that an observer is held to be objectively unaware of a stimulus if her sensitivity to this stimulus or d prime (d') is null. An observer with greater-than-zero sensitivity may nonetheless report not seeing the stimulus, in which case she is objectively aware of the stimulus but subjectively unaware of it. No single objective index can serve to determine whether an observer is subjectively aware of a stimulus, because the introspective report that is the measure of subjective awareness depends on both d' and the criterion this observer adopts.

To prevent conscious perception of a stimulus, different techniques can be used (see Kim & Blake, 2005, for a review). The most popular method in the context of studies of attention without conscious perception is backward masking. The critical stimulus is presented very briefly and followed by a second visual stimulus, called the mask, which dramatically impairs the visibility of the first stimulus with appropriate cue-to-mask SOAs. The criterion used to determine whether prevention of conscious perception is effective, of course, depends on which definition of awareness is adopted. With subjective measures, observers are held to be unaware of the target whenever they report not having seen the stimulus or when they rate its visibility at the minimal value. Unconscious perception often refers to above-chance performance on forced-choice tasks in

the absence of subjective awareness. With objective measures, null sensitivity is required. Unconscious perception is probed using indirect measures of processing such as priming. Within each perspective, the procedures used to assess awareness also vary. The most reliable method is to measure conscious perception at the end of each trial. However, conscious perception is often assessed in a separate block of trials or in a separate experiment involving the same sequence of stimulus events as the main experiment, because collecting several responses on the same trial can often be confusing for the participants.

Is Attention Sufficient for Awareness?

What type of evidence would support the idea that attention is not sufficient for awareness? One should demonstrate effects of attention in the absence of conscious perception. In other words, one has to show attentional enhancement of the processing of a visual stimulus that is not accompanied by conscious awareness of this stimulus. Studies that addressed this question can be divided into three main categories.

Unconscious Orienting of Attention to Exogenous Cues

One line of research has investigated stimulus-driven capture of attention without awareness (see Mulckhuyse & Theeuwes, 2010 for a review). The rationale is that if attention can be summoned to the location of a stimulus that is not consciously perceived, then we have a case of attention without consciousness and we may, therefore, conclude that attention is not sufficient for conscious perception. In a typical experiment, a cue that is not consciously perceived appears at a peripheral location. A target follows shortly afterward and spatial congruity effects are measured. If the cue captures attention, RTs are expected to be faster when the target appears at the same location as the cue at short cue-to-target time intervals and to be slower in the same-relative to the different-location condition at longer intervals (a pattern indicative of inhibition of return).

Jiang, Costello, Fang, Huang, and He (2006) used an interocular suppression paradigm in which awareness of the cue in one eye was suppressed by strong noise presented to the other eye. The invisible cue was the picture of either a nude female or a nude male, presented on either the left or right side of fixation. Shortly after the cue was offset, a Gabor patch was presented and participants had to respond to its orientation. Responses to the targets were faster when these appeared at the same location as the cue than at a different location, suggesting that the invisible cue had captured attention. Interestingly, this effect occurred only when the depicted nude was of a sex the observer was attracted to.

McCormick (1997) used the modified spatial cueing paradigm pioneered by Posner et al. (1980). On each trial, a cue appeared on either the left or right side of fixation but on most of the trials, its location invalidly cued the target location: The target was most likely to appear at the opposite location. Critically, the cue could either be highly visible (high luminance contrast) or imperceptible (low luminance contrast). The author reasoned that, if subjects could see the cue, they would rapidly reorient their attention to the opposite direction, and RTs should, therefore, be faster on different-location than on same-location trials. If a subliminal cue could capture attention, however, then when subjects failed to see the cue, they should fail to reorient their attention and same-location trials should be slower than different-location trials. The results were generally consistent with this hypothesis.

Such findings suggest that subliminal cues can capture attention exogenously. However, does this type of evidence invalidate the claim that attention is necessary for awareness? Obviously, whatever causes an item to capture attention occurs at the preattentive stage: The slight increase in luminance of the low-contrast onset cue in McCormick's study, for instance, triggers an attentional shift before attention is directed to the cue. These are the questions: Once attention is shifted to the cue location (a) can attentional enhancement of the cue representation be measured and (b) is such enhancement accompanied by conscious awareness of the cue? The reviewed findings do not provide answers to these questions. First, while they show that attentional enhancement occurs at the location previously occupied by the cue, these effects are measured for the subsequent target and there is typically ample time for attentional effects to develop until the target is onset. Thus, as the cue either disappears very quickly (e.g., after 30 ms in McCormick, 1997) or is immediately masked (e.g., Ivanoff & Klein, 2003; but see Jiang et al., 2006, for an exception), the time during which attention is focused at the cue location is longer with regard to the measurement of attentional effects (indexed by RTs to the target) than with regard to the measurement of awareness (indexed by reports of cue visibility). In addition, even when conscious awareness of the cue is measured on a trial-by-trial basis, it is typically not measured separately for attended and unattended cues. Yet, such distinction is crucial; if attention is necessary for conscious perception, one would expect higher awareness for attended than for unattended cues.

In conclusion, to date, investigations of exogenous capture of attention by subliminal cues have generally not provided findings that are relevant to the question of the necessity of attention for conscious perception.

Attentional Modulation of Unconscious Priming

A related line of research partially solves the problems associated with studies of attentional capture by subliminal cues as a tool to test sufficiency of attention for awareness. In these studies, the cue is fully visible but a masked prime is introduced between presentation of the cue and presentation of the target (e.g., Lachter, Forster, & Ruthruff, 2004; Finkbeiner & Palermo, 2009, Kentridge, Nijboer, & Heywood, 2008; van den Bussche, Hughes, Humbeeck, & Reynvoet, 2010). Thus, the sequence of events typically includes a visible cue, a masked prime, and a visible target. The prime is associated with a response that is either compatible or incompatible with the response required by the target. With this procedure, the cue-to-prime interval is typically long enough to ensure that attention is fully focused by the time the masked prime is onset. The effect of interest is whether priming by the invisible prime is modulated by attention.

For instance, Kentridge et al. (2008) used metacontrast masking in a simple color discrimination task (see Figure 9.5). In the critical condition, the sequence of events involved a visible central location cue, a prime consisting of one red disk and one green disk, one above and the other below fixation, and two targets either both red or both green at the same locations as the prime. The target served as a meta-contrast mask for the prime. The prime followed cue onset by an interval exceeding 300 ms, such that there had been ample time to focus attention on the cued location when the prime appeared. The target followed the prime at an SOA known to be optimal for metacontrast masking (40 ms, see Breitmeyer, Ro, & Ogmen, 2004). The

Displays and procedure used in Kentridge et al.'s (2008) study. In this example, the congruent prime location is cued.

Figure 10.5 Attentional modulation of unconscious priming

observers had to respond to the targets' color. The color of the attended prime could either be congruent or incongruent with the targets' color.

RTs were faster when the prime at the cued location was of the same color as the target than when it was of a different color, indicating that attention modulates processing of invisible objects. Effects of attention on visibility of the primes was analyzed in a separate experiment, in which subjects had to perform a two-alternative forced-choice (2AFC) task and determine in which of two consecutive trials a prime had been present. Signal detection analyses showed that sensitivity to the prime did not differ, regardless of whether it was attended.

Similar findings were reported with different classes of stimuli including words (e.g., Lachter et al., 2004), tools, vegetables, and animals but not with faces (Finkbeiner & Palermo, 2009). Specifically, priming effects were of similar magnitude, regardless of whether the face prime was attended, but this finding appears to be the exception rather than the rule.

Although the studies reviewed in this section provide demonstrations of attention without conscious perception, it is noteworthy that lack of awareness was always either assumed based on earlier experiments (e.g., Lachter et al., 2004), or measured in a different experimental block rather than assessed on a trial-by-trial basis (e.g., Kentridge, et al., 2008; Finkbeiner & Palermo, 2009; van Bussche et al., 2010). As task demands differed in the condition in which attentional effects on masked priming were measured and the condition in which conscious perception of the primes was assessed, one cannot confidently reject the possibility that attention may nonetheless have affected prime visibility during the masked priming experiment.

Effects of Visible Spatial Cues on Processing of Invisible Targets

A third rationale used to investigate effects of attention in the absence of conscious perception consists of presenting a visible cue and measuring its effects on responses to an invisible target. Kentridge and colleagues (Kentridge, Heywood, & Weiskrantz 1999; 2004) took advantage of the blindsight phenomenon to study this question. Blindsight refers to the ability of patients with clinical blind field defects caused by damage to the primary visual cortex, to detect, localize, and even discriminate visual stimuli that they deny seeing. In Kentridge et al. (1999), a central arrow indicated the most probable location of a subsequent target presented in the patient's blind field. The patient was required to discriminate the orientation of the target.
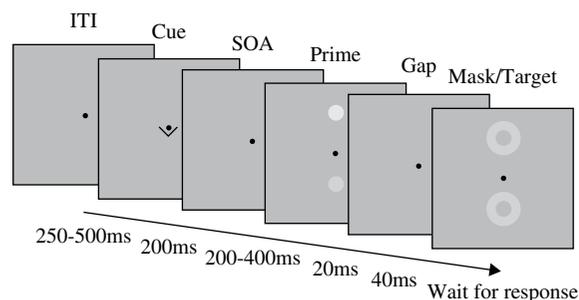
Response latencies on correctly discriminated targets were faster on valid-cue than on invalid-cue trials. In addition, discrimination accuracy was above chance in all conditions and tended to be higher (but not significantly so) on valid-cue than on invalid-cue trials. Subjective awareness of the target was assessed at the end of each block and the subject denied being ever aware of any of the targets, whether at the cued or at the uncued location. The authors concluded that attention to a target (reflected in the RT advantage in validly cued locations) is not a sufficient condition for awareness of that target.

To conclude, the current literature suggests that attention is not sufficient for awareness. Although studies of exogenous attentional capture by invisible cues are typically not suited to investigate this issue, masked priming studies and studies of attentional cueing in blindsight provide more convincing evidence. However, future experiments should privilege procedures in which awareness is assessed on a trial-by-trial basis.

Is Attention Necessary for Awareness?

As Mack (2002) noted, phenomena such as inattentional blindness "seem to have established that there is no perception without attention, but in doing so have led us to wonder why we nevertheless have the impression that we see everything before us when in fact we seem to see only what we are attending to. If we must attend to see, and we cannot attend to everything at once, then it would appear to follow that we do not see everything, and probably only see a small part of all that at any moment is potentially seeable" (p. 103).

Opponents of the view that attention is necessary for awareness deny that our impression of seeing more of the world than what is in the focus of our attention is an illusion. They have presented two types of arguments. One is that inattention does not lead to a failure to see, but rather to a failure to remember. Because observers are prompted to report on their awareness of an unexpected event only after this event has elapsed, observers may forget it during the interval between offset of the critical stimulus and time of questioning (e.g., Moore & Egeth, 1997; Wolfe, 1999). The crux of this argument is that attention is not necessary for phenomenal consciousness, defined as visual representations that exist only in the present tense, and thus depends on what definition of conscious perception one adopts. Note that the inattentional amnesia argument does not undermine the claim that attention is necessary for access consciousness or subjective report.

The second argument is that, although attention is required for the identification of some aspects of the world, we are always aware of certain other aspects, such as scenes' gist (e.g., Li et al., 2002) or faces (e.g., Reddy, Reddy, & Koch., 2006), even when attention is intensely focused elsewhere. Support for this view is typically drawn from studies using the dual-task paradigm.

For instance, Li et al. (2002) showed that subjects were able to detect a target animal or tool with similar accuracies under dual and single task conditions (see section 2.1.2.3. of this chapter). The authors concluded that conscious detection did not require attention.

The finding that conscious detection of the target in the peripheral scene is not associated with a drop in performance on the central task is crucial to this conclusion; it is held to indicate that conscious detection does not result from a shift of attention toward the peripheral stimulus. However, it is important to distinguish between focal attention and distributed attention. Dual-task studies such as Li et al.'s (2002) or Reddy et al.'s (2006) certainly indicate that focal attention is not required for conscious perception of gist or faces. However, they provide no evidence against the idea that some attention may nevertheless be required.

The pattern of results obtained using the inattentional blindness paradigm clearly illustrates this point. For instance, relative to a control condition in which no peripheral item was presented, Rock, Linnett, Grant, and Mack (1992) found no evidence of central task impairment caused by the unexpected object on either the inattention trial (in which the unexpected stimulus was presented for the first time) or the divided attention trial (in which it was presented for the second time). As the number of participants who noticed the unexpected object substantially rose from the inattention to the divided-attention trial, it is reasonable to conclude that knowledge that the peripheral distractor might turn out to be relevant again sufficed to cause enough attention to be allocated to the peripheral stimulus—which resulted in conscious perception of it, but not enough to produce perceptible impairment on the central task. The dramatic difference between complete inattention (when the peripheral object is utterly unexpected) and near absence of attention (when attention is focused on a demanding central task but participants are aware of the secondary task) is precisely what motivated the design of the inattentional blindness paradigm.

To conclude, then, the dual-task paradigm does not appear to be suited to the investigation of whether attention is necessary for conscious perception because trials in that paradigm are similar to the divided-attention trial of the inattentional blindness paradigm.

CONCLUSIONS

Two main conclusions emerge from our review. One is that early intuitions about central issues in attention have been confirmed by recent research. Fifty years ago, Broadbent proposed filter theory, giving rise to early-selection views of attention. Despite intensive research brought forward in support of either the late-selection view or hybrid accounts arguably reconciling the two opposite views, a survey of the literature shows that early selection prevails. More than a century ago, William James drew a distinction between active attention and passive attention which overlaps the current distinction between goal-directed and stimulus-driven attention, and suggested that both types of attention contribute to selection. Again, after protracted dichotomization between views assigning attentional control to either only stimulus-driven or only to goal-directed processes, the current state of the literature strongly suggests that both types of factors contribute to allocation of attentional priority. However, the large amount of research that these debates have generated has yielded a wealth of findings and important distinctions that have considerably deepened our understanding of attentional selection.

The second conclusion is that there is a clear trend toward an integrative approach to the study of attention. From the methodological viewpoint, the recent expansion of cognitive neuroscience has led to genuine integration of behavioral and neurophysiological measures of attentional processes, leading to increased refinement of the theoretical constructs underlying these measures. From a theoretical viewpoint, increased effort is being made to understand how attention relates to and interacts with other cognitive processes such as working memory and conscious awareness, highlighting the notion that attention is intimately linked to higher stages of processing. This integrative approach has greatly contributed to recent advances and promises to be the most fruitful approach in future research on selective attention.

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Queries in Chapter 10

Q1.   Please provide the figure callout for the Figure 10.5.