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What You See Is What You Set: Sustained Inattentional Blindness and the Capture of Awareness

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This article reports a theoretical and experimental attempt to relate and contrast 2 traditionally separate research programs: inattentional blindness and attention capture. Inattentional blindness refers to failures to notice unexpected objects and events when attention is otherwise engaged. Attention capture research has traditionally used implicit indices (e.g., response times) to investigate automatic shifts of attention. Because attention capture usually measures performance whereas inattentional blindness measures awareness, the 2 fields have existed side by side with no shared theoretical framework. Here, the authors propose a theoretical unification, adapting several important effects from the attention capture literature to the context of sustained inattentional blindness. Although some stimulus properties can influence noticing of unexpected objects, the most influential factor affecting noticing is a person's own attentional goals. The authors conclude that many—but not all—aspects of attention capture apply to inattentional blindness but that these 2 classes of phenomena remain importantly distinct.

> "It is against state policy to pave over a deer," said . . . an engineer for the department. "If in fact the deer was in the work area, it should have been removed before the work was done."
>
> —Associated Press, August 22, 1996, reporting on road workers who failed to see and thus paved over a dead deer

People fail to notice things all the time, even when there are no obvious factors hampering their vision. Although the consequences are usually insignificant, sometimes the results can be ludicrous: The accidental paving over of a dead deer by a Pennsylvania highway crew would seem to fall into this latter category. Unfortunately, the results can also be tragic. In 2000, for example, an American naval submarine rammed a Japanese fishing vessel, killing 9 Japanese crew members and students on board. According to one account, despite a quick sweep with the periscope, the commander failed to notice the fishing trawler nearby (Sciolino, 2001). More commonplace examples can be found in traffic accident reports, which are replete with accounts of drivers failing to see obvious obstacles in their way (e.g., McLay, Anderson, Sidaway, & Wilder, 1997).

Inattentional blindness is a striking phenomenon in which people fail to notice stimuli appearing in front of their eyes when they are preoccupied with an attentionally demanding task (Mack & Rock, 1998). Although conscious perception is a complicated matter—perhaps more of a graded phenomenon than all or nothing, in which case one can never rule out the possibility of some level of subjective experience—the extent to which people appear incapable of reporting salient stimuli is intuitively surprising. Furthermore, empirical evidence and everyday experience suggest that inattentional blindness is more than merely a failure to report a stimulus: Indices of such perceptual deficits include failures to modify actions as well as subjective report. For example, in one experiment, professional airline pilots operated a flight simulator in which flight console information was projected directly onto the cockpit windshield (Haines, 1991). Presumably, this "heads-up" display should have decreased pilot errors because the pilots could view both the console information and the external world simultaneously. However, some of the pilots attempted to land the plane even though the runway was clearly obstructed by another airplane. When queried afterward, these pilots reported having never been aware that there had been any obstruction at all. In other

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words, by their own reports—and as evidenced by their actions—they never saw the other airplane despite looking directly at it.

Perception is impoverished without attention, but researchers still know little about the factors involved in directing attention to the unexpected. This is an important issue, both theoretically and practically. From a standpoint most applicable to everyday life, the question of why people *fail to notice* unexpected items can be inverted, rephrased to inquire, "What kinds of stimulus properties and/or perceiver-controlled processes influence the likelihood that someone will notice an unexpected object or event?" (i.e., what will capture awareness; in this article we refer to inattentional blindness and the capture of awareness as inverses of each other). This article pursues these questions from two perspectives. Theoretically, we argue that an understanding of attention and awareness requires a combination of insights from the literatures on *attention capture* and on inattentional blindness. We suggest that both types of phenomena can be accommodated under a model influenced by the notion of a "perceptual cycle" (Neisser, 1976). Experimentally, we then report the results of a systematic exploration in which several of the most important themes from the attention capture literature are tested in inattentional blindness experiments, presenting a series of studies investigating both how properties inherent in a stimulus can affect whether people notice it (i.e., *bottom-up* properties) and how processes under the control of a perceiver can affect what he or she notices (i.e., *top-down* processes). These studies provide additional experimental "glue" that helps to support our primary theoretical conclusions: Although some stimulus properties (e.g., uniqueness) can affect noticing, to a larger extent the unexpected objects that people consciously see depend on the ways in which they "tune" their attention for processing of specific types of stimuli—that is, on the *attentional set* that they adopt.

Across the Great Divide: Implicit Versus Explicit Capture

Two substantial lines of research—inattentional blindness and attention capture —have provided insights relevant to the noticing of unexpected stimuli. *Attention capture* refers to instances in which stimuli draw a person's attention without that person's volition (see Folk & Gibson, 2001). These kinds of attention shifts have alternately been referred to as *reflexive*, *involuntary*, or *automatic*. Research on inattentional blindness and attention capture have illuminated different processes relevant to the noticing of unexpected objects. Whereas inattentional blindness research directly probes whether participants notice unexpected stimuli, attention capture research traditionally relies on implicit measures rather than awareness—observations of response times and eye movements, for example—to infer shifts of attention (e.g., Jonides & Yantis, 1988; Theeuwes, Kramer, Hahn, & Irwin, 1998). This difference in measurement has important consequences for the kinds of conclusions that can be generalized from one branch of research to the other. For example, the kinds of stimuli that have been found to capture attention implicitly might not also capture awareness; indeed, there have been reports of stimuli in such experiments affecting response times without people becoming aware of them (e.g., McCormick, 1997; Yantis, 1993, Footnote 2; see also Posner, 1980). Because of this potential divergence, instances in which stimuli affect performance without necessarily impinging on awareness might appropriately be called *implicit attention capture*, to distinguish them from instances in which there is evidence of awareness, or *explicit attention capture* (Simons, 2000). Although inattentional blindness research has yielded information about the conditions under which people can or cannot report visual stimuli, it has been less successful in illuminating the mechanisms underlying the guidance of attention to unexpected things. Implicit attention capture research, conversely, has yielded numerous insights about the conditions under which unplanned shifts of attention will occur, but few attempts have been made to link such shifts to subsequent awareness (but see Gibson & Peterson, 2001; Lamme, 2000). Thus, research on implicit attention capture alone is of uncertain practical relevance to everyday life. If a child runs in front of your car as you are fiddling with the radio, it is important that you notice the child, not that you are slower in turning the knob.

Although it seems logical that the two lines of research should engage in a fair amount of cross talk, within each literature little reference has been made to the other. In effect, the literature lacks a shared theoretical framework that incorporates inattentional blindness and attention capture. Constructing that framework requires that insights from one literature be tested in the other, and one goal of this article is to set this process in motion.

The distinction between implicit and explicit attention capture reflects a fundamental paradox concerning the nature of attention. On one hand, people engaging in challenging tasks must often maintain focus, effectively ignoring irrelevant information that might distract them from their goal. Thus, teachers will often admonish their students to pay attention in class and not be distracted by their classmates. Inattentional blindness research underscores this aspect of attention. On the other hand, attention must be distractible; if potentially dangerous or behaviorally relevant objects appear, they should divert cognitive resources. Attention capture research emphasizes this aspect of attention. A complete explication of attention must incorporate both these seemingly conflicting requirements (Allport, 1989), but unfortunately, attention research has tended to pursue these two aspects independently.

It is possible, of course, that one need look no further than the implicit attention capture literature to infer what captures awareness— once a person has shifted attention to an object, he or she might necessarily become aware of it. However, this is unlikely to be true. Whereas the time courses of automatic attention shifts are largely transient (e.g., Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989), visual awareness might arise through a temporally sustained process involving higher level cognitive activity. Such activity might involve preconscious cycles of interpretation and verification or the mapping of visual information onto representations in long-term memory (e.g., Di Lollo, Enns, & Rensink, 2000; Minsky, 1975; Neisser, 1976; Potter, 1993).

Indeed, as mentioned earlier, stimuli do sometimes engage attention implicitly without reaching subjective awareness (e.g., Kentridge, Heywood, & Weiskrantz, 1999, 2004; Lambert, Naikar, McLachlan, & Aitken, 1999; McCormick, 1997; Naccache, Blandin, & Dehaene, 2002; Woodman & Luck, 2003; Yantis, 1993, Footnote 2). For example, in one study, participants fixated on a point between two potential target locations and were informed that antipredictive cues would precede the targets. That is, when a cue appeared in one of the two locations, the actual target was most likely to appear in the opposite location. When a cue was presented in a suprathreshold manner, participants were faster to respond to the target when, as expected, it appeared at the opposite location. Because they were aware of the cue, the participants were able to use this information to shift their attention strategically to the opposite location. However, when the cue was presented subliminally, participants were faster to respond to the target when it appeared at the same location as the cue (McCormick, 1997). In other words, participants oriented to the subliminal cue, but because they were not aware of it, they did not shift their attention strategically. Although implicit shifts of attention may often coincide with awareness, such incidents of noncoincidence underscore the need to assess awareness directly, rather than relying on implicit measures of attention capture to infer what might capture awareness. In the following sections, we review research on implicit and explicit manifestations of attention capture respectively, and we begin to explore how they might be related.

Implicit Attention Capture: The Search for Automaticity in Orienting

Attention is central to visual processing, and if someone is to notice an object or event that is unexpected, then attention presumably must first shift to that stimulus. However, when a stimulus is unexpected, observers cannot shift their attention to it intentionally. Here, the notion that attention can shift automatically, drawn entirely by bottom-up stimulus features, can usefully bypass this dilemma, but this notion has proven controversial. Although some evidence suggests that particularly salient objects, sudden onsets, and some motion signals can automatically draw attention (e.g., Abrams & Christ, 2003; Franconeri & Simons, 2003; Theeuwes, 1992; Yantis & Jonides, 1984), it has been difficult to rule out the possible involvement of top-down guidance. In fact, as we discuss below, some results have thrown the very notion of completely automatic orienting into question (e.g., Folk, Remington, & Johnston, 1992).

A number of different implicit tasks have been used in the endeavor to find evidence of automatic attention capture, with varying degrees of success. In large part, they emerged from the use of two traditional attention paradigms, *visual search* and *attention cuing*. Both paradigms tend to rely on explicit target detection to infer attentional engagement, but response times sometimes stand alone as an index of attention shifts, thereby seeming to obviate the need to use explicit report about a stimulus to infer that it has captured attention.

Visual Search

Visual search tasks typically require participants to look for a predetermined target embedded within a display of distractors, and the time it takes to complete this kind of visual search normally increases as the number of distractors increases. However, some classes of features seem to defy this pattern, and participants tend to respond quickly to targets containing these features regardless of the number of display items. In these cases, attention is thought to prioritize the target features over any of the distractors, and such features are said to "pop out" (Treisman & Gelade, 1980). Although pop out search has sometimes been interpreted as evidence that a target has automatically captured attention (e.g., Öhman, Flykt, & Esteves, 2001), in a strict sense this kind of evidence is insufficient to infer automatic attention capture. Because the observer is actively looking for the target, his or her attention is presumably broadly and purposefully distributed throughout the display (see Mack & Rock, 1998; Yantis & Egeth, 1999). Furthermore, because the observer knows the identity of the target, the match between the target and the observer's perceptual readiness to locate it certainly enhances search efficiency.

Attention Cuing

The attention cuing paradigm has also served as a basis for much implicit attention capture research. As in visual search, participants look for and explicitly report a predetermined target. Often the target appears as the only item in the display, and it is preceded by a cue indicating its likely location. When the cue accurately predicts the target's location, participants are quick to respond to the target. However, when the cue is misleading, response times are slowed (e.g., Colegate, Hoffman, & Eriksen, 1973; Eriksen & Hoffman, 1972; Jonides, 1981; Posner, 1980; Posner, Snyder, & Davidson, 1980). This pattern of results is the root of the notion that response times can be used in place of awareness as an index of attention shifts. Two types of cues—*central* and *peripheral*—have been used in such experiments, and they have different consequences for the efficiency of target detection. Central cues can appear anywhere other than at the potential target locations. Thus, for the cue to predict the target location, it must symbolically represent where the target is most likely to appear (e.g., a symbol indicating the location; see Posner, 1980), requiring participants to actively interpret the meaning of the cue. In contrast, peripheral cues appear at one of the potential target locations and therefore do not need to be interpreted prior to an attention shift (see Jonides, 1981; Posner, 1980). Attention shifts in response to peripheral cues tend to be faster and more effortless than those in response to central cues, and they are also difficult to inhibit. Thus, attention shifts to peripheral cues are said to be relatively automatic (Jonides, 1981). This discovery paved the way for subsequent studies using implicit measures of attention capture, and new approaches have both directly elaborated on the attention cuing paradigm (e.g., Folk et al., 1992) and combined it with the visual search paradigm to study attention capture with increased rigor (e.g., Theeuwes, 1992; Yantis & Jonides, 1984).

The Additional Singleton Task

One example of a hybrid paradigm is the *additional singleton* task (e.g., Theeuwes, 1992, 1994). In this task, participants search for a unique target in an array of distractors and report the orientation of a line embedded within the target. For example, in a display of green diamonds, participants report on the line contained within the only green circle. On some of the trials, an additional unique property is present—for example, one of the distractor diamonds might be unique in color—whereas other trials contain no unique property. When the additional property was a unique color, a unique shape, or contained a sudden onset, response time in the primary search task was slowed compared with response time in trials containing no unique distractor (Theeuwes, 1992, 1994). Furthermore, the degree to which the unique distractor affected response time depended on how salient it was compared with the target. When the target–distractor discrimination was easy (e.g., a green target among red items), an additional unique shape did not affect response times. However, when the target–distractor discrimination was harder (e.g., a yellowish-green target among yellowish-red items), response times were slowed in the presence of the unique additional shape (Theeuwes, 1992). Irrelevant eye movements have also been examined within this type of paradigm as an index of involuntary attention shifts (Theeuwes et al., 1998).

Results from the additional singleton paradigm have been the focus of some debate, and they illustrate a nuanced distinction between automatic and voluntary attentional shifts. Because participants knew that their target would be characterized by a unique property, they might have entered into a so-called *singleton detection mode*, whereby they readied themselves to attend to any unique singleton appearing within the display (Bacon & Egeth, 1994). If so, the observed shifts of attention might have depended on strategic influences and thus would no longer qualify as being strictly automatic. Indeed, when the task was changed so that the target was embedded in a display filled with heterogeneous distractors, rather than homogeneous ones, unique colors and shapes no longer affected response time (Bacon & Egeth, 1994). The singleton detection mode was no longer an effective strategy, and unique features no longer captured attention. This finding implies that attention shifts revealed in the additional singleton paradigm are strategic in nature. Nevertheless, the line between automatic and voluntary shifting is fuzzy. For example, the effects of unique distractors on response times persisted across over 2,000 trials (Theeuwes, 1992), indicating that participants could not learn to ignore them. The adoption itself of a singleton detection strategy might be automatic and occur because of the nature of the task.

The Irrelevant Feature Task

A second implicit attention capture paradigm is the *irrelevant feature* task, in which observers typically search for a target letter embedded among varying numbers of distractor letters. In contrast to the additional singleton task, a unique but irrelevant feature is present on every trial. Also unlike the additional singleton task, the unique property can sometimes belong to the target; however, it belongs to the target of the search only $1/n$ of the time, where n is the total number of letters in the display. If display size does not affect search time when the irrelevant property belongs to the target, attention capture by the target is inferred. With this task, unique colors, luminances, and even some motion signals do not appear to capture attention, but objects with sudden onsets do (Hillstrom & Yantis, 1994; Yantis & Hillstrom, 1994). For example, when testing the influence of sudden onsets, each trial begins with all letters masked by a figure eight. After 1 s, segments of these figure eights disappear to reveal letters, and simultaneously, an additional letter appears abruptly at a previously unoccupied location. When this new letter happens to be the target of the search, response times are relatively unaffected by variations in the number of items in the array (Yantis & Jonides, 1984).

The apparent failure of motion signals other than abrupt onsets to capture attention within this paradigm (e.g., Hillstrom & Yantis, 1994) runs contrary to many previous intuitions (e.g., James, 1890/1950). One proposed interpretation of this pattern of results is that sudden onsets are especially prioritized by the attention system because they signal the appearance of new perceptual objects (Yantis & Hillstrom, 1994). This implies that any obviously new object will become the focus of visual attention. However, recent studies have given reason to doubt the primacy of new visual objects, showing that some motion signals might capture attention nearly as well as onsets do (Abrams & Christ, 2003; Franconeri & Simons, 2003).

Attentional Set and the Irrelevant Precue Task

Although sudden onsets and motion signals often appear to receive attentional priority, the orienting responses they elicit are not immune to top-down influence. For example, when observers know in advance where the target will appear, sudden onsets occurring elsewhere in a display do not capture attention (Yantis & Jonides, 1990). In fact, results from a third paradigm, the *irrelevant precue* task, suggest that all implicitly measured shifts of attention might be contingent on the expectations of the observer (e.g., Folk et al., 1992). In raising this possibility, these results throw into question the very notion that attention can shift to a stimulus automatically, drawn overwhelmingly by the properties of the stimulus itself. In this task, sudden onsets do not affect performance unless participants expect that their target will also be characterized by a sudden onset. When observers know in advance that the target will be characterized instead by an alternative property, such as a unique color, onsets no longer affect response time (Folk et al., 1992). Participants looked for a target in one of four potential target locations, and just prior to the target presentation a cue was presented at one of the four locations. When participants knew the target would be an item with a sudden onset, uniquely colored precues did not affect response time whereas precues with sudden onsets did. When participants knew that the target would have a unique color, the reverse result emerged: Precues with sudden onsets did not affect response time, but precues with unique colors did (Folk et al., 1992).

It seems that when observers adopt a specific *attentional set*—whereby they ready themselves to receive a specific type of information—this top-down constraint overrides the capturing power of other, irrelevant information. The possibility does still remain that sudden onsets and motion signals capture attention in the absence of any top-down attentional set (Yantis, 1993). However, one of the enduring dilemmas plaguing research on attention capture is the seeming impossibility of ever ruling out the chance that an observer is exercising some sort of expectation during a task (Folk, Remington, & Johnston, 1993).

Despite the complications inherent in arguing for strong forms of automatic attention capture, the experiments conducted within this tradition have provided important insights into the conditions under which attention is most likely to shift without a person's intent. The influence of top-down guidance might be difficult to rule out, but accumulated evidence suggests that some kinds of properties—onsets, motion signals, and perhaps uniqueness—are especially likely to become targets of unplanned shifts of attention. Furthermore, top-down expectations appear to play a substantial role in both inhibiting and facilitating implicitly measured shifts of attention. Surprisingly, although such investigations have successfully documented factors contributing to implicitly measured shifts of attention, with few exceptions (see Mack & Rock, 1998) no such systematic investigations have explored the factors underlying inattentional blindness—or its converse, the capture of awareness.

Selective Looking and Inattentional Blindness

The dissociation between subjective awareness and implicitly measured shifts of attention (e.g., Kentridge et al., 1999; Lambert et al., 1999; McCormick, 1997; Woodman & Luck, 2003) underscores the importance of studying factors leading to subjective noticing separately from those eliciting attention shifts. Attention shifts alone may not be sufficient to push a stimulus into awareness, but attentional selectivity does help govern what people become aware of. At any given moment, a person's senses are bombarded with more information than he or she can possibly take in, and through attention the person selects only subsets of this information for further processing. Information that does not receive such further processing often fails to reach awareness. The well-known cocktail party effect, in which one's own name is detected even when embedded within a previously ignored auditory stream, suggests that especially meaningful information might have a low threshold for entrance into awareness (e.g., Moray, 1959). This, in turn, raises the possibility that even information not reaching awareness does receive some degree of processing. However, most kinds of ignored information fail profoundly to impinge on subjective awareness (Cherry, 1953; Treisman, 1964; but see Holender, 1986). Such failures within the visual modality—inattentional blindness—are particularly striking because they violate the intuition that people should see whatever they direct their eyes to.

In this section, we describe work on selective visual processing that began in the mid-1970s, ranging from early, video-based experiments on *selective looking* (in which participants intentionally ignore subsets of information) to more recent, computer-based experiments on inattentional blindness (in which participants do not expect an additional stimulus and thus cannot ignore it intentionally). In contrast to research on implicit attention capture, this work focuses on subjective awareness. In the course of this discussion, we introduce a framework loosely based on the *perceptual cycle* model (Neisser, 1976), which has implications for how insights from the implicit attention capture literature can be used to make specific predictions regarding the capture of awareness. Although this formulation presaged many findings garnered well after it was developed, to our knowledge it has not been discussed in relation to attention capture until now.

Video-Based Studies of Selective Looking and Inattentional Blindness

In an early series of selective looking studies, observers watched a monitor displaying two video clips that were superimposed such that each clip had a transparent, ghostlike appearance (Neisser & Becklen, 1975). One of the clips was of a group of people passing a basketball, and the second was a close-up view of two sets of hands engaged in a hand-slapping game. Observers selectively attended to one of these two clips and their awareness of unexpected events in the unattended clip was subsequently probed. For example, when attending to the basketball game, observers failed to notice that the hands in the other clip stopped slapping each other and engaged in a handshake. This failure to notice the unexpected events is informative and surprising: Observers were aware of both video clips from the start and were looking directly at them. This experiment demonstrated how people are able to filter out information when they actively try to ignore it.

An even more interesting finding emerged when a completely new, unexpected object appeared during an ongoing selective looking task. Although attention is often thought to prioritize new information (e.g., Yantis & Hillstrom, 1994), when the new object was unexpected, people often failed to become aware of it at all. For example, in an extension of the selective looking paradigm, observers engaged in a task involving three superimposed video recordings (Neisser & Dube, 1978, cited in Neisser, 1979). One was of a group of people in white shirts interweaving and passing a basketball among themselves. The second was of the same people passing a basketball, but now wearing black shirts. Participants simply attended to one of the two teams and indicated each time that the designated team passed the ball. Partway through the task, a third recording—that of a woman with an open umbrella walking across the screen—was superimposed as well. Though the woman's presence was obvious to anyone not engaged in the tracking task (Neisser, 1979), people engaged in the task rarely noticed her. In one study, for example, only 21% detected her (Neisser & Dube, 1978, cited in Neisser, 1979), and in another 35% noticed her (Becklen & Cervone, 1983). The surprise expressed by participants who reviewed the tape afterward reflected the degree to which they had failed to detect her initially (Neisser, 1979). Note that in this case, the failure to notice the new object did not result from the intent to ignore it, because observers never knew that it would appear.

Contrary to hypotheses suggesting that a lack of expectation is the major cause of inattentional blindness (e.g., Braun, 2001), the availability of attention (or lack thereof) has emerged as a crucial factor as well. For example, in the selective looking experiments, observers who were practiced at selectively tracking the passes made by one of the two basketball teams were twice as likely to notice the unexpected umbrella woman as were novice observers (Neisser & Dube, 1978, cited in Neisser, 1979). Presumably, practice reduced the attentional demands of the selective task, thereby freeing more attention resources for processing of the unexpected object. This interpretation is consistent with evidence that the distracting influence of irrelevant information is greater under conditions of low, rather than high, perceptual load (Lavie, 1995). Furthermore, the availability of attention in a selective looking task is affected not only by task demands but also by factors subject to voluntary control, such as the observer's beliefs and motivations about the difficulty of the task. Participants who were told that they were engaged in a practice trial or that the task was easy were somewhat more likely to notice the umbrella woman (Neisser & Dube, 1978, cited in Neisser, 1979).

Some recent studies have begun to explore whether the unusualness of an unexpected object or its visual relationship to other display items influences the likelihood of detection. For example, in a replication and extension of the selective looking paradigm, a person in a black gorilla suit, instead of a woman with an umbrella, walked through the middle of two groups of ball players. In some conditions, as in the earlier studies (Becklen & Cervone, 1983; Neisser & Dube, 1978, cited in Neisser, 1979), all the figures were transparent. Despite the striking and unusual spectacle, 73% of observers failed to notice the gorilla (Simons & Chabris, 1999). In contrast to some earlier results (see Neisser, 1979), the rate of noticing seemed to depend in part on which of the two groups observers tracked. Specifically, 8% of the observers in this condition who counted the passes made by the players in white noticed the black gorilla, whereas 46% of those attending to the team in black noticed it (Simons & Chabris, 1999). These results suggest that similarity to other items in a scene can influence the likelihood of noticing an unexpected object. However, the study was not designed with this question in mind, and the video display was not optimal for addressing this possibility.

Computerized Studies of Inattentional Blindness

To elucidate more precisely the factors that lead to noticing of unexpected objects, recent studies of inattentional blindness have turned to more controlled computer-based tasks (e.g., Mack & Rock, 1998; Most, Simons, Scholl, & Chabris, 2000; Most et al., 2001; Newby & Rock, 1998; Rock, Linnett, & Grant, 1992). Initial studies used brief presentations of simple shapes (e.g., Mack & Rock, 1998; Newby & Rock, 1998). In a typical experiment, observers engaged in a perceptual discrimination task for several trials: A cross appeared at fixation for 200 ms per trial before being replaced by a mask, and participants indicated for each trial whether the horizontal or vertical component of the cross was longer. On the first few trials, nothing unexpected occurred. On a critical trial, however, an additional, unexpected item appeared simultaneously with the cross in one of the cross's quadrants (see Figure 1). Participants were then asked whether they had seen anything on that trial other than the cross. Regardless of whether the unexpected items contained a unique color, orientation, or motion signal, about 25% of the participants reported no awareness of the item (Mack & Rock, 1998). As it turned out, some meaningful stimuli, such as the participant's own name or a schematic happy-face icon, were detected with greater frequency, indicating that high-level analyses could help determine awareness. And, counterintuitively, higher rates of inattentional blindness (75%) were found when the cross appeared peripherally and the unexpected item appeared at fixation, suggesting that participants had actively inhibited processing at fixation to focus attention on their assigned target (Mack & Rock, 1998).

Findings from this paradigm provide valuable insights into awareness. However, how well they generalize to more realistic perceptual situations is an open question. Objects in the real world rarely appear for just 200 ms, and they are rarely masked. These caveats are particularly important, considering that temporally extended processes might be required to establish a conscious percept. Although unexpected objects that were salient or moving did not appear to enter awareness any more than nonmoving, nonsalient stimuli did, it is possible that under less constrained conditions, such stimuli would effectively trigger the cascade of processing that would lead to greater noticing. The short duration of the stimulus presentation is also problematic because it leaves this paradigm particularly vulnerable to claims that participants might have seen the unexpected object but then forgotten about it by the time awareness was probed (*inattentional amnesia*; Wolfe, 1999). This alternative explanation would be consistent with findings that whereas identification of rapidly presented pictures may occur within 125 ms, consolidation of such stimuli in memory requires up to 300 ms (Potter, 1975, 1976; Potter & Levy, 1969).

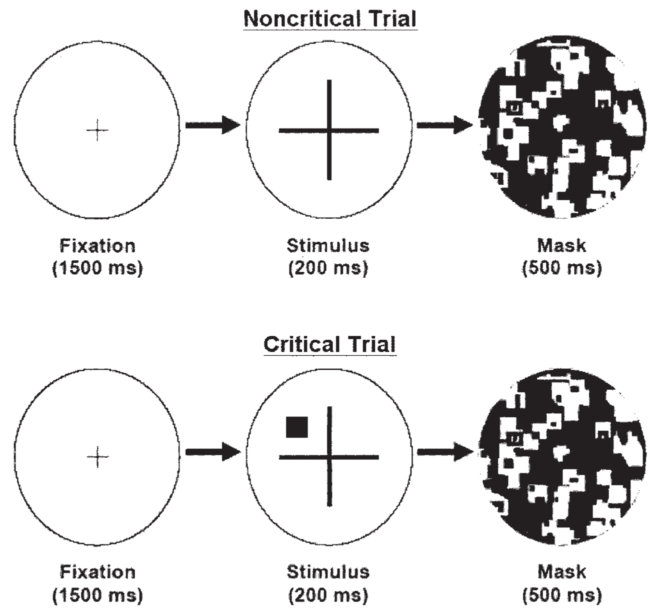

Figure 1. Example of a typical inattentional blindness trial from Mack and Rock (1998). On each trial, participants judge whether the horizontal or vertical part of the cross is longer. On the first few noncritical trials, nothing unexpected appears. However, on a critical trial, an unexpected shape appears in one of the cross's quadrants. Regardless of whether the unexpected object has a unique color, shape, or motion signal, participants fail to notice it about 25% of the time. From *Inattentional Blindness* (p. 7) by A. Mack and I. Rock, 1998, Cambridge, MA: MIT Press. Copyright 1998 by MIT Press. Adapted with permission.

It is important, then, to assess the factors that might lead to noticing under more sustained and dynamic conditions.

Sustained Inattentional Blindness and the Role of Similarity

To address this and other questions directly, we developed a sustained and dynamic computerized task in which we were able to keep parameters such as similarity under tight control (Most et al., 2000, 2001; Scholl, Noles, Pasheva, & Sussman, 2003). In a typical task, participants viewed a display in which four black items and four white items moved on haphazard paths, occasionally bouncing off the edges of the display. For each 15-s trial, participants were asked to count the total number of bounces that either the white items or the black items made. For the first two trials, this is all that happened. During the motion on the third (i.e., the critical) trial, however, a unique item unexpectedly entered the display from the right, traveled horizontally across the display for 5 s (passing behind a fixation point), and exited the left side of the display (see Figure 2). This technique proved effective in inducing inattentional blindness: Even when the unexpected item had both a unique shape (a cross among circles and squares) and a unique color (red in a field of black and white items), almost 30% of participants failed to detect it (Most et al., 2001, Experiment 3). Note that although participants were counting bounces made at the edges of the display, the unexpected object traversed the middle of the display, potentially too far from the locus of attention to be

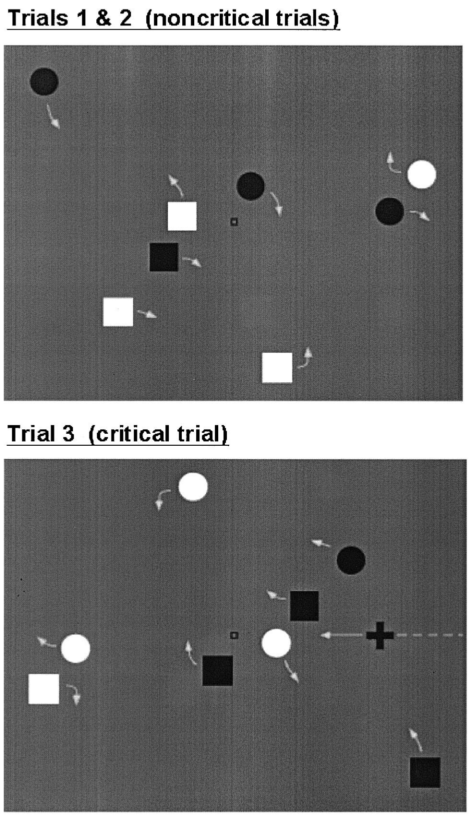

Figure 2. Still frames from Most et al. (2001, Experiment 3; arrows were not present in actual display). On each trial, four black and four white shapes moved on haphazard paths, frequently bouncing off the display's edges. Participants counted the bounces made by either the black or white shapes. On the first two trials, nothing unusual happened. On the critical trial an unexpected red cross (depicted here in black) traversed the display. Even though it was bright red, 28% of participants failed to notice it.

sufficiently processed. However, an advantage of this computerized paradigm is that it allows the systematic manipulation of a number of parameters to look at issues such as this. For example, we subsequently tested two different ways that similarity between an unexpected object and other display objects might influence noticing rates: (a) similarity in terms of spatial proximity and (b) similarity in visual features.

In the first case, to the extent that attention acts like a metaphorical spotlight, illuminating objects and features that fall within its "beam," noticing rates might vary as a function of the distance that an unexpected object appears away from some spatial focus of attention (Newby & Rock, 1998). Alternatively, to the degree that attention selects for objects or features rather than location (e.g., Duncan, 1984; Egly, Driver, & Rafal, 1994; Kanwisher & Driver, 1992; for a review see Scholl, 2001), noticing might vary as a function of the unexpected object's featural similarity to other items in the display.

Spatial proximity. The first, location-based hypothesis is certainly plausible (e.g., Eriksen & St. James, 1986; Posner, 1980). To test the role of distance, we modified the task so that a horizontal line bisected the display, and participants were asked to count the number of times a subset of items came into contact with the line (Most et al., 2000). When the unexpected object appeared, it traveled on a path parallel to the line, either on the line or at varying distances away from it (see Figure 3). Presumably, the line or the area around it marked the spatial focus of attention. By systematically varying the unexpected object's distance from the line, we examined the influence of spatial proximity on detection. The results from this study suggested that spatial proximity to the focus of attention plays some role in determining whether unexpected objects will be noticed. However, the effect was relatively small and could not entirely explain noticing rates. In particular, even when the object traveled on the line, fewer than 50% of the participants detected it on the critical trial.

Featural similarity. Spatial attention seemed to account only for a small degree of variation in noticing, leaving open the possibility that featural similarity might also play a role. In an experiment designed to test this possibility (Most et al., 2001, Experiment 1), participants counted the number of times that either a black subset of items or a white subset of items bounced off the edges of a display window (with both subsets present in all displays). When participants were counting the number of bounces made by white items, almost all of them (94%) reported seeing the unexpected item when it also was white. Conversely, when the unexpected item was black and participants were attending to the white subset of shapes, only 6% reported seeing it. The rates of noticing for light- and dark-gray unexpected items were intermediate. Furthermore, when participants were counting the number of bounces made by the black subset of items, rather than the white subset, these rates of noticing were qualitatively reversed—even though the physical display was identical. Thus, the more similar an unexpected item was to a set of already-attended items and the less similar it was to a set of distractor items, the more likely it was to be noticed (see Figure 4).

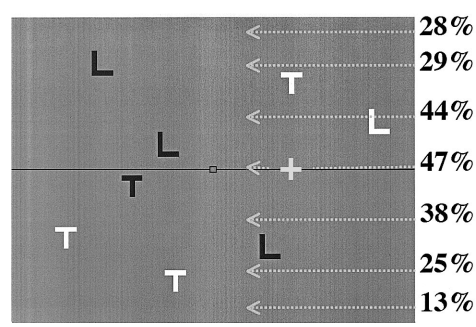

Figure 3. Still frame from a critical trial in Most et al. (2000). Four black and four white shapes moved haphazardly and frequently made contact with the horizontal line bisecting the display. On the critical trial, an unexpected cross traversed the display on a path parallel to the line, either on the line or at varying distances away from it (here, the arrows indicate the possible paths). More people noticed it as its path became closer to the line, but over half of the participants still failed to see it even when it traveled on the line, which was presumably close to the focus of attention. The noticing rates at each distance are shown on the right. Adapted from "Sustained Inattentional Blindness: The Role of Location in the Detection of Unexpected Dynamic Events," by S. B. Most, D. J. Simons, B. J. Scholl, and C. F. Chabris, 2000, *Psyche, 6*(14), Figure 1. Copyright 2000 by Steven B. Most, Daniel J. Simons, Brian J. Scholl, and Christopher F. Chabris.

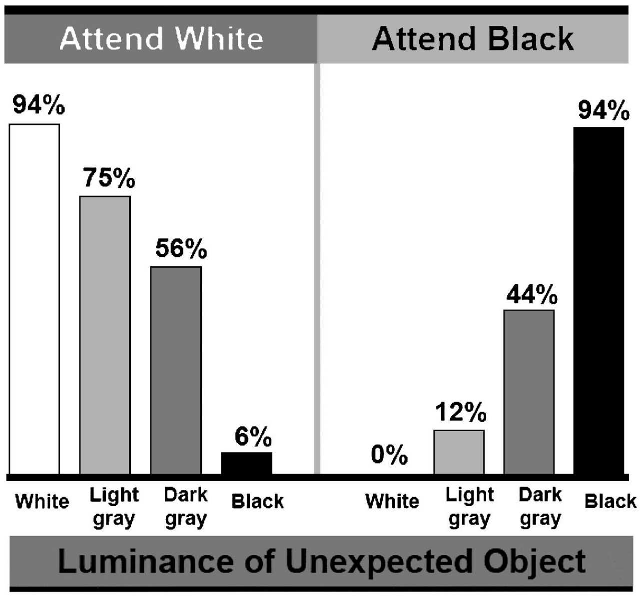

Figure 4. Percentage of observers who noticed the unexpected object on the critical trial in Most et al. (2001, Experiment 1). As the unexpected object's luminance became more similar to that of the attended items, it was noticed by more people. From "How Not To Be Seen: The Contribution of Similarity and Selective Ignoring to Sustained Inattentional Blindness," by S. B. Most et al., 2001, *Psychological Science, 12*, p. 12. Copyright 2001 by Blackwell. Adapted with permission.

This similarity effect may have been driven by active selection of stimuli resembling the targets, but it also may have stemmed in part from the active suppression of stimuli resembling the distractors. The two possibilities have different implications. In the first case, observers would be expected to process only those items resembling the attended targets. In the second case, observers would be expected to process all items except those akin to the distractors. We addressed this issue using a variation of the basic task: Observers attended to gray items moving on a blue background and ignored a distractor set composed of either white items or black items. Depending on the condition, the unexpected object itself was either white or black. Thus, the unexpected object was always different from the gray target items but was either similar to or different from the distractor set. We reasoned that if noticing relied critically on the unexpected object's similarity to the target items, then observers should be equally likely to notice it across all conditions. However, if noticing was also influenced by the object's similarity to the distractor items, then people should be more likely to notice it when it was different from the distractor items than when it was similar to them. In fact, the results matched this latter prediction well: When the unexpected item was the same luminance as the distractor items, only 6% of the observers noticed it on average. However, when the unexpected object was different from the distractors, 81% noticed it (Most et al., 2001, Experiment 2). Although these findings support the notion of a role for active ignoring in inattentional blindness, this conclusion is tentative. Because the unexpected object was actually more salient when it was different from the distractors—and thus unique in the display—it may be that salience was the underlying factor leading to greater noticing.

The Perceptual Cycle Framework: A Foundation for Integrating Implicit Attention Capture and Awareness

It may be fruitful to describe a view of attention and perception called the *perceptual cycle* (Neisser, 1976). Although rarely discussed in the context of attention capture—indeed, work on attention capture had barely begun when it first was proposed—the perceptual cycle framework was an attempt to reconcile stimulus-driven and strategic attentional processing in vision. Neisser (1976, 1979) suggested that this model could account for successful perception as well as for failures to notice unexpected objects and events. More central to our purpose, the perceptual cycle account provides the basis for a framework integrating implicit attention capture with the capture of awareness, one that generates predictions about the conditions under which awareness will occur.

According to the perceptual cycle view, conscious perception emerges through a temporally extended and active engagement with the environment. Items do not leap into awareness on initial attentional engagement. Rather, a cyclical process of visual interpretation and reinterpretation ultimately determines our conscious percepts. Some kinds of information impinge on the senses and elicit an orienting response, but information that is processed only in this way is fragmentary and transient, incapable of forming the basis of a conscious representation. Once attention has been oriented, expectations, or anticipatory schemas, based on limited preconscious information, serve as the vehicle for attentional exploration. Each attention shift yields information that modifies the observer's interpretation of what stimulus might be present and guides subsequent attentional exploration. This cycle of attentional guidance continuously enriches the emerging representations and modifies the observer's expectations, eventually leading to a conscious percept. Depending on the complexity of the scene, this whole process can occur within milliseconds, and indeed, observers appear able to identify pictures presented for less than 125 ms (Intraub, 1980, 1981; Potter, 1975, 1976; Potter & Levy, 1969).

The central claims and implications of the perceptual cycle model include the following:

1. Environmental cues can trigger automatic orienting responses, but these reflexive responses by themselves do not directly produce awareness.

2. Conscious percepts require sustained attention and an iterative process of interpretation and reinterpretation.

3. Preconscious information processing guides sustained attentional selection. Because the model suggests that processing of the immediate past helps guide processing of the immediate future, it yields the somewhat counterintuitive notion that implicit memory may sometimes precede conscious perception.

4. Visual stimuli that do not become part of a cycle of expectation, exploration, and reinterpretation may never be noticed at all.

Although the proposed iterative nature of the perceptual cycle is consistent with evidence elsewhere in the literature (e.g., Di Lollo et al., 2000), the aspects of the model most relevant to the current discussion are (a) its distinction between attentional orienting and active, extended attentional engagement with the environment and (b) its emphasis on the role of expectations.

Setting the Stage for Reformulation: Revising the Perceptual Cycle Framework in Light of Recent Evidence

Although the mechanisms underlying the perceptual cycle account are vague, it does fit well with findings garnered years after it was originally proposed. The notion that iterative and reciprocal processes underlie conscious perception has support from neurophysiological evidence for cortical feedback from higher cortical areas to earlier visual areas (e.g., Hochstein & Ahissar, 2003; Lamme, 2000, 2003; Zeki, 1993; Zeki & Shipp, 1988). Moreover, the relatively recently discovered phenomenon of *object substitution masking* is thought to depend on recurrent, cyclical processing (see Di Lollo et al., 2000). When two nonoverlapping but proximal stimuli appear together and one of them disappears immediately, the resulting percept is often of just the remaining stimulus. The transitory, vanished stimulus is not identified, suggesting that it was overwritten by the remaining one (Di Lollo et al., 2000; Enns & Di Lollo, 1997; Giesbrecht & Di Lollo, 1998). Yet, perception of the same stimulus is unimpaired if the two objects disappear at the same time (Di Lollo, Bischof, & Dixon, 1993; Di Lollo et al., 2000). This finding is consistent with a perceptual cycle interpretation: Ascending, feedforward signals provide the basis for a crude and tentative visual representation, and feedback signals serve to confirm or modify these signals in a cyclical process leading to awareness. If the higher level interpretation matches the feedforward information, then processing continues. When both the mask and the target disappear simultaneously, a veridical visual percept of the target may still be constructed, as there is nothing remaining in the display that would overwrite the initial bottom-up information. However, if the target disappears before initial top-down interpretations can be verified, leaving the mask in the display, then a match cannot be found between higher level and lower level representations. Processing must proceed on the mask alone, and this is what is consciously perceived (Di Lollo et al., 2000).

Although intriguing, the potentially cyclical nature of processes underlying conscious vision is tangential to our formulation of the relationship between implicit attention capture and visual awareness. In our approach, other aspects of the perceptual cycle framework are more central, and they too are supported by extant data. For example, the perceptual cycle distinguishes between an orienting response and the more extended processing necessary for subjective awareness, and existing evidence supports a distinction between transient and sustained components of attention. These two components are associated with reflexive and voluntary attention shifts, respectively (e.g., Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989). That is, transient shifts of attention can be relatively automatic, but sustained shifts are more open to the influence of strategic processes. Components of attention associated with transient and sustained shifts might have different consequences for visual perception (e.g., Briand & Klein, 1987).

The perceptual cycle framework also suggests that preconsciously processed information may guide attention, a notion supported by the phenomena of *priming of pop out* (Maljkovic & Nakayama, 1994, 1996, 2000) and *contextual cuing* (e.g., Chun, 2000; Chun & Jiang, 1998; Olson & Chun, 2001). Priming of pop out is revealed in series of visual search trials in which the likelihood of the target identity changing from trial to trial is varied. When two trials contain targets with similar attributes, visual search for the second is facilitated even when the trials are separated by several intervening ones. Contextual cuing is also revealed through a series of visual search trials; here, various aspects of the distractors (e.g., their spatial layout in the display) vary, and facilitation occurs when a target appears in an array with a repeated context. Such facilitation occurs even when participants fail to notice the repetition of arrays and fail to identify in a forced choice the patterns they had previously seen. Both phenomena demonstrate a role for implicit memory mechanisms in helping guide attention independent of the observer's explicit search strategies (see Chun & Nakayama, 2000).

In summary, the original perceptual cycle framework proposed that objects are consciously perceived only if they are incorporated into a cyclical interaction among bottom-up sensory information, top-down interpretations of this information, and strategic deployments of attention based on these preconscious interpretations. Although it is possible to identify mechanisms in the literature that might be integral to such a cycle, Neisser's (1976) original formulation did not specify the factors that allow an unexpected object to become incorporated into the process in the first place.

Nevertheless, the perceptual cycle framework serves as a useful inspiration for the formulation of a more specific and detailed model because its strength lies in its treatment of a potentially deadlocked issue in the attention literature: the degree to which the allocation of attention is stimulus-driven or strategically determined (e.g., Folk et al., 1992; Theeuwes, 1992). Proponents of the notion that attention can be captured automatically might argue that certain stimuli will become incorporated into visual awareness through brute force, via the power of their inherent properties. In this case, attentional set should play little to no role in determining awareness. In contrast, those favoring the primacy of top-down constraints might argue that only stimuli consistent with expectations will reach awareness. By treating the allocation of attention as an extended, multistage process, the perceptual cycle framework provides guidance for how these perspectives can work in tandem. Our own approach follows this example. We root our approach in the distinction between implicit attention capture and the capture of awareness (e.g., Simons, 2000), and we argue that attentional set functions as the critical link between them. In the following section, we outline this view.

Reframing the Perceptual Cycle Framework: A Linchpin Account of Attentional Set

The vagueness of Neisser's (1976) original formulation, and the degree to which it accommodates a range of phenomena, prompts justifiable questions regarding its falsifiability. Although the perceptual cycle notion presaged later distinctions between different types of attention shifts, it was less successful in describing how and why different types of attention shifts do or do not give rise to awareness. Our reformulation of the perceptual cycle framework synthesizes work on implicit attention capture and inattentional blindness with the goal of making specific predictions about the conditions likely to lead to the noticing of unexpected objects.

The initial model suggests that the process begins with a transient orienting response, which—although not sufficient for registering a stimulus in awareness—can lead to the allocation of further attentional processing. For our purposes, this transient orienting response can be linked to the type of attention shift measured in implicit attention capture studies. This link is strengthened by findings that automatic shifts of attention are themselves of a transient nature (Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989) and can be dissociated from visual awareness (e.g., McCormick, 1997).

Given the distinction between transient and sustained attention as well as the possibility that the latter is required for awareness of an unexpected object, the question naturally arises as to what determines whether a transient shift is followed by sustained allocation of attention. Neisser (1976) proposed that a person's own expectations of what belongs in a scene, influenced by the relatively sparse information gleaned through a transient shift, determine how sustained attention is directed. Less broadly, we propose that the linchpin connecting transient and sustained attention shifts is an attentional set. If a new stimulus induces a transient, implicit shift of attention while a person is actively attending to the properties of another stimulus or searching for a particular property in a display, then the degree to which the properties of the new stimulus match those of the target stimuli determines whether it becomes the focus of sustained attention. If the properties do not match, then attentional processing will likely end after the transient shift. If the properties do match, however, then more sustained attentional processing follows the transient shift. The closer the match, the more likely it is that the new object will become the object of sustained attention, eventually leading to conscious awareness.

The feasibility of this relationship is bolstered by evidence that sustained shifts of attention are typically associated with a fair degree of strategic control (e.g., Nakayama & Mackeben, 1989). We have already described evidence for a role of attentional set in implicit attention capture, in which stimuli are more likely to capture attention if they are similar to a person's actual target (e.g., Folk et al., 1992). Because the additional processing required to bring a stimulus to awareness would seem to leave open more opportunity for influence by top-down processes, we expect the role of attentional set in awareness to be even more profound than in implicit attention capture.

Unexpected stimuli containing properties found to capture attention implicitly might be more likely than other stimuli to spark the processing required for noticing. Such stimuli may enjoy some benefit in becoming noticed, even given the power of attentional sets, because people are unlikely to sustain attentional sets in perfect, unwavering form for extended periods. However, because transient shifts of attention do not always lead to subsequent sustained attention, the properties robustly found to capture attention implicitly will not be as effective at capturing subjective awareness. Instead, one's attentional set will be the dominating determinant of visual awareness. This should be especially apparent in experimental situations in which attentional set is carefully controlled (e.g., Most et al., 2001; Simons & Chabris, 1999). Stated succinctly, unexpected objects containing the kinds of features found to capture attention implicitly might more likely be noticed than other unexpected objects, but the influence of such features should pale in comparison to the influence of attentional set.

In summary, our account of the relationship between implicit attention capture and awareness provides several testable predictions: (a) Sustained shifts of attention are critical for a person to become aware of an unexpected object—transient shifts (typically measured in implicit attention capture studies) are not sufficient; (b) an unexpected object will become the focus of sustained attention only after it has induced a transient shift; (c) when engaged in an attention-demanding task, a person's attentional set is one of the most important factors determining whether a transient attention shift leads to the sustained deployment of attention and ultimately awareness; and (d) although implicit indices of attention capture are not always accompanied by awareness, evidence for the conscious detection of an unexpected object should always be accompanied by evidence of implicit attention capture.

Experimental Support

Twenty-five years ago, Neisser (1979) wrote, "we do not know what preattentively noted fragments of information lead to noticing . . . . We do not know what a perceiver must bring to a situation if he or she is to notice what another equally skilled perceiver would overlook" (p. 218). Despite the intervening decades, these sentiments are still applicable today. In the following sections, we begin to remedy this situation by putting some of the predictions of our theoretical framework to the empirical test. Whereas our previous research validated the current sustained inattentional blindness paradigm—demonstrating its usefulness in exploring the roles of unique features, luminance similarity, and distance—here we systematically begin to explore the relative contributions of bottom-up and top-down factors to the capture of awareness. In Experiments 1–3 we explore the contribution of attentional set. Our earlier finding of a luminance similarity effect (Most et al., 2001) could reflect something about a privileged place of luminance in visual processing (e.g., Marr, 1982). However, it is also possible that variations in luminance made a large difference because luminance happened to be the dimension along which participants could differentiate the attended and ignored items. That is, perhaps participants were able to establish an attentional set allowing for some kinds of features to draw processing resources while filtering others out. This attentional set could be based on whatever feature dimensions are critical to an attentionally demanding task.

Although we noted that reflexive orienting to a stimulus does not necessarily lead to conscious awareness of the stimulus, it is possible that such transient shifts trigger the start of more sustained processing, which in turn leads to conscious awareness. Therefore, in searching for bottom-up factors that increase the chances of detection, it seems logical to begin with those properties that have been shown to draw attention implicitly. In Experiment 4, we test the effect of salience on noticing by manipulating the unexpected object along a dimension orthogonal to the one distinguishing the attended from the ignored sets of items. In addition, we demonstrate the usefulness of this paradigm for investigating the role of sudden onsets in capturing awareness. Because sudden onsets have a robust effect on implicit measures of attention capture (e.g., Yantis & Jonides, 1984), in Experiments 5–7 we investigate the possibility that stimuli with sudden onsets may be noticed most of the time. Finally, in Experiment 8, we begin to explore a potential relationship between implicit and explicit forms of capture by examining participants' performance on the primary counting task both when they do and when they do not notice the unexpected object. If counting performance in the primary task is affected by the presence of the unexpected object even when the object goes unnoticed, this could be taken as an index of implicit attention capture. In summary, our aim is to begin to apply a systematic exploration, characteristic of the implicit attention capture work, to the capture of awareness.

General Method

Except where noted, all experiments used variants of the same basic sustained inattentional blindness paradigm.

Materials and Procedure

Stimuli were presented on a Macintosh G3 PowerBook with a 14.1-in. (35.8-cm) active matrix display, with custom software written with the VisionShell C libraries (Comtois, 2002). Observers sat at a comfortable distance from the display (on average, approximately 35 cm), and head position was not fixed. Except in Experiment 3, all of the events on each trial took place against a gray 13.4- × 17.8-cm display window (luminance = 32.1 cd/m^2) with a small blue fixation point located at its center. In Experiment 3, the background was white (luminance = 88.0 cd/m^2) instead of gray. (Note that luminance values are approximate and vary with the orientation of the monitor relative to the viewer.) Within this window, eight items moved independently on haphazard paths at variable rates. Four of the items were designated as target items, and four were designated as distractor items. The featural differences between these two sets varied as a function of the experimental condition (e.g., the target and distractor sets might differ from each other in shape or in luminance). As they moved, each item periodically bounced off the edges of the display window. Each trial lasted for a total of 15 s, and each observer completed five trials.

Observers were instructed to fixate on the central point and keep a silent tally of the total number of times that the designated target items bounced off the edges of the display window during each trial. Following each trial, observers indicated the number of bounces they had counted by typing a number in response to a computer prompt.

Except for Experiment 8, which was run as a control condition, the sequence of trials was modeled after previous inattentional blindness experiments (Mack & Rock, 1998; Most et al., 2000, 2001). The first two trials contained no unexpected event. Five seconds into the third trial (the *critical* trial), an additional item unexpectedly entered the display from the right, moved on a horizontal linear path across the center of the screen, passed behind the fixation point, and exited the left side of the display. During this trial, the additional item was visible for 5 s. Because observers were not forewarned about this event, its occurrence was unanticipated.

After the critical trial, observers responded to questions probing whether they had seen anything in the display that had not been there before. Depending on the experiment, the questions appeared either in a five-item booklet, on a two-item questionnaire, or as two interactive prompts on the computer screen (see the Appendix for the printed five- and two-item sequences; the interactive computer prompts are described in Experiment 2). In all cases, the observers were asked to report the details of whatever unexpected object they had seen. Observers then completed a fourth trial on which the additional item again appeared. Although they were not explicitly told to look for the additional item, the probes after the previous trial had alerted them to the possibility that an additional object might appear. Therefore, this trial tested perception under *divided-attention* conditions. After completing this trial, observers responded to the same probes as in the previous trial.

On the fifth trial, observers were told, "On this trial, the instructions are slightly different. As before, keep your eyes fixated on the fixation point, but this time don't count the bounces any of the shapes make. Simply watch the display." Because observers did not have to count bounces, they could devote full attention to the formerly unexpected object. After this *full-attention* trial, they responded to probes identical to those after the critical and divided-attention trials. We used this trial as a control to ensure that they could understand and follow task instructions (see also Mack & Rock, 1998). Accordingly, observers who failed to report seeing the now-expected additional object on this trial were replaced, and their data were excluded from the analyses.

After completing all five trials, observers answered follow-up questions designed to gather demographic information and to determine if they had been familiar with this or other related experiments (e.g., Becklen & Cervone, 1983; Most et al., 2001; Simons & Chabris, 1999). If they spontaneously mentioned experiments from the selective-looking or inattentional blindness literatures prior to debriefing, they were considered to be familiar with the paradigm, and their data were excluded from the analyses (because we wanted observers to have no prior expectation that another object might appear). Participating in the experiment took 5–10 min, and observers were debriefed afterward.

Data Analyses

The measure of primary interest was whether participants were aware of the unexpected object on the critical trial. We coded a participant as having seen the object if they responded "yes" when asked whether they had noticed anything other than the original target and distractor items and if they were able to report at least one accurate detail, such as its shape, color, direction of motion, or that something had exited the display. Most participants who responded affirmatively were able to report at least one accurate detail. We refer to participants who saw the unexpected object on the critical trial as *noticers*. Those who failed to see it on the critical trial we refer to as *nonnoticers*. Reported noticing rates are rounded to the nearest whole percentage point.

Throughout the experiments, we also kept track of the accuracy with which participants were able to count the number of bounces made by the target items. Thus, for each participant, we calculated a weighted error index for each trial: We took the absolute value of the difference between the actual number of target bounces and the reported number and divided this difference by the number of actual target bounces. The higher this number, the less accurate a participant was on a given trial. The error index record allowed us to ensure that noticers and nonnoticers did not differ from each other in the degree of attentional effort devoted to the task, as indexed by their accuracy on the second, precritical trial. The error index also allowed us to gauge the effect of the unexpected appearance of an additional object on attentional performance in the primary counting task, both when participants did and when participants did not see it. Error indices pertaining to such possible effects are presented and addressed in Experiment 8. We report the error indices as percentages and round them to the nearest whole percentage point. All *t* tests conducted throughout the experiments are two-tailed.

Experiment 1: Attentional Sets for Shape and Luminance

Previous experiments showed that when people attended to black items and ignored white items, they were likely to notice an additional, unexpected black item and were likely to miss seeing an additional, unexpected white item. When they were attending to white items instead of black items, these results were reversed (Most et al., 2001). If these findings reflect a general, flexible ability to filter information on the basis of attentional set, then we should find the same pattern when observers distinguish between attended and ignored objects along a different dimension, such as shape. Alternatively, if this effect is specific to the luminance dimension, then we should see no attentional set effect when the target and distractor items are distinguished from each other on the basis of shape. This alternative is plausible, given the important role of luminance in scene perception (e.g., Marr, 1982). In the current experiment, all the items in the display, including the unexpected object, were identical between conditions. The only manipulated variable was which subset of items observers attended to. Thus, we specifically explored the effect of attentional set on awareness of an unexpected object.

Method

Participants. Eighty-five observers were tested in exchange for candy. Data from 20 observers were dropped because of prior knowledge of similar experiments ($n = 7$) or failure to report the unexpected object in the final control trial ($n = 13$). The remaining 65 participants (37 men, 28 women; mean age = 20.1 years) were distributed across the four experimental conditions (described in the next section).

Materials and procedure. In the gray rectangular background, four black items (luminance = 1.2 cd/m^2) and four white items (luminance = 88.0 cd/m^2) all moved independently on haphazard paths. The items in the display consisted of two black squares, two black circles, two white squares, and two white circles, and thus the display items could be parsed into two groups on the basis of either luminance or shape (e.g., black vs. white or squares vs. circles). Each shape had a height and width of 1 cm. Participants were placed in one of four conditions, defined by their primary task for the duration of the experiment: (a) Count the number of bounces made by all the black shapes (both circles and squares); (b) count the number of bounces made by all the white shapes (both circles and squares); (c) count the number of bounces made by all the circles (both black and white); or (d) count the number of bounces made by all the squares (both black and white). On the critical trial (and subsequent trials), the unexpected object was an additional black circle. Note that the display items were identical across all conditions. Only the participants' understanding of what constituted the target set was manipulated. After each critical trial, divided-attention trial, and full-attention trial, participants' awareness of the unexpected circle was probed with a two-item questionnaire (see the Appendix).

Results

Results demonstrated a clear effect of attentional set on the subjective awareness of an unexpected object, and this effect generalized to instances in which the attentional set was based on shape as well as luminance. Replicating our earlier findings (Most et al., 2001), participants who attended to the subset of black shapes were likely to notice the additional black circle on the critical trial (88% noticing). In contrast, nobody who attended to the white shapes reported noticing the unexpected black circle. Similarly, participants who attended to the subset of circles (both black and white) were likely to see the additional black circle (81% noticing), whereas those who attended to the subset of squares (both black and white) were unlikely to notice it (6% noticing; see Figure 5 and Table 1). These differences in noticing rate were reliable for observers attending on the basis of luminance, $\chi^2(1, N = 32) = 24.36$, $p < .001$, and for those attending on the basis of shape, $\chi^2(1, N = 33) = 19.19$, $p < .001$. Strikingly, this pattern of results remained consistent on the divided-attention trial as well, for observers attending both according to luminance, $\chi^2(1, N = 32) = 18.29$, $p < .001$, and according to shape, $\chi^2(1, N = 33) = 22.11$, $p < .001$ (see Table 1).[1] This is informative, as it demonstrates a strong role for attentional set even with heightened expectations.

Because of experimenter error, counting accuracy in the primary counting task was not available when observers attended to the circles, so we did not compare accuracy between the conditions in which observers attended on the basis of shape. However, across the attend-black and attend-white conditions there was no significant difference in accuracy during the second, precritical trial between noticers and nonnoticers (mean error for noticers = 10%, $SD = 10\%$; mean error for nonnoticers = 14%, $SD = 8\%$), $t(30) = 1.22$, $p = .231$. Thus, differences in noticing rate on the critical trial were not likely due to different levels of initial attentional investment in the primary task.

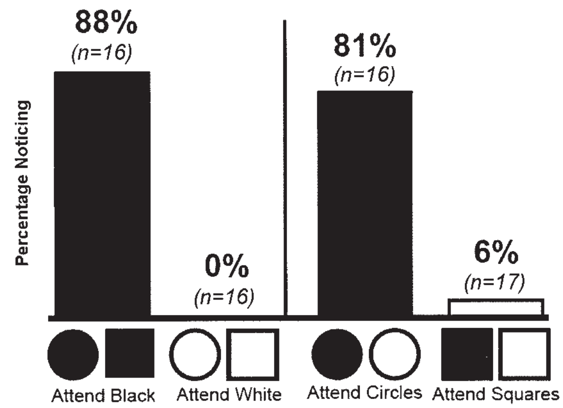

Figure 5. The effect of attentional set on the critical trial in Experiment 1. The unexpected object was always an additional black circle. When participants were attending to black shapes or to circles, almost all of them noticed the unexpected black circle. When they were attending to white shapes or to squares, nearly all of them failed to notice it.

Discussion

Earlier findings had shown that similarity in the luminance of an unexpected object to the luminance of attended and ignored items had greatly affected the likelihood that people would notice the unexpected object (Most et al., 2001). Here, the similarity effect was not limited to the luminance dimension. Instead, when the attended items were distinguished from ignored ones on the basis of shape, then shape was the dimension that affected noticing. These results suggest that when observers are engaged in a challenging task that requires selective processing, they establish an attentional set on the basis of the dimension critical to proper selection. When an unexpected object matches the preset characteristics of the attentional set, then a person is likely to notice it. However, when it does not match the attentional set, detection is unlikely.

One confound in the present study stems from the fact that, other than its trajectory of motion, the unexpected object was identical to some items already in the display. It is not clear whether those who failed to report it actually failed to process it to a conscious level or whether they did notice it but then disregarded it, assuming it was merely one of the to-be-ignored items present from the start of the trial. Note that when observers are tracking a set of four items,

[1] In both the attend-squares and attend-black conditions, 1 person who had seen the unexpected object on the critical trial failed to see it on the divided-attention trial.

Table 1
Percentage of Observers in Experiments 1–7 Who Noticed the Unexpected Object in the Critical and Divided-Attention Trials

Unexpected object	Attended set	n	Trial type: Critical	Trial type: Divided attention
	Experiment 1			
Black circle	White shapes	16	0	19
	Black shapes	16	88	94
	Squares	17	6	12
	Circles	16	81	94
	Experiment 2			
Gray circle	Squares	14	7	21
	Circles	14	86	100
	Experiment 3			
Caucasian face	Caucasian	25	68	96
	African American	25	40	80
African American face	Caucasian	25	56	88
	African American	27	81	93
	Experiment 4			
White triangle	Black circles (ignore black squares)	22	68	77
Black triangle		21	38	43
	Experiment 5			
Gradual onset gray	Black shapes	22	36	73
Sudden onset gray		22	41	77
	Experiment 6			
Gradual onset black	White shapes	22	23	77
Sudden onset black		23	43	48
	Experiment 7			
Gradual onset black	Circles	21	67	76
Sudden onset black		22	50	64

they can generally keep track of the location of each target item (Pylyshyn & Storm, 1988), and this has also been demonstrated for the very same motion algorithm used in our study (Scholl, Pylyshyn, & Feldman, 2001). Therefore, if an observer is tracking circles and another circle unexpectedly appears, the observer might see it and recognize it as not being one of the target circles. However, if the observer is tracking squares and an unexpected circle appears, the observer might notice it but, having not kept track of where the other circles are, might not realize that this one is new. This scenario paints a very different picture than one in which the observer is inattentionally blind to the new object. This had not been a problem in the previous experiments demonstrating a role for luminance similarity (Most et al., 2001, Experiment 1) because the unexpected object had always been unique in shape, thereby minimizing the likelihood that it would be mistaken for one of the distractors. In Experiment 2, we seek to replicate the effect of shape similarity while ensuring that the unexpected object contains a feature making it unique in the display.

Experiment 2: Attentional Set for Shape Despite Featural Uniqueness

Method

Participants. Thirty-eight observers were tested in exchange for candy. Data from 10 observers were dropped because of prior knowledge of similar experiments (n = 8) or failure to notice the unexpected object on the final control trial (n = 2). The remaining 28 participants (16 men, 12 women; mean age = 20.0 years) were distributed across the two experimental conditions (described in the next section).

Materials and procedure. The materials and procedure were identical to those in Experiment 1, with three exceptions. First, the unexpected circle was gray (luminance = 19.2 cd/m^2) instead of black. This ensured that it was distinct from the other items in the display and, if seen, would not be mistaken for one of the circles that had been present at the start of the trial. Second, participants were placed in one of only two conditions: Either they counted the number of bounces made by the black and white circles, or they counted the bounces made by the black and white squares. Third, after the critical, divided-attention, and full-attention trials, participants answered questions in response to a computer prompt (instead of a printed questionnaire). The first question asked them, “On the last trial, did you see anything that had not been present during the original two trials (e.g., other than the black and white circles and squares)? Press ‘y’ if yes, ‘n’ for no.” If participants indicated that they had not seen anything different, no further questions were asked, and the next trial commenced. If participants indicated that they had seen something different, they were then instructed, “We would now like you to briefly describe the additional item that you saw on the previous trial.”

Results and Discussion

As in Experiment 1, we found a strong effect of attentional set based on shape. Of the observers attending to the circles, 86% noticed the unexpected gray circle, but only 7% (1 observer) who attended to the squares noticed it, $\chi^2(1, N = 28) = 17.37, p < .001$ (see Table 1). This pattern carried over to the divided-attention trial as well, with those attending to circles more likely to notice than those attending to squares, $\chi^2(1, N = 28) = 18.10, p < .001$ (see Table 1).

Counting accuracy on the precritical trial was no different for noticers and nonnoticers (mean error for noticers = 16%, SD = 11%; mean error for nonnoticers = 16%, SD = 13%). Thus, differences in noticing rate on the critical trial were not likely due to different levels of initial attentional investment in the primary task.

Together with the results from Experiment 1, the current results indicate that people are able to establish attentional sets on the basis of shape as well as luminance, and they support the notion that attentional sets may be established on the basis of a number of different dimensions. Such attentional sets strongly mediate the kinds of unexpected objects and events that reach awareness, a finding that is analogous to the role of attentional sets in influencing implicit attention capture (Folk et al., 1992). This experiment also helps rule out the possibility that participants in Experiment 1 had actually seen the additional, unexpected circle but had mistaken it as belonging to the ignored set in the display.

Experiment 3: Attentional Set for Complex Features

Experiments 1 and 2, together with previous findings (Most et al., 2001), demonstrate that people can establish attentional sets on the basis of simple features—luminance and shape—by which only certain aspects of the environment gain admittance into subjective awareness. Beyond the purposeful attending to or ignoring of visual stimuli that one is already aware of, such preset attentional parameters also influence the likelihood that someone will notice a completely new and unexpected object. But how applicable is this finding to everyday life? There are occasions when people distinguish between objects in the world on the basis of simple features; when a person looks for a black and white speed limit sign while driving, he or she might fail to notice an unexpected red stop sign. However, most of the people, animals, and objects in the world consist of more than uniform, simple visual features. For example, faces are not distinguished from each other merely on the basis of color or luminance; they also differ in their unique arrangements of surfaces, shadows, protrusions, and internal features. Can people establish attentional sets that influence awareness of unexpected objects on the basis of complex arrangements of features? We tested this question by increasing the visual complexity of the target, distractor, and unexpected objects in the selective counting task. Each item was either a grayscale African American face or a grayscale Caucasian face, equated with each other for overall mean luminance, hairline, and external shape (see Figure 6). Evidence suggests that race may be encoded as a single feature dimension, even if only internal facial features are available (Levin, 1996, 2000).

Method

Participants. One hundred and eleven Caucasian observers were tested in exchange for candy. Data from 9 observers were dropped because of prior knowledge of similar experiments ($n = 6$), unusual visual impairment ($n = 1$), or failure to report awareness on the final trial ($n = 2$). The remaining 102 participants (59 men, 43 women; mean age = 19.5 years)[2] were distributed across the four experimental conditions (described in the next section).

Materials and procedure. Four identical African American male faces and four identical Caucasian male faces moved on haphazard paths across a white background (luminance = 88.0 cm/m^2), bouncing off the display edges in the same manner as stimuli in the previous two experiments. Each face was about 1.3 × 1.8 cm and was a computer-morphed average of 16 same-race exemplars, balanced for mean luminance, contrast, hairline, size, and external shape (Levin, 2000).[3] Thus, only the internal arrangement of facial features could be used to distinguish between the two sets. Depending on the condition, the unexpected object was either an identical, additional African American face or an identical, additional Caucasian face. The four experimental conditions consisted of a 2 (attend Caucasian, attend African American) × 2 (unexpected Caucasian face, unexpected African American face) design. Awareness of the unexpected face was probed using a two-item printed questionnaire (see the Appendix).

Figure 6. The African American face and Caucasian face used in Experiment 3. Each face is a computer-morphed average of 16 same-race exemplars, and they are balanced with each other for mean luminance, hairline, contrast, size, and external shape. These stimuli were created and provided by Daniel T. Levin (Levin, 1996; Levin, 2000). Adapted from "Race as a Visual Feature: Using Visual Search and Perceptual Discrimination Tasks to Understand Face Categories and the Cross-Race Recognition Deficit," by D. T. Levin, 2000, *Journal of Experimental Psychology: General, 129,* p. 562. Copyright 2000 by the American Psychological Association.

Results and Discussion

As in Experiments 1 and 2, the induced attentional set had a substantial impact on the likelihood of noticing the unexpected face. More people noticed the additional Caucasian face when they were attending to Caucasian faces (68%) than when they were attending to African American faces (40%), $\chi^2(1, N = 50) = 3.95$, $p = .047$. This result was reversed for the unexpected African American face, with more people noticing it when attending to African American faces (81%) than when attending to Caucasian faces (56%), $\chi^2(1, N = 52) = 3.96$, $p = .047$ (see Figure 7 and Table 1). The pattern of results in the divided-attention trial followed the same trend but was nonsignificant for both the unexpected Caucasian face (Fisher exact test = .084) and the unexpected African American face, $\chi^2(1, N = 52) = 0.32$, $p = .575$ (see Table 1). It is interesting that although the effect of attentional set in this experiment is consistent with those in Experiments 1 and 2, the size of the effect is noticeably smaller. One potential explanation is that as a critical stimulus and the items surrounding it become more complex, more processing is required before a person can compare the critical stimulus to his or her own attentional set. Because such a comparison takes place later in the stream of processing, there is less subsequent processing prior to awareness that can potentially be affected by the person's attentional set. On another note, it is also interesting that overall, more participants noticed the unexpected African American face on the critical trial (69%) than the Caucasian face (54%), although this difference was not statistically significant, $\chi^2(1, N = 102) = 2.50$, $p = .114$. This trend is consistent with findings that people are typically faster to locate a cross-race face among same-race ones than vice versa; it has been suggested that race may be processed

[2] Three participants neglected to report their age.

[3] We thank Daniel Levin, the creator of these stimuli (e.g., Levin, 1996, 2000), for his permission to use them.

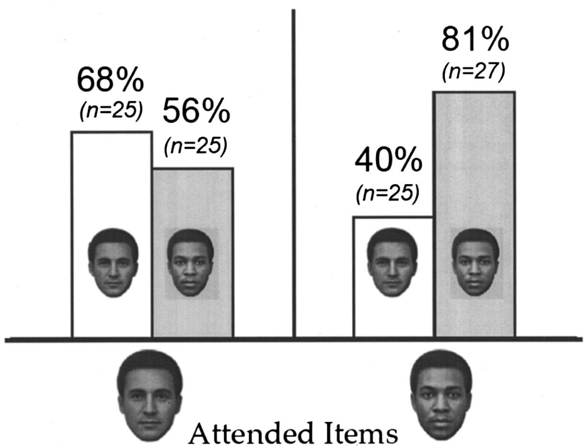

Figure 7. Effect of attentional set to complex features on the critical trial in Experiment 3. More people noticed the unexpected African American face when attending to other African American faces than when attending to Caucasian faces. More people noticed the unexpected Caucasian face when attending to other Caucasian faces than when attending to African American faces.

as more of a feature for cross-race than same-race faces (Levin, 2000).

Across the four conditions, there was no significant difference in counting accuracy in the precritical trial between noticers and nonnoticers (mean error for noticers = 26%, SD = 15%; mean error for nonnoticers = 24%, SD = 19%), $t(99) = 0.71$, $p = .447$; so, differences in noticing rate on the critical trial were not likely due to different levels of initial attentional investment in the primary task.

The results of this experiment support the notion that people can establish effective attentional sets on the basis of more than simple features. The two sets of faces in the display differed from each other only in their internal facial structures; yet, observers appeared capable of filtering visual information on the basis of this relatively complex visual information. Although the additional face in each condition conspicuously entered and exited the display, remained visible for 5 s, traveled on a unique path of motion, and crossed over a point of fixation, these attributes did not guarantee conscious detection. It is interesting to note that as stimuli become more complex, it becomes more difficult to argue that they are processed preattentively. The fact that attentional set wielded influence even when stimuli represented complex arrangements of features supports notions that the unexpected stimuli in this paradigm receive some degree of attentional processing.

The possibility that people can filter unexpected information on the basis of complex arrangements of features holds important implications for everyday life, but there are alternative interpretations for the pattern of results in this experiment. For example, rather than establishing an attentional set on the basis of complex features, participants might have selected information for awareness on the basis of category membership. That is, rather than selectively processing information on the basis of visual similarity, noticing may have been influenced by whether the unexpected face could be placed into one racial category or another. Alternatively, observers may have used one particular feature to differentiate the two groups of faces. For example, although the hairlines, luminances, and external shapes of the two sets of faces were equated, observers could still rely on individual parts of the faces, such as the nose or eyebrows, to discriminate the sets. However, this strategy would require more focused, rather than diffuse, attention. A third alternative is that observers might have seen the additional face in all conditions, but when it was the same as the distractor faces, they did not realize that the unexpected shape was new to the display. As with the confound in Experiment 1, observers might have known where all their target shapes were during the trial, so when an additional face identical to the targets appeared, they realized it was not one they had been tracking before. However, when a new face identical to the distractors appeared, there was no basis for judging whether it was one of the distractors that had been there all along. Despite these alternatives, attentional set influenced the likelihood that observers could report the presence of a new object. Thus, the results extend the potential implications of attentional set to detection of more complex stimuli.

Experiment 4: A Bottom-Up Role for Stimulus Salience

In the previous experiments (and in earlier ones; Most et al., 2001), variations along the dimension critical to distinguishing between the attended and ignored items played a large role in determining awareness. However, the unexpected objects were often unique on dimensions unrelated to the critical dimension. For example, when observers were selectively attending on the basis of grayscale luminance, the unexpected objects sometimes contained a unique color or shape (Most et al., 2000, 2001). Despite their uniqueness, these properties did not cause the items to pop into awareness; it was the item's consistency with the observers' attentional set that seemed to influence awareness. Thus, one open question is whether variations along a dimension irrelevant to the attentional set can affect noticing at all. That is, can some bottom-up properties force their way into subjective awareness regardless of a person's attentional set? On the basis of the earlier results, we could reasonably predict that irrelevant variations should not affect noticing. However, this would be inconsistent with suggestions derived from implicit attention capture research that property salience is a factor in capturing attention (e.g., Theeuwes, 1992). To the degree that salient stimuli capture attention implicitly, we predict that such stimuli will have an increased chance of being noticed. However, the benefit to noticing derived from such bottom-up properties should not be as profound as those conferred when a stimulus matches a person's attentional set. In Experiment 4, we directly examine the effect of variations along a noncritical dimension, which nonetheless alter the salience of the unexpected object.

Method

Participants. Fifty observers were tested in exchange for candy. Data from 7 observers were dropped because of prior knowledge of similar experiments (n = 6) or failure to report awareness on final trial (n = 1). The remaining 43 participants (18 men, 25 women; mean age = 21.8 years) were distributed across the two experimental conditions (described in the next section).

Materials and procedure. The materials and procedure were identical to those for Experiment 1, with two exceptions. First, all the target and distractor items were black, distinguished from each other solely on the basis of shape. Four black squares and four black circles moved through the display, and participants counted the number of bounces made by the circles. Second, the nature of the unexpected object was different. In one condition the unexpected object was a black triangle (luminance = 1.2 cd/m^2), and in the other condition it was a white triangle (luminance = 88.0 cd/m^2). Thus, the unexpected item was always the same shape (the critical dimension) but was either identical in luminance to all other items in the display or was unique in luminance (see Figure 8). Awareness of the unexpected object was probed using a two-item printed questionnaire (see the Appendix).

If variations only along the critical dimension affect the likelihood of noticing, then there should be no difference in noticing between the two types of unexpected objects. Alternatively, if salience or distinctiveness in the display plays a role independent of attentional set, then the white triangle should be noticed more. A third possibility is that because participants are more likely to notice objects similar to the attended objects, more people should notice the black triangle.

Results and Discussion

Variations along an irrelevant dimension did affect noticing. When the unexpected triangle was black, 38% of the observers noticed it. However, when it was white, 68% noticed it, $\chi^2(1, N = 43) = 3.90$, $p = .048$. This pattern of results remained consistent for the divided attention trial, with 43% noticing the black triangle and 77% noticing the white triangle, $\chi^2(1, N = 43) = 5.32$, $p = .021$. It is interesting to note that of the people who had seen the unexpected item on the critical trial, 1 person in the white triangle condition and 5 people in the black triangle failed to see it in the divided-attention trial. Across both conditions, counting accuracy was no different for noticers and nonnoticers in the precritical trial (mean error for noticers = 16%, *SD* = 12%; mean error for nonnoticers = 16%, *SD* = 13%).

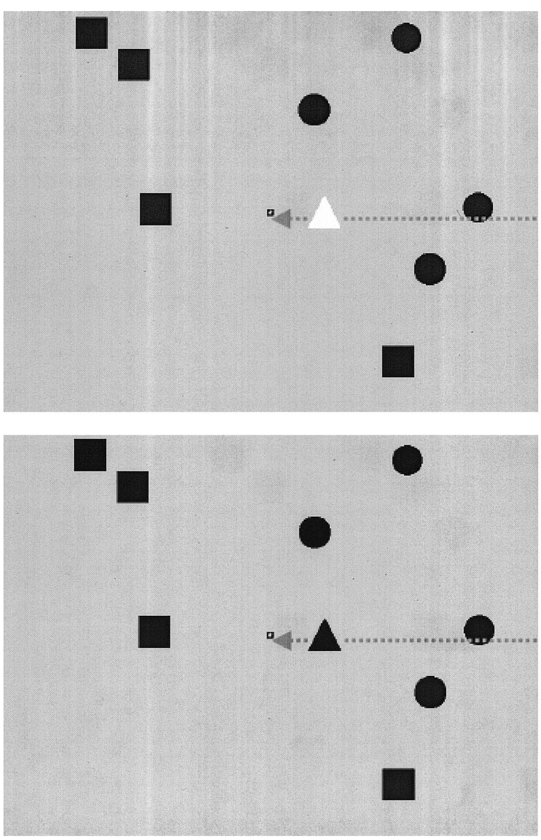

Figure 8. Schematic diagrams of critical trial from the two conditions in Experiment 4. Note that the attended items are distinguished from distractor items only on the basis of shape (squares vs. circles). Between the two conditions, the unexpected triangle differs only in luminance (black vs. white), which is presumably a dimension orthogonal to the participants' attentional set. The white triangle was noticed by 68% of participants, whereas the black triangle was noticed by 38%. Thus, variations along task-irrelevant dimensions do affect noticing.

Experiments 1–3 demonstrated that attentional sets could wield considerable power over the likelihood that observers would notice an unexpected moving object. The difference in noticing rate ranged from 0% to nearly 90% depending on whether the unexpected object's properties matched those of the attended items or those of the distractor items. Furthermore, the magnitude of the effect of shape-based attentional set was almost identical in Experiments 1 and 2, although the unexpected object was more distinctive in the latter experiment. Although attentional sets play a strong role in detecting unexpected stimuli, evidence from the implicit attention capture literature suggests that particularly salient stimulus properties might be noticed more often than nonsalient ones, regardless of attentional set (e.g., Theeuwes, 1992). Indeed, in the current experiment, we found that variations along an irrelevant dimension do wield some influence over detection: More people noticed the salient and distinctive white triangle than noticed the black triangle. Still, it is striking that the noticing rate for the white triangle wasn't higher. Although salience appears to increase the likelihood of detection, it does not seem to match the power of attentional set in influencing detection.

Experiments 5–7: An Especially Powerful Role for Sudden Onsets?

Results from Experiment 4 indicate that salient irrelevant features do affect the probability of noticing an unexpected object and, hence, that certain environmental cues are more likely than others to enter awareness. This is consistent with the notion that stimulus-based properties can draw automatic shifts of attention. Even if such shifts are not sufficient in themselves for awareness to occur, they might trigger chains of processes that do lead to awareness. Among the properties that have been shown to draw attention automatically within the implicit attention capture literature, sudden onsets seem to do so most robustly (e.g., Jonides & Yantis, 1988; Yantis & Jonides, 1984). On the basis of the implicit attention capture results alone, one might predict that suddenly onsetting stimuli will be noticed by most participants. In the following experiments, we test this prediction by having the unexpected objects appear suddenly in the display, rather than emerging via gradual disocclusion from one of the display's edges.

Experiment 5: Sudden Onsets

Method

Participants. Fifty-four observers were tested in exchange for candy. Data from 10 observers were dropped because of prior knowledge of similar experiments (n = 6), failure to complete the experiment (n = 1), tracking of the wrong set of shapes (n = 2), and accidental viewing of a final forced-choice question[4] prior to answering the open-ended questions (n = 1). The remaining 44 participants (31 men, 13 women; mean age = 21.8 years) were distributed across the two experimental conditions (described in the next section).

Materials and procedure. The materials and procedure for this experiment were almost identical to those of Experiment 1. Four black circles and squares and four white circles and squares moved on haphazard paths within the display, and participants were instructed to count the number of bounces made by the black shapes. On the critical trial, an unexpected gray cross (luminance = 49.3 cd/m^2) appeared and traveled across the display. The two experimental conditions varied only in the manner in which the cross first entered the display. In the *gradual onset* condition, the cross emerged gradually from the right edge of the display before traveling on a horizontal path and exiting the left side of the display. In the *sudden onset* condition, the cross appeared abruptly, its center 7.4 cm away from the fixation point and 1.5 cm away from the right edge of the display. As in the gradual onset condition, the cross then traveled in a linear, horizontal path and exited the left side of the display.

Results

In contrast to implicit attention capture work showing that abrupt onsets reliably divert attention, the abrupt onset did not increase rates of noticing. When the unexpected gray cross appeared as a sudden onset, only 1 more observer noticed it than when it emerged gradually from the side of the display (41% vs. 36%), $\chi^2(1, N = 44) = 0.10$, $p = .757$ (see Table 1). In the divided-attention trial, again only 1 more person saw the cross in the sudden onset condition than in the gradual onset condition (77% vs. 73%), $\chi^2(1, N = 44) = 0.12$, $p = .728$ (see Table 1). Across both conditions, counting accuracy was no different for noticers and nonnoticers in the precritical trial (mean error for noticers = 15%, SD = 11%; mean error for nonnoticers = 16%, SD = 11%).

Experiment 6: High-Contrast Sudden Onsets

Although the sudden onset in Experiment 5 did not lead to greater noticing relative to a gradual onset, the sudden appearance of a gray cross against a gray background might not have produced a large enough transient signal to capture awareness. To explore this possibility, Experiment 6 introduced the sudden onset of a black cross. This larger transient signal better tests the prediction that sudden onsets will capture attention explicitly. In this case, participants attended to the white subset of items. Therefore, the unexpected object simultaneously contained a large onset and was featurally more similar to the ignored set of items than to the attended set of items.

Method

Participants. Forty-nine observers were tested in exchange for candy. Data from 4 observers were dropped because of prior knowledge of similar experiments. The remaining 45 participants (24 men, 21 women; mean age = 21.1 years)[5] were distributed across the two experimental conditions.

Materials and procedure. The materials and procedure were identical to those in Experiment 5, with the exception that the unexpected cross on the third, fourth, and fifth trials was black (luminance = 1.5 cd/m^2) instead of gray.

Results and Discussion

The larger transient signal of the unexpected black cross did seem to influence noticing more than the weaker onset signal of the gray cross. However, the increase in noticing fell short of statistical significance. When the black cross emerged gradually from the side of the display, 23% of the observers reported seeing it; when it onset suddenly in the display, 43% noticed it, $\chi^2(1, N = 45) = 2.18$, $p = .140$ (see Table 1). Although not statistically significant, this relative increase in noticing supports the notion that sudden onsets may provide unexpected stimuli with an advantage in being seen but that they do not guarantee noticing. Oddly, this pattern reversed in the divided-attention trial, with 77% noticing the gradual onset and 48% noticing the sudden onset, $\chi^2(1, N = 45) = 4.15$, $p = .042$ (see Table 1). Five of the participants who had noticed the sudden onset on the critical trial failed to see it on the divided-attention trial. Across both conditions, counting accuracy was no different for noticers and nonnoticers in the precritical trial (mean error for noticers = 16%, SD = 14%; mean error for nonnoticers = 16%, SD = 13%).

At first glance, Experiments 5 and 6 suggest that, consistent with implicit capture research (e.g., Yantis & Jonides, 1984), unexpected objects that appear suddenly might gain attentional priority more than unexpected objects that appear gradually do. Although we found no such effect with the gray cross, the larger transient signal of the black cross led to somewhat higher rates of noticing. Yet, this effect was not large: Over half of the observers failed to notice the black cross with the sudden onset. Indeed, it is striking that participants were less likely to notice the sudden onset than the gradual onset in the divided-attention trials of this experiment. It is possible that the sudden onset would have led to a greater increase in noticing had the black cross not contained features similar to the ignored set (observers attended to white shapes and ignored black shapes). Investigations of this possibility could reveal whether the current findings reflect a weak ability of sudden onsets to draw awareness or, rather, the top-down overriding of an otherwise more powerful ability to draw awareness. Another possibility, given the thus far insignificant effect of sudden onsets, is that when Experiments 5–7 are combined, no evidence will emerge for a benefit of sudden onset in noticing. In Experiment 7, we modify the experiment to eliminate attentional sets against the unexpected black object.

Experiment 7: High-Contrast Sudden Onsets Irrelevant to Attentional Set

The stimuli in this experiment were identical to those in Experiment 6, with the unexpected object a black cross that appeared either suddenly or gradually from the side. The only difference in this experiment is that rather than counting the number of bounces made by white shapes and ignoring black shapes, participants counted the number of bounces made by the black and white circles while ignoring the black and white squares. The purpose of this modification was to eliminate the establishment of task-induced attentional sets against the processing of black shapes.

[4] See the five-item questionnaire in the Appendix.

[5] One participant neglected to report their age.

With no attentional set against black shapes and the relatively large onset signal created by black shape against a gray background, the chances of finding benefits of a sudden onset for noticing should be maximized.

Method

Participants. Forty-eight observers were tested in exchange for candy. Data from 5 observers were dropped because of prior knowledge of similar experiments (n = 3); failure to follow instructions (n = 1); or because the unexpected object onset on top of another black item, thereby eliminating the appearance of an abrupt onset (n = 1). The remaining 43 participants (23 men, 20 women; mean age = 19.8 years) were distributed across the two experimental conditions. Because of experimenter error, 1 participant's counting accuracy data in the divided-attention trial of the gradual onset condition were discarded.

Materials and procedure. The materials and procedure were identical to those in Experiment 6, with the exception that participants attended to the subset of black and white circles rather than the subset of white shapes. Thus, the only difference here was the participants' attentional set.

Results and Discussion

Contrary to our expectations, the transient signal of the unexpected black cross did not lead to increased noticing when participants had no attentional set against black items. Even more unexpectedly, the black cross with the sudden onset was noticed slightly (although not significantly) less than the gradually emerging black cross on the critical trial, $\chi^2(1, N = 43) = 1.23$, $p = .268$ (see Table 1). When the black cross emerged gradually from the side of the display, 67% of the observers reported seeing it on the critical trial. This is consistent with the prediction that more people would see it than in the gradual onset condition in Experiment 6, $\chi^2(1, N = 43) = 8.41$, $p = .004$. However, when it onset suddenly in the display, only 50% noticed it, not much more than the sudden onset condition in Experiment 6, $\chi^2(1, N = 45) = 0.19$, $p = .661$. In the divided-attention condition, too, a greater number of participants noticed the unexpected object in the gradual onset condition (76%) than in the sudden onset condition (64%), though this comparison fell short of statistical significance, $\chi^2(1, \underline{N} = 43) = 0.80$, $p = .370$ (see Table 1). Three of the participants who had noticed the sudden onset on the critical trial and 2 who had noticed the gradual onset on the critical trial failed to see it on the divided-attention trial. Across both conditions, counting accuracy was no different for noticers and nonnoticers in the precritical trial (mean error for noticers = 16%, SD = 12%; mean error for nonnoticers = 20%, SD = 23%), $t(41) = 0.68$, $p = .503$.

It is important to note that the decrease in noticing in the sudden onset condition, relative to the gradual onset condition, throws into question the notion that suddenly onsetting stimuli have an advantage in grabbing visual awareness, at least within dynamic scenes. We expected that sudden onsets should have the largest effect on noticing in this experiment; as in Experiment 6, the unexpected stimulus was black and thus constituted a large transient signal when it appeared. However, unlike in Experiment 6, participants had no attentional set against processing of black items. One possibility is that the apparent benefit of sudden onsets in Experiment 6 was an aberration. When combined across all three onset experiments, Experiments 5–7, no benefits of sudden onsets emerge. Across all three experiments, there was no significant difference in the number of people who noticed the unexpected objects with sudden onsets (45%) than those with gradual onsets (42%), $\chi^2(1, N = 132) = 0.14$, $p = .707$. Furthermore, in no experiment did more than half of the participants notice the object with the sudden onset. This is in marked contrast to the implicit attention capture literature, in which sudden onsets seem to capture attention consistently.

Although the current experiments provide no evidence that sudden onsets capture awareness, several qualifications must be noted. First, it is possible that the transient signal caused by the abruptly appearing object was too small in all three experiments. Even when the unexpected object was black, it still appeared against a gray background, yielding a smaller transient signal than it would have had it appeared against a white background. It is possible that with a larger luminance difference between the unexpected object and the background, objects with sudden onsets would have been noticed more often. Note, however, that in the implicit capture literature, sudden onsets have been found to capture attention even when the display objects are equiluminant with the background (Yantis & Hillstrom, 1994). Second, when the unexpected object appeared abruptly, its position in the display was more peripheral than in most implicit attention capture paradigms. It is possible that awareness of the unexpected object would have been more influenced by sudden onsets if they took place closer to the center of the display. Third, although the properties of the unexpected object were carefully controlled across trials and experiments, the trajectories of the attended and ignored shapes were randomized by the computer. Thus, the proximity of the unexpected object to the other items in the display was random, and there was a small probability that the unexpected object could appear on top of another display item. It is possible that the transient signal created by the sudden onset of the unexpected object was masked by the motion signals of other objects nearby. Most implicit attention capture experiments contain sudden onsets appearing within otherwise static displays. It would be worthwhile to investigate whether the robust effect of sudden onsets on implicit indices of attention capture diminish when they appear within displays containing other motion. Fourth, in studies of implicit attention capture, sudden onsets do not affect performance if participants know in advance where their target will appear (e.g., Yantis & Jonides, 1990). In our current experiments, participants maintained focused attention on their four moving targets. This leaves open that possibility that sudden onsets could more effectively capture awareness when attention is more diffuse. Despite these qualifications and especially in light of previous work demonstrating the power of sudden onsets to capture attention, it is striking that no more than 50% of participants noticed the objects containing sudden onsets in any of our experiments. It is interesting to note that whereas most attention capture studies have tended to rely on response times averaged across trials, one benefit of the current type of trial-by-trial examination is the demonstration that such capturing effects might not occur on all—or even nearly all—trials.

Most generally, these less-than-striking effects for sudden onsets emphasize the importance of studying attentional capture in a variety of paradigms and using a variety of dependent measures. The role of sudden onsets in attentional capture has been studied in dozens of articles, but typically using only the few paradigms discussed in the introduction. Nearly all of these articles measure only the effects of an onset on performance, with little mention of the impact of onsets on awareness. Given that perceivers likely need awareness to change their behavior in response to a critical event, the lack of awareness in our studies suggests that attention capture, as measured in many visual search tasks, might not measure the most ecologically important aspect of attention capture. More broadly, the fact that onsets had so little power to capture awareness in the present studies underscores the need to study attentional capture in its most general form across many particular instantiations, rather than limiting such study to only a few closely related paradigms.

Experiment 8: Attention Capture Without Awareness?

One of the major themes of our discussion so far has been the distinction between implicit attention capture and awareness. This has largely been a theoretical distinction, and only a handful of studies have specifically explored whether attention shifts can occur without awareness of the shift-eliciting stimulus (e.g., Kentridge et al., 1999; Lambert et al., 1999; McCormick, 1997; cf. Naccache et al., 2002; Woodman & Luck, 2003). Virtually no studies have explored the functional relationship between implicit and explicit attention capture. One possibility, consistent with both the original perceptual cycle model (Neisser, 1976) and our reformulation, is that implicit shifts of attention generally precede explicit capture, even though such shifts do not guarantee that awareness will follow. If this proposal is accurate, then evidence of implicit attention capture should be observable both when observers notice an unexpected object and when they do not. Some early inattentional blindness experiments found no implicit evidence of distraction caused by an unexpected object, but these measures may have been relatively insensitive (Rock, Linnett, & Grant, 1992).

Records of the observers' counting accuracy throughout Experiments 1–7 provide a potential means to search for such an effect. If participants' counting accuracy suffers in the presence of an additional, unexpected object, this might reflect an implicit shift of attention. Although counting accuracy is a qualitatively different index than changes in response time during a search task, it seems to be an equally valid measure of attention in principle. An effect on attentional performance without awareness would further underscore the need to understand the capture of awareness independently of implicit attention capture.

Throughout the previous experiments, participants' counting accuracy often decreased in the third, critical trial (containing the unexpected object) compared with accuracy on the second, precritical trial (see Table 2). Although, across all experiments, this effect was most pronounced for noticers (mean error on precritical trial = 19%, SD = 14%; mean error on critical trial = 26%, SD = 17%), $t(169) = 5.36$, $p < .001$, it was also evident among those who did not see the unexpected object (mean error on precritical trial = 18%, SD = 15%; mean error on critical trial = 21%, SD = 14%), $t(181) = 2.90$, $p = .004$. The relative change in accuracy was significantly greater for noticers than for nonnoticers, $t(350) = 2.15$, $p = .032$. The decrease in accuracy from the precritical to the critical trials among nonnoticers might support a dissociation between awareness and implicit attention capture, but this suggestion is tentative because of the absence of a control group. In every condition throughout the preceding experiments, the unexpected object invariably made its first appearance on the third trial. Thus, it is possible that something else about this trial caused an increase in error rates—participants might have lost motivation or become fatigued by the third trial. Therefore, we ran a control condition in which no unexpected object appeared on the third or fourth trials, appearing at last only on the final, full-attention trial.

Table 2
Mean Error Rates in the Bounce-Counting Task for Each Experiment

	Counting error rates (%)			
	Noticers		Nonnoticers	
Experiment	Precritical trial	Critical trial	Precritical trial	Critical trial
1	10	25	13	17
2	16	30	16	17
3	26	31	24	27
4	16	28	16	27
5	15	19	16	19
6	16	26	16	18
7	16	17	20	21
1–7, pooled	19	26	18	21
	Precritical trial		Critical trial	
8 (control)	17		15	

Note. Higher numbers indicate less accurate performance. For Experiments 1–7, error rates increased among both noticers and nonnoticers from the precritical trial to the critical trial (which contained the unexpected object). Only in Experiment 8, when no unexpected object appeared during the critical trial, did error rates not increase.

Method

Participants. Thirty-seven observers were tested in exchange for candy. Data from 7 observers were dropped: Two observers were dropped because of prior knowledge of similar experiments, and 3 others were dropped because of difficulty in understanding the instructions. The data from a 6th participant were discarded because he spontaneously explained that he had changed his criteria for counting bounces between the second and third trials. Data from the 7th participant were improperly saved and thus were lost. All participants (18 men, 12 women; mean age = 20.4 years) saw the unexpected object on the final, full-attention trial.

Materials and procedure. The materials and procedure were identical to those in Experiment 2, with the exception that the unexpected object appeared only during the fifth trial. Four black squares and circles and four white squares and circles moved within the display, and observers counted the bounces made by the circles. Although no unexpected object appeared on the third or fourth trials, after each of these trials observers nevertheless responded to two-item questionnaires probing whether they had been aware of any new items (see the Appendix). On the final, full-attention trial, an additional gray circle (luminance = 19.2 cd/m^2) traveled across the screen in a manner mirroring the previous experiments, and observers' awareness of it was probed at the end of the trial.

Results and Discussion

Consistent with the possibility that in the previous experiments, decreased accuracy on the critical trial among nonnoticers was caused by the appearance of the unexpected object, no such decrease occurred in this control condition. The mean error was 17% on the second trial (*SD* = 13%) and 15% on the third trial (*SD* = 10%), $t(29) = 0.59$, $p = .560$. In comparison with this control condition, the decrease in counting accuracy from the second to the third (critical) trials across the previous experiments was significant both for noticers ($U = 1757.0$, $z = -2.71$, $p = .007$) and for nonnoticers ($U = 2104.5$, $z = -2.01$, $p = .045$; both Mann–Whitney tests were two-tailed; see Figure 9 and Table 2).

The results from this experiment support two conclusions about the relationship between implicit attention capture and awareness. First, implicit and explicit attention capture appear to be dissociable from each other: Counting accuracy decreased on the critical trials across Experiments 1–7, even when observers did not notice the unexpected object (indeed, this trend was apparent within all of these individual experiments), but no decrease occurred in the control condition. In fact, had the accuracy change between trials in the control condition been significant, it would have suggested improvement of accuracy on the critical trial. Second, the fact that accuracy decreased among those who noticed the unexpected object as well as those who did not suggests that implicit attention capture and awareness might not be entirely independent of each other. Instead, consistent with the perceptual cycle framework (Neisser, 1976), implicit attention shifts might precede and contribute to awareness of an unexpected object without necessarily guaranteeing awareness of it. Two interpretations might account for the larger decrease in accuracy among noticers than among nonnoticers. One possibility is that allocation of attention to the unexpected object was sustained only once observers noticed it, thereby detracting further from performance on the counting task. Alternatively, the likelihood that observers would notice the unexpected object might have depended on how much attention was initially diverted to it. In this case, the larger drop in accuracy among noticers might reflect a larger attention shift, which subsequently allowed them to notice the unexpected object. Both interpretations open interesting avenues for future research.

It is important to note that counting accuracy throughout these experiments was not recorded with this kind of analysis in mind,

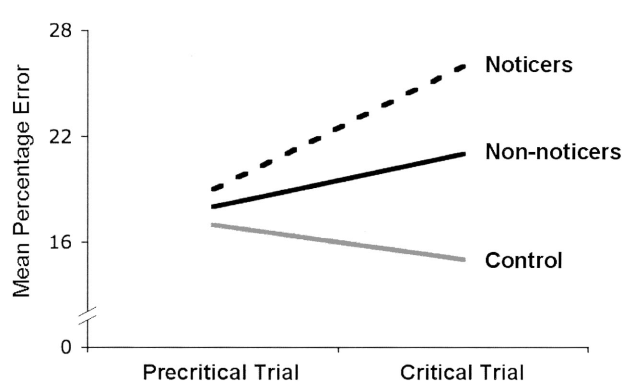

Figure 9. Mean error rates on the bounce-counting task across the precritical and critical trials. When no unexpected object appeared on the critical trial, no decrease in counting accuracy occurred (control group in Experiment 8). However, combined across Experiments 1–7, a decrease occurred on the critical trial even among those who did not notice the unexpected object. The decrease in accuracy was greatest for those who did notice the unexpected object.

and it constitutes only a rough index of attentional distraction. Observers' strategies for the counting task may have varied; for example, 1 participant remarked that she had added bounces to her reported counts in case she had missed a few, and another commented that his strategy had changed from the second to the third trial. (This participant was part of the control group and was removed from the analysis.) Furthermore, it is possible that decreased accuracy on the critical trials of Experiments 1–7 reflected a filtering cost rather than a shift of attention; in contrast to the preceding trials, the critical trial contained five nontarget items rather than four. This interpretation would be consistent with earlier findings that inattentional blindness results partly from active ignoring of irrelevant stimuli (Most et al., 2001, Experiment 2). Note, however, that this interpretation can be applied to some traditional implicit attention capture paradigms as well (e.g., Theeuwes, 1992, 1994).

Despite drawbacks of counting accuracy as an index of attentional distraction, the decreased accuracy in the critical trials—even in the absence of noticing—drives home the necessity of directly studying the capture of awareness instead of relying on implicit measures to infer what might capture awareness. At most, these results demonstrate that implicit attention capture can occur without awareness, and they suggest a functional nature to the relationship between the two phenomena as well. Further research should seek to elucidate this relationship, perhaps using more rigorous indices of implicit capture.

General Discussion

Recall a scenario described earlier: A child unexpectedly runs in front of a car while the driver is fiddling with the radio. At least two different indices can be examined to determine whether the child has caught the driver's attention: One is the driver's awareness of the child, and the other is the effect of this unexpected event on the driver's radio-tuning performance. Important insights about the mechanisms of attention shifting can be drawn from the latter index, but what is crucial in this situation is that the driver notices the child. Traditional attention capture research parallels the assessment of the driver's radio-dial manipulation—for example, changes in response times on a primary task are used to infer whether a task-irrelevant event automatically diverted attention (e.g., Folk et al., 1992; Theeuwes, 1992, 1994; Yantis & Jonides, 1984). From a practical standpoint, a weakness of this approach is that its findings might not generalize to the capture of awareness. Conversely, research on inattentional blindness directly probes awareness, demonstrating that people often fail to notice unexpected objects and events when their attention is preoccupied (e.g., Becklen & Cervone, 1983; Mack & Rock, 1998; Neisser & Dube, 1978, cited in Neisser, 1979; Simons & Chabris, 1999). This research seems especially ecologically valid and could even play an important role in public policy decisions. For example, recent research using the computerized sustained inattentional blindness paradigm has demonstrated that the degree of inattentional blindness increases when observers are simultaneously talking on a cellular telephone (Scholl et al., 2003; see also Strayer, Drews, & Johnston, 2003). Despite this ecological relevance, this literature has yielded only limited insights into the factors that determine whether an unexpected object in a dynamic scene captures awareness.

A major goal of this article has been to theoretically bridge these two fields of research. Studies using implicit measures have detailed complex interactions between top-down and bottom-up properties underlying unplanned, transient shifts of attention. Applying such an understanding to the problem of inattentional blindness helps illuminate mechanisms of visual awareness, essentially shifting the emphasis of the field from demonstrations of perceptual failure to investigations of factors underlying successful noticing. The lack of connection between these two fields may be in part due to an underestimation of the chasm between implicit attention shifts and awareness, although recent studies have begun to demonstrate the separability of the two fields (e.g., Kentridge et al., 1999; McCormick, 1997; Woodman & Luck, 2003). Consequently, virtually no experiments have explored functional relationships between them. In this article, we have attempted to (a) highlight the gulf between research on implicit attention capture and inattentional blindness, as well as the need to bridge it; (b) show how bringing together the two fields can elucidate factors determining visual awareness of unexpected objects and events, as well as suggest functional links between implicit and explicit attention capture; and (c) put such ideas into practice by noting some of the most important factors that determine the capture of awareness.

In Experiments 1–3, we found that the likelihood of noticing an unexpected object was powerfully mediated by a person's attentional set. When the unexpected object was visually similar along a critical dimension to an attended set of items, people were likely to notice it. However, noticing greatly decreased when the unexpected object was similar along the critical dimension to the distractors, even when the object contained a unique feature (Experiment 2) and even though it always traveled on a unique path of motion. It is important to note that this attentional set effect generalized across several dimensions. Experiments 1 and 2 demonstrated that people could establish effective attentional sets on the basis of simple features like luminance and shape. In Experiment 3, we found evidence that such attentional sets could also be based on complex features, such as those that differentiate between faces. In summary, people appear capable of establishing an attentional set—successfully filtering even unexpected information from conscious awareness—on the basis of a range of features that might distinguish attended from ignored items during a selective looking task.

How strong is this effect of attentional set? The strongest prediction would be that only variations along a dimension relevant to attentional set affect noticing and that irrelevant variations have no bearing on what enters awareness. Indeed, support for this notion came from a comparison of results in Experiments 1 and 2. In both studies, the unexpected object was an additional circle among black and white shapes, but in Experiment 2 the additional circle was gray, making it more distinctive than the black unexpected circle in Experiment 1. Despite its greater distinctiveness, the gray circle was not noticed substantially more than the unexpected black circle had been. However, the results of Experiment 4 demonstrated that bottom-up properties beyond attentional set, such as salience, can wield some influence over noticing. Participants were more likely to notice a salient, unexpected white triangle among black targets and distractors than an unexpected black triangle, even though their attentional sets were based on shape rather than luminance.

This appeared not to be the case for sudden onsets, however. Taken together, Experiments 5–7 suggested that abrupt onsets within dynamic scenes provide little or no benefit for the noticing of unexpected objects. Initially, it appeared that sudden onsets, if constituting large enough transient signals, could draw awareness somewhat more effectively than gradual onsets. When a relatively low-contrast gray cross suddenly appeared against a gray background in Experiment 5, it was not noticed more than a gradually appearing gray cross; but the abruptly onsetting black cross in Experiment 6 was noticed slightly more than one that gradually appeared. However, our first interpretation of this as being due to a presumably larger transient signal was not confirmed in Experiment 7, in which the unexpected object was again a suddenly onsetting or gradually emerging black cross. Because participants presumably did not establish an attentional set against black items in Experiment 7, we had expected that the effect of sudden onset would be even stronger. Instead, even fewer participants noticed the black cross with the sudden onset than noticed the black cross with the gradual onset. When the results from all three sudden onset experiments were pooled, there appeared to be no reliable effect of onset at all. Although several factors need to be better controlled in future onset experiments, the current results provide an intriguing contrast to the conclusions that might be drawn by much of the implicit attention capture literature, in which sudden onsets appear consistently to capture attention. In particular, future experiments should investigate more carefully the role of static versus dynamic displays when assessing the impact of sudden onsets. The current experiments suggest that attention capture due to sudden onsets may not always occur as robustly in dynamic displays (a result with obvious ecological implications). In summary, in the experiments presented in this article, the most important single factor influencing noticing rates was the attentional set of the participants. Quite literally, the probability that people will notice an unexpected object depends largely on what they have set their minds to see.

Integrating Implicit Attention Capture and Inattentional Blindness

In addition to predicting the factors that mediate the awareness of unexpected objects, the theoretical framework discussed here—and the experiments presented in support of it—demonstrates how a relationship can be forged between implicit attention capture and awareness. First, the fact that counting accuracy decreased on the critical trials even when observers failed to notice the unexpected objects lends empirical support to the contention that awareness of an unexpected object requires more than an implicitly measured attention shift. Second, the fact that a decrease in accuracy also occurred among those who noticed the unexpected object suggests that the dissociation between implicit and explicit attention capture might not work both ways. That is, whereas an implicit shift of attention might occur without resulting in awareness, noticing of an unexpected object might likely be preceded by an implicit attention shift, or orienting (see also Posner et al., 1980).

This proposal for a functional relationship might prove useful in finally integrating the fields of implicit attention capture and inattentional blindness. If it is applied to our data while taking into account earlier insights from the implicit attention capture literature, a tentative picture begins to emerge of how a person who is engaged in a selective attention task might become aware of an unexpected object. When a new, unexpected object enters a scene, it might capture attention implicitly and automatically. This shift is likely to be transient (e.g., Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989) and possibly insufficient to serve as the basis of a conscious percept. Neisser's (1976) perceptual cycle suggests that conscious perception results from temporally extended processes beyond transient shifting, but it remains vague about what determines whether a transient shift of attention is followed by additional sustained processing. We propose that the linchpin connecting the transient, automatic shift to a subsequent sustained, more voluntary shift is a person's own attentional set. If the properties of the unexpected object gleaned through a transient shift match the person's attentional set, then attentional processing of the object is sustained, increasing the likelihood that it will be noticed. If the properties of the object do not match the person's attentional set, then attentional processing ends with the transient shift. Note that this model is also consistent with other notions of iterative processes in perception (e.g., Di Lollo et al., 2000). It must be noted that this model applies to situations in which a person is (a) not expecting a new stimulus, (b) already engaged in an attentionally demanding task, and (c) actively using an attentional set to achieve their goal. Failure to meet any one of these conditions can change the nature of the processes dramatically.

In summary, our model makes several predictions. Central among these is the prediction that when people are engaged in attention-demanding tasks, their attentional sets will be one of the most important factors determining whether they become aware of unexpected objects. Consistent with this prediction, we found that attentional set powerfully mediated awareness: In Experiments 1 and 2, manipulations of attentional set alone determined whether the unexpected object was noticed by almost everyone or by virtually nobody. We also predicted that because people may be unable to maintain an unwavering attentional set, properties that draw attention implicitly—for example, salience or sudden onsets—might lead to increased noticing but that these benefits would be small compared with the influence of attentional set. Consistent with this prediction, increased salience in Experiment 4 led to increased noticing, although nearly a 3rd of the participants still failed to notice even the most salient unexpected object. In contrast, sudden onsets in Experiments 5–7 did not lead to a reliable increase in noticing. Finally, we suggested that transient shifts of attention alone are not sufficient for noticing unexpected objects; instead, transient shifts must be followed by more sustained allocation of attention. We thus predicted that it would be possible to find evidence of implicit shifts of attention even in the absence of awareness, and the results of Experiment 8 were consistent with this.

Inattentional Blindness Versus Inattentional Amnesia

One of the most pointed issues surrounding inattentional blindness research is whether such findings reflect an actual failure of perception or, instead, a failure of memory (e.g., Moore, 2001; Moore & Egeth, 1997; Wolfe, 1999). In other words, instead of failing to perceive the unexpected object, perhaps observers simply do not remember having seen it. This possibility is difficult to rule out because most procedures probe awareness after the unexpected object has come and gone. Of course, this limitation is virtually unavoidable, given that the research question involves the perception of unexpected things; asking observers ahead of time to indicate when they see something new would render the critical item expected. Some studies have tried to minimize this problem by stopping the trial before the unexpected item has exited the display (e.g., Becklen & Cervone, 1983) and by using particularly unusual unexpected items (e.g., Simons & Chabris, 1999). For example, it is difficult to believe that observers would forget having seen a gorilla walk through a group of basketball players once they have fully perceived it (Simons & Chabris, 1999). Neither stopping a trial early nor increasing the strangeness of the unexpected object increases rates of noticing.

The suggestion that people simply fail to remember the unexpected object despite having been fully aware of it has merit when applied to studies using briefly presented stimuli (e.g., Mack & Rock, 1998). Studies using rapid stimulus presentations have demonstrated that pictures can be identified when flashed at a rate of less than 125 ms per item but that representations of these items quickly fade or are overwritten; pictures must be processed for about 300 ms if they are to be consolidated into explicit memory (e.g., Potter, 1975, 1976; Potter & Levy, 1969). (This is consistent with the phenomenology of rapid serial visual presentation, wherein one feels that all stimuli are seen, but in a fleeting sense such that the stream cannot be recalled.) Therefore, instant forgetting remains a serious alternative explanation for studies of inattentional blindness that use briefly flashed stimuli (Mack & Rock, 1998; Newby & Rock, 1998) as well as other paradigms—such as the attentional blink (Chun & Potter, 1995; Raymond, Shapiro, & Arnell, 1992) and repetition blindness (Kanwisher, 1987)—that investigate perception under severe temporal constraints.

In contrast, studies like the ones presented here, in which unexpected objects are present for longer periods of time, are less open to this alternative explanation. To apply the amnesia hypothesis to the current experiments, for example, one must argue that although people saw the unexpected objects while they were visible, top-down constraints continuously inhibited their consolidation into memory over the course of 5 s. This argument would need to be made about previous sustained inattentional blindness studies as well (e.g., Becklen & Cervone, 1983; Most et al., 2000, 2001; Neisser & Dube, 1978, cited in Neisser, 1979; Scholl et al., 2003). This is conceivable, but such an explanation obscures the meaning of conscious perception. If, as in another experiment (Haines, 1991), airline pilots using a flight simulator engage in landing procedures despite the obstruction caused by another airplane on the runway, then suggestions that they saw the obstruction but did not remember it are of limited practical interest. That said, from a theoretical standpoint it must be noted that visual awareness may not be an all-or-nothing phenomenon. The possibility remains in our experiments that people became aware that something was moving across the display, but they did not encode the properties necessary to register that the item was something new, different, or noteworthy. This could be considered, perhaps, a form of *inattentional agnosia* (see Simons, 2000). Future research should delineate the fine distinctions along the way from attending to encoding to full subjective awareness. To date, inattentional blindness research informs us about the latter aspects of this spectrum, providing insight into conditions under which people can respond to stimuli or report them appropriately.

Conclusion

Implicit attention capture and inattentional blindness have traditionally constituted parallel lines of research within the attention literature, but the insights of one have rarely been applied to the other. This is unfortunate because studies using implicit measures of attention capture have revealed important mechanisms underlying unplanned shifts of attention, and such mechanisms might inform us of how people become aware of unexpected objects and events in the world. However, because this line of research relies on measures of performance to infer attentional shifts, rather than on awareness directly, its current revelations might not generalize directly to how we consciously notice unexpected things. Indeed, we have reviewed evidence—both in previous research and in our own data—that implicitly measured attention shifts can occur without awareness. In contrast, research on inattentional blindness, with its focus on the relationship between attention and awareness, is more directly relevant to everyday life. Inattentional blindness is ubiquitous, and depending on the context, its consequences can be trivial, humorous, embarrassing, or tragic. Yet, research on this phenomenon has not made the same progress as implicit attention capture research in detailing the mechanisms involved.

In this article, we forged a link between these two fields. We first highlighted the gap between them, then bridged this gap with an experimentally supported theoretical framework. The result illustrates how top-down and bottom-up processes combine to determine the capture of awareness. Some bottom-up properties, such as salience, influence the likelihood that someone will notice an unexpected object, but the most powerful mediator appears to be the attentional set adopted by the individual. Furthermore, by considering our findings, as well as previous research, within the context of a model influenced by the notion of a perceptual cycle (Neisser, 1976), we have taken steps toward integrating implicit capture and inattentional blindness into a unified theoretical framework. An understanding of the factors determining the likelihood that one will notice an unexpected object or event holds substantial theoretical value. Also, it carries with it important applications to everyday life, where the difference between comedy, tragedy, and fortune often rides on whether one sees the unexpected.

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(*Appendix follows*)

Appendix

Questionnaires

The following questionnaires were administered after each critical, divided-attention, and full-attention trial. The two-item questionnaire was used in Experiments 1, 3, and 4, and the five-item questionnaire was used in Experiments 5 and 6. Participants in Experiment 2 responded to a computer prompt instead of a printed questionnaire (described in Experiment 2). Note that the precise wording of the first question varied slightly as a function of the target and distractor items in the display. For example, on the two-item questionnaire in Experiment 3, "the 4 circles and the 4 squares" was replaced with "the 4 Caucasian faces and the 4 African American faces." Participants answered each question in sequence. On the five-item questionnaire, they did not see any question before answering the previous one. Question 5 (the forced-choice question) in the five-item questionnaire was included to provide pilot data for future experiments. However, it was not counterbalanced across participants, and results from this question were not used in the current analysis.

Two-Item Questionnaire

1. On the last trial, did you see anything other than the 4 circles and the 4 squares (anything that had not been present on the original two trials)?

Yes No

2. If you did see something on the last trial that had not been present during the original two trials, please describe it in as much detail as possible.

Five-Item Questionnaire

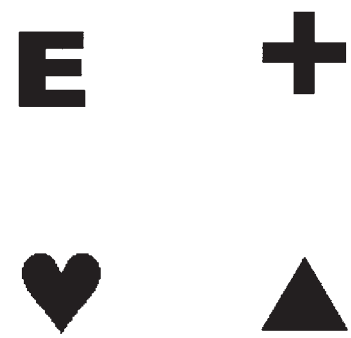
1. On the last trial, did you see anything other than the black and white circles and squares (anything that had not been present on the first two trials)?

2. If you did see something on the last trial that had not been present during the first two trials, please describe it.

3. If you did see something on the last trial that had not been present during the first two trials, what color was it? If you did not see something, please guess.

4. If you did see something during the last trial that had not been present in the first two trials, please draw an arrow on the "screen" below showing the direction in which it was moving. If you did not see something, please guess.

5. If you did see something during the last trial that had not been present during the first two trials, please circle the shape of the object below. If you did not see anything, please guess.



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