Attraction, Distraction, and Action: Multiple Perspectives on Attentional Capture
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Attention Capture, Orienting, and Awareness

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Any viable model of attention must navigate between two requirements: the need for sustainability and the need for interruptibility (Allport, 1989). Successful completion of our goals often requires extended periods of focused attention. For example, building a house out of playing cards requires sustained attention to the cards, the table, and the position of your hands. Any disruption of focused attention would likely result in failure. However, some distractions are important to notice. If a lion were to appear just as you were putting the last couple of cards in place, it would be better to notice it than to obliviously finish building the house; attentional engagement should be interrupted or re-allocated in the face of unexpected dangers. This book focuses on how and when attention is diverted away from a primary goal by an irrelevant or unexpected event, a phenomenon known as *attention capture*.

This definition of attention capture accommodates most of the current approaches to studying the diversion of attention, in part because it is sufficiently broad. However, conflicting operational definitions of capture, based on different assumptions about the role of attention, have muddied the theoretical landscape of capture research. For example, the term "attention capture" sometimes refers to changes in response time caused by irrelevant stimuli, regardless of whether or not the stimuli also capture awareness. This operational definition implies that attention itself is a mechanism by which selection occurs prior to or independent of awareness. What, then, if not attention, drives processing of items to the level of consciousness? On the other hand, the notion of *inattentional blindness*—the failure to become cognizant of an unexpected stimulus when already engaged in a primary task (e.g., Mack & Rock, 1998; Most, et al., 2001)—assumes that if an unexpected stimulus does not reach awareness, it must not have been attended. If, as implied by this assumption, attention functions as the gateway to awareness, what is captured when response times are affected in the absence of awareness?

We use the term *implicit attention capture* to refer to instances when irrelevant stimuli affect response times in a primary task but do not necessarily lead to awareness. We use the term *explicit attention capture* when unexpected stimuli leap into conscious awareness despite an individual's efforts to attend to something else (Simons, 2000). The explicit capture of awareness is perhaps the more intuitive notion of attention capture. When someone remarks that an attractive stranger at a dinner party "captured their attention," we usually take this to mean that they noticed the stranger—not that they were a moment slower in reaching for a cocktail wiener. There are moments when it is absolutely essential for objects and events to enter our consciousness. When a small child runs into the path of our car, it is essential that we register him explicitly.

The distinction between implicit and explicit capture provides a reasonable way to cluster existing capture research (Simons, 2000), but few studies have directly explored the relationship between implicit and explicit capture (see Gibson, this volume, for initial studies along these lines). For example, studies using implicit measures of capture often ignore entirely whether or not observers were aware of the capturing stimulus, and studies of explicit capture typically ignore the involuntary spatial orienting often measured in implicit capture studies. Consequently, it would be premature to make strong claims about the functional independence of these forms of capture. Nonetheless, in this chapter we hope to show that a complete understanding of attention capture depends on considering both implicit and explicit measures, and we provide a model for how these forms might interact. Readers should keep in mind, however, that the implicit and explicit capture literatures are largely separate, and that the relationship between these literatures has not yet been firmly established. Our model stresses the need for research that measures both implicit effects on performance and explicit effects on awareness by providing one speculative view of how these distinct forms of capture might interact.

The attention literature is replete with proposals to account for different types of attention shifts. For example, attention shifts can be characterized based on the degree to which they are voluntarily directed (e.g., Jonides, 1981) and based on their relative time-courses (e.g., Nakayama & Mackeben, 1989). To complicate matters, these dimensions are neither cleanly overlapping nor completely orthogonal. The central goal of this chapter is to place findings using implicit and explicit measures of capture into the broader context of research on attention. We first review evidence for different forms of attention orienting, noting the distinction between voluntary orienting and reflexive orienting. We then review evidence for implicit attention capture, noting the difficulty in determining when orienting is entirely reflexive and when it is influenced by the observer's expectations. Given this difficulty, we suggest that implicit and explicit capture can be better understood by appealing to the distinction between transient and sustained components of attention. After discussing evidence for implicit capture, we turn our focus to the explicit capture of awareness, providing an overview of recent work from our lab on selective looking and inattentional blindness. Finally, we reintroduce and update Neisser's (1976) model of a perceptual cycle as a way to integrate implicit and explicit capture into a single framework. By considering different forms of orienting as well as the importance of both implicit and explicit capture, we can gain a more complete understanding of the role of capture in perception and awareness.

Orienting and attention

Most early work on attention capture focused on visual *orienting*: shifts of attention in response to visual cues or other stimuli. Unlike recent work on implicit attention capture, early empirical work on orienting emphasized the relationship between attention and awareness. Studies explored how orienting affects conscious awareness of a target, finding that subjects are faster, more accurate, and more likely to detect targets when a prior cue forewarns them where they should shift their attention (e.g., Colegate, Hoffman, & Eriksen, 1973; Eriksen & Hoffman, 1972). This section briefly reviews evidence for different forms of orienting and the nature of the cues that drive them.

Orienting can produce observable behavioral responses such as eye or head movements, but it can also be measured in the absence of observable behavior (Posner, 1980; Posner & Petersen, 1990; Posner, Snyder, & Davidson, 1980). Such *covert* orienting is typically inferred from differences in response times between trials in which a cue accurately predicts the target location (a valid cue) and trials in which it signals the wrong location (an invalid cue). If observers are better able to respond to targets on valid than on invalid trials, then they must have oriented to the presence of the cue. Perhaps the most important distinction to arise from studies of orienting is that between *reflexive* (*exogenous*) and *voluntary* (*endogenous*) shifts of attention. To explore the difference between these two forms of attention shifts, orienting studies have used two distinct types of cueing. *Peripheral cues* appear away from fixation, usually at the location of the target (e.g., Eriksen & Hoffman, 1972; Eriksen & Hoffman, 1973) whereas *central cues* appear at fixation and indicate symbolically where the target is likely to appear (e.g., the cue might be an arrow; see Posner, 1980). Because central cues are separated from the location of the target of an attention shift, they must be interpreted before the observer knows where to direct attention. In contrast, peripheral cues typically appear at the target location, so they require no such cognitive effort or interpretation. Consistent with this claim, shifts following peripheral cues are unaffected by concurrent cognitive load and are difficult to suppress (Jonides, 1981). Furthermore, they lead to faster responses to valid cues and slower responses to invalid cues than do central cues. Thus, compared to shifts in response to central cues, attention shifts following peripheral cues appear to be more reflexive and automatic (Jonides, 1981).

Building on these initial demonstrations that peripheral cues produce reflexive orienting, more recent research has sought to determine whether any peripheral cue can automatically capture attention or whether capture depends on the characteristics of the cue. Note that this question is not a new one: William James (1950/1890) suggested that one class of cue, object motion, is especially likely to draw attention:

> "movement is the quality by which animals most easily attract each other's attention. The instinct of 'shamming death' is no shamming of death at all, but rather a paralysis through fear, which saves the insect, crustacean, or other creature from being noticed at all by his

> enemy. It is paralleled in the human race by the breath-holding stillness of the boy playing 'I spy' to whom the seeker is near; and its obverse side is shown in our involuntary waving of arms, jumping up and down, and so forth, when we wish to attract someone's attention at a distance." (pp. 173-174)

Although it has long been recognized that not all cues are equally effective in drawing attention, findings of reflexive orienting in response to peripheral cues led to a marked shift in the focus of attention research. Rather than exploring how attention influences conscious detection of a target, much recent work has focused on the sorts of stimuli that induce automatic orienting. This emphasis on the characteristics of the cue rather than on conscious detection of the target has led to the operationalization of attention capture as an effect on response time, or implicit capture.

Implicit Evidence for Capture

Most studies infer the presence of capture from response times in visual search tasks, without systematically measuring whether or not the capturing stimulus was explicitly noticed. The conclusions drawn from these studies are far from consistent. Some suggest that only a select class of stimuli produce automatic, reflexive orienting whereas others suggest that many stimuli will capture if observers have the appropriate expectations. More importantly, some of these tasks lead to the conclusion that capture *only* occurs if observers have the appropriate attention set. In other words, differences in task characteristics have led to a debate about whether attention shifts can ever be determined solely by the properties of the stimulus or whether all capture depends on the observer's expectations. If, as some suggest, there is no such thing as a completely stimulus-driven shift of attention, does it make sense to talk about attention "capture" at all? This section reviews evidence from studies using implicit measures of capture, focusing especially on this debate.

The stimulus perhaps most frequently mentioned as one that might capture attention is the abrupt onset of a new stimulus. Indeed, when subjects engage in a speeded search for a target, abruptly appearing stimuli consistently seem to affect response time (e.g., Jonides & Yantis, 1988; Yantis & Jonides, 1984). In fact, studies using the *irrelevant feature task* often find that only abrupt onsets capture attention. In a typical experiment using this task, subjects search for a letter target in an array. Initially, the array contains a set of place-markers in the form of figure-8s. Then, after 1 second, segments on the place markers disappear to reveal letters. At the same time that these segments disappear, an additional letter appears in a location not previously occupied by a place marker. This new letter constitutes an abrupt onset because no object had previously occupied that location. However, the location of this abrupt onset is not predictive of the target location — it is the target of the search only 1/n of the time, where n is the number of items in the display. Under these conditions, capture is inferred from the relationship between the search speed and the number of items in the display. If the onset captures attention, then observers should search that item first. Thus, on those trials when the onset just happens to be the target of the search, search speed should be unaffected by the number of items in the display.

In the irrelevant feature task, abrupt onsets appear to be special: color, luminance, and motion singletons are not as effective at capturing attention (Hillstrom & Yantis, 1994; Jonides & Yantis, 1988; but see Franconeri & Simons, 2001 for evidence that some types of motion do capture in this task). One interpretation of this finding is that abrupt onsets signify the appearance of a new object, an event which might have special significance for the visual system (Yantis & Hillstrom, 1994). However, whatever special role onsets may play, they only seem to capture attention when observers are uncertain about where the target will appear. Sudden onsets do not capture attention when subjects know in advance where to attend in order to see the target (Yantis & Jonides, 1990).

Although most findings from the irrelevant feature task suggest that only onsets capture attention, results from the *additional singleton task* suggest instead that the most salient features in a scene determine capture. In these studies, observers typically search for a target defined by a unique color or shape (e.g., a green circle among red circles or a green circle among green diamonds) and report the orientation of a line positioned inside the target (Theeuwes, 1992; Theeuwes, 1994). On some trials, an additional distracter singleton appears (e.g., a blue item) and on other trials no such distracter appears. The additional singleton is anti-predictive of the target location (i.e., it is never the target of the search) and capture is indicated by a slowed search in the presence of this additional singleton. If observers are unable to avoid attending to this additional singleton, then it will slow their search, thereby indicating attention capture. Unlike the irrelevant feature task, in the additional singleton paradigm, not only can sudden onsets capture attention, but so can color and shape singletons (Theeuwes, 1992; Theeuwes, 1994). Capture is determined by the salience of the additional singleton when compared to rest of the items in the display. For example, when subjects search for a red item among green ones, an irrelevant shape singleton does not affect search speed. However, when the color discrimination is more difficult, the irrelevant shape singleton does affect response time (Theeuwes, 1992).

One interpretation of findings from the additional singleton task is that the visual system calculates how different each item is from the rest of the display, preattentively and in parallel, and attention is allocated serially and in descending order, starting with items having the largest difference signals (Theeuwes, 1992; Theeuwes, 1994). Alternatively, interference may depend on the search strategy observers adopt. If observers know that the target of their search will be a unique item, they will actively search for singletons in the display. Consequently, if the additional item is also a singleton, they would search it as well. That is, observers establish an *attention set* for singletons, and any singleton that appears in the display will disrupt performance (Bacon & Egeth, 1994). According to this view, capture occurs not because it is the most salient item in the display, but because observers are actively searching for singletons. Consistent with this interpretation, when the target appears amid a heterogeneous assortment of distracters, thereby eliminating the usefulness of the strategy of searching for a singleton, additional form and color singletons no longer capture attention (Bacon & Egeth, 1994).

The notion that the observer's attention set can influence whether or not stimuli capture attention gains additional support from yet another search task. Evidence from the *irrelevant pre-cue task* indicates that top-down control can override reflexive orienting, thereby suggesting that all attention capture is mediated by the observer's attention set (Folk & Remington, 1998; Folk & Remington, 1999; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). In this task, observers make a speeded response to a pre-specified target that appears in the location of one of four peripheral placeholders. Just prior to the target display, a pre-cue appears at one of the placeholders. Capture is indicated when an invalid pre-cue slows performance on the search task — it draws attention to the wrong location. In this task, when the pre-cue is a unique color, it disrupts performance only if observers are searching for a uniquely colored item; if observers are searching for an abruptly onsetting item, the color pre-cue does not capture attention. Similarly, when the pre-cue is a sudden onset, it captures attention when subjects are searching for an onset, but not when they are searching for a unique color. Thus, orienting is contingent upon the demands of the task; observers establish an attention set for the target feature, and any feature that subsequently matches their attention set will capture attention. This idea is known as the *contingent involuntary orienting hypothesis* (Folk, et al., 1992). More recent work (Folk & Remington, 1998) further suggests that these control settings can restrict capture to specific values on a feature dimension (e.g, red items will only capture attention when observers have a set for red).

The claim that attention capture is contingent on the observer's attention set has been controversial. The primary support for this claim comes from the pre-cue task, but this task is open to the same criticism levied at the additional singleton task: because of the task demands, performance may be heavily influenced by the observer's strategy. In order to verify that capture is driven entirely by the stimulus itself, the task must be devoid of such strategic influences. Because subjects in the pre-cue task know that the target will be characterized by a critical feature, they might intentionally marshal attention resources the moment a stimulus sharing that feature appears. Thus, the influence of the pre-cue on task performance might result from a voluntary attention shift rather than from capture by the stimulus itself (Yantis, 1993). Nevertheless, the finding that irrelevant onsets do not always capture attention, even in cases where observers are uncertain about the target's location, has constrained claims about involuntary orienting. Onsets may be unique in their power to capture attention, but their impact might be limited to cases in which observers have not already established a search strategy or an attention set for another feature (Yantis, 1993).

The idea of contingent orienting raises a more general problem for claims that a stimulus can influence processing independent of the attention set of the observer. The irrelevant feature task assumes that observers have no task-relevant attention set—that observers are effectively in a "neutral" attention state (Yantis, 1993). However, observers may never be completely free of constraints on attention (Folk, Remington, & Johnston, 1993). Past experiences or individual differences might lead to long-lasting attentional biases, regardless of the demands of the current task. For example, clinically anxious patients respond faster when a target appears in the location previously occupied by a threat cue than in a location previously occupied by a neutral cue (MacLeod, Mathews, & Tata, 1986). These patients may have developed a default attention set for threat-related stimuli, which could influence performance even when the threatening nature of the cue is irrelevant. Perhaps a lifetime of experiences can contribute to default attention biases such that no person is ever in a truly "neutral" state. The notion that attention settings might vary across individuals is entirely consistent with the contingent involuntary orienting hypothesis (Folk, et al., 1992).

The difficulty of determining an observer's default attention set raises a broader concern about the dichotomy between stimulus-driven, exogenous orienting of attention and goal-directed, endogenous orienting. Variability in the default attention set, together with findings that strategic control can modulate involuntary attention shifts (Bacon & Egeth, 1994; Folk, et al., 1992; Müller & Rabbitt, 1989; Yantis & Jonides, 1990) and with evidence that people can learn to orient to parts of a transient peripheral cue (Kristjánsson, Mackeben, & Nakayama, in press; Kristjánsson & Nakayama, submitted), contribute to a blurring of the exogenous/endogenous dichotomy.

An alternative dichotomy: The time-courses of orienting

The distinction between exogenous and endogenous orienting divides attention shifts into those driven by the stimulus and those driven by the intentions of the observer. Consequently, they focus on the locus of control (external vs. internal) for attention shifts rather than on the nature of the attention shifts themselves. Clearly some attention shifts are relatively reflexive and others are more voluntary (Jonides, 1981; Müller & Findlay, 1988; Nakayama & Mackeben, 1989; Posner, 1980). Although this distinction does provide a useful categorization of attention shifts, a different distinction might help to bypass the somewhat fuzzy category boundary between voluntary and involuntary shifts. Specifically, two distinct classes of attention shifts emerge when we focus on the time course of shifts rather than on the factors driving the shift. These distinct timing profiles are related to the locus of control of the shift, but the mapping might not be perfect.

One class of shift tends to be *transient* in nature: facilitation of processing at the cued location occurs almost immediately, but the effectiveness of the cue diminishes rapidly. This decline in effectiveness is particularly interesting because it appears obligatory, occurring even when subjects know that the cue validly predicts the target location (Nakayama & Mackeben, 1989). That is, following this sort of attention shift, processing at the cued location is temporary and is inhibited briefly following peak facilitation, even if observers try to avoid this inhibition. Such transient shifts are generally thought to be reflexive rather than voluntary. This sort of transient orienting to a cue is maximally effective when the cue precedes a target by 50-250 ms (Müller & Findlay, 1988; Nakayama & Mackeben, 1989); if the cue precedes the target by less than 50ms, attention does not have enough time to shift to the cued location before the target appears, so facilitation is reduced. If the cue precedes the target by more than 250ms, attention can shift to the cue, but the facilitation at the cued location diminishes and inhibitory processes take effect.

In contrast to transient shifts, another class of attention shifts tends to produce maximal facilitation only after as much as 300ms from the appearance of the cue (Müller & Findlay, 1988). Following this somewhat delayed shift of attention, processing benefits at the cued location can persist for an extended period. That is, such *sustained* shifts lead to a benefit that survives even a substantial delay between the cue and target (Müller & Findlay, 1988; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989). Thus, whereas transient shifts tend to be relatively reflexive, sustained shifts tend to be associated with voluntary control. For example, peripheral cues such as a flash often elicit transient attention shifts, whereas central cues such as an arrow can elicit sustained, voluntary attention shifts. Unfortunately, most studies of attention capture have not measured the time course of the attention shift to the capturing stimulus. It is possible that the kinds of processing costs and benefits apparent in abrupt onset studies reflect transient shifts of attention, in which case processing of a valid onset item should be slowed given an appropriate lead time. More extensive studies of the presence of transient or sustained shifts in capture tasks might help to account for some of the variability in the literature without the need to determine whether or not a shift was influenced by an attention set or a voluntary goal.

In some respects, the distinction between transient and sustained orienting might provide a truer dichotomy than the exogenous/endogenous distinction. Transient and sustained shifts might well reflect the operation of independent attention mechanisms for orienting, conceivably with different functions (see Briand & Klein, 1987 for further discussion of independent attention mechanisms). In fact, evidence suggests that they can operate simultaneously and independently. When cues eliciting sustained and transient orienting (e.g., an arrow and a flash) are presented in the same display, their effects are additive if the shifts are compatible and subtractive if they are incompatible. That is, if the flash and an arrow both cue the same location, facilitation is greater than when they cue conflicting locations. If they cue different locations, then peripheral cueing interferes with sustained orienting more strongly than central cueing interferes with transient orienting. However, facilitation is attenuated in both cases (Müller & Rabbitt, 1989). The potential independence of these two forms of orienting might allow observers to maintain sustained attention on one aspect of a display without precluding transient attention capture by sudden, important events. We consider a possible functional role for the interplay between transient and sustained attention more fully later in the chapter.

Interim Summary

Early work in modern attention research focused on the relation between attention and conscious detection of a target (Colegate, et al., 1973; Eriksen & Hoffman, 1972; Posner, et al., 1980). However, the discovery that peripheral cues tend to draw attention more automatically than central cues (Jonides, 1981) led to a surge of interest in the kinds of stimuli capable of automatically attracting attentional resources. Research has since investigated the effects of stimulus salience (Theeuwes, 1992; Theeuwes, 1994), abrupt onsets (Hillstrom & Yantis, 1994; Jonides & Yantis, 1988; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984; Yantis & Jonides, 1990), and top-down control settings (Bacon & Egeth, 1994; Folk & Remington, 1998; Folk & Remington, 1999; Folk, et al., 1992) on attention capture. Much of this research has focused on the distinction between exogenously- and endogenously-driven shifts of attention. However, this distinction might be a red herring, displacing the components of attention themselves as the main focus of investigation. An emphasis on the distinction between transient and sustained attention shifts may prove more useful, especially when both implicit and explicit aspects of attention capture are considered together. In the next section we provide an overview of work on explicit attention capture, and in the final section, we attempt to integrate these findings with the implicit capture literature.

Selective Looking, Inattentional Blindness, and Explicit Attention Capture

Orienting and awareness

Most of the studies reviewed thus far inferred the existence of attention capture from indirect response times measures, without systematically measuring whether or not stimuli also capture conscious awareness. If implicit attention capture were always associated with instances of conscious detection, the need to measure explicit awareness would be obviated. However, this is not the case. For example, despite the robust effects of abrupt onsets on response time measures, subjects often report not noticing the onsets (Yantis, 1993, footnote 2). The dynamic signal produced by the onset has no temporal persistence, and observers do not always notice its occurrence even if they are drawn to it.

The notion that orienting may occur independently of awareness has been with us for some time. To quote Posner, Snyder, and Davidson (1980): "…it is possible to entertain the hypothesis that subjects may orient toward a signal without having first detected it. This would mean simply that the signal was capable of eliciting certain kinds of response (e.g., eye movements or shifts of attention) but has not yet reached systems capable of generating responses not habitual for that type of signal" (p. 162). This hypothesis gains further support from work with blindsight patients (Kentridge, Heywood, & Weiskrantz, 1999) as well as non-patient populations (Lambert, Naikar, McLachlan, & Aitken, 1999; McCormick, 1997). For example, normal subjects were given a task in which a target could appear in one of two locations, preceded by a cue that produced transient orienting. In contrast to typical cueing tasks, the target was more likely to appear in the uncued location and observers knew this. When the cue was visible to observers, they were faster to respond in the target location (opposite the cue). That is, they were able to make a voluntary attention shift to the appropriate location. However, when the cue was presented below the threshold for conscious awareness, observers were faster to respond to a target appearing in the cued location, indicating that they had oriented to the cue without consciously perceiving it (McCormick, 1997).

Such findings of orienting without awareness are consistent with the operational definition of capture used in the irrelevant feature, additional singleton, and irrelevant pre-cue tasks: provided that a stimulus automatically influences behavior, it can be said to have captured attention. Awareness of the stimulus is irrelevant in such tasks. However, not all researchers accept this operational definition of capture. An alternative approach argues that a stimulus has not captured attention unless it has entered into conscious awareness (e.g., Mack & Rock, 1998). According to this view, “attention is nothing but perception” (Neisser, 1976, p. 87). Effects on performance might involve the diversion of attentional resources, but they do not necessarily involve attention capture. Attention capture must involve the explicit capture of awareness by a previously unexpected stimulus. Paralleling studies using implicit measures, studies of explicit capture have rarely assessed indirect evidence such as response times, instead focusing exclusively on awareness. Thus, they provide little further insight into the relationship between orienting and awareness. As a result, studies of explicit capture are consistent with the possibility that awareness can occur without prior orienting or with the possibility that orienting always precedes awareness. In the sections that follow, we propose a model in which we assume that orienting must precede awareness. This supposition is speculative and has yet to be empirically tested. However, the model based on this assumption produces a number of interesting and testable empirical predictions.

The perceptual cycle

One framework that helps to explain the difference between these two definitions of capture draws on what Neisser (1976) termed the *perceptual cycle*. According to this model, conscious perception is a gradual, constructive process, rather than an all or none phenomenon. Observers have schemas or expectations for what belongs in the scene (i.e., which objects should be present, what they should look like, etc.), which are modified by information in the environment. These schemas guide attention, thereby allowing the observer to pick up more information from the scene. As observers gain more details about the objects in the world, they accommodate their schemas to these details and adjust subsequent visual exploration appropriately (See Figure 1). The immediate past constantly guides subsequent information processing.

The perceptual cycle model has two central tenets: 1) conscious awareness of a stimulus accumulates gradually, and 2) the observer plays an active role in this process. Therefore, awareness of a stimulus requires a degree of sustained processing, and unless it is incorporated into a cycle of expectation and exploration, it might not be "seen" at all (Neisser, 1979). In order for unexpected stimuli to be seen they must either modify the existing perceptual cycle or trigger the formation of a new cycle. In order to modify an existing cycle, the stimulus must be

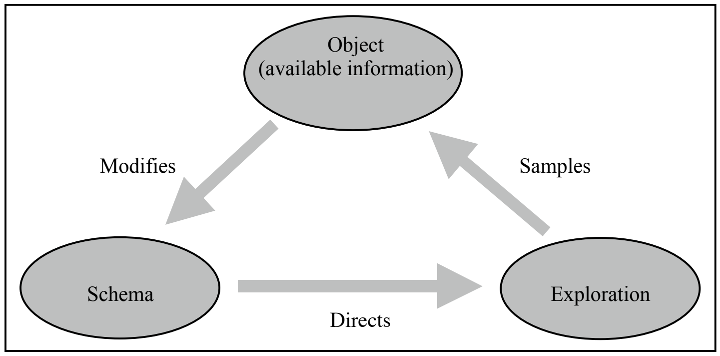

Figure 1. Schematic diagram of a perceptual cycle. Adapted from Neisser (1976).

sufficiently relevant to the current cycle to be noticed in the exploration phase. Some classes of stimuli, such as brightly flashed lights, might automatically trigger the formation of a new perceptual cycle or they could simply induce a transient orienting response without conscious perception. Observers will only become aware of an unexpected stimulus if it is available long enough for a complete cycle of accommodation and exploration to take place.[1] Furthermore, if a person is already engaged in a perceptual cycle—for example, engaged in an attentionally demanding task—then even new stimuli that elicit transient attention shifts and are present for prolonged periods of time may fail to capture awareness, because to do so would mean interrupting the current cycle.

Inattentional blindness and early studies of selective looking

The hypothesis that new stimuli will remain "unseen" if they fail to interrupt or modify an ongoing perceptual cycle gains support from increasing evidence for inattentional blindness, the finding that unexpected salient events often go unnoticed when attention is otherwise engaged (Mack & Rock, 1998). In a typical inattentional blindness task, observers view a series of trials in which a cross appears for 200 ms followed immediately by a mask. On each trial, they judge whether the horizontal or the vertical line of the cross was longest. After a few trials in which nothing else happens, a critical trial occurs in which an additional stimulus appears simultaneously with the cross. After that trial, observers are asked if they saw anything other than the cross. Under these conditions, nearly 25% of observers failed to detect the additional stimulus, even when it had a unique color, shape, or motion (Mack & Rock, 1998).[2]

In these inattentional blindness studies, the unexpected object was only present for 200ms. Consequently, observers might not have had time to complete a perceptual cycle. However, even unexpected objects that are visible for extended periods of time can escape detection if the observer's attention is otherwise engaged. For example, in one series of studies on selective looking, observers watched a movie in which a group of people in white shirts and a group of people in black shirts each passed a basketball among themselves (Becklen & Cervone, 1983; Neisser & Dube, 1978, cited in Neisser, 1979). The two groups were filmed separately and the films were then overlaid so that the figures had a partially transparent appearance and often shared the same space on the screen. The primary task was to count the total number of passes made by one of the two groups. Partway through the movie, a woman carrying an open umbrella (overlaid in the same manner) walked through the middle of the basketball players, from one side of the display to the other. Despite the fact that she shared the same physical space as the basketball players, was present for an extended period of time, and was clearly visible to anyone not engaged in the counting task, in one study only 21% of the subjects noticed her (Neisser & Dube, 1978, cited in Neisser, 1979). These results have recently been replicated and extended to a condition in which none of the figures are partially transparent (Simons & Chabris, 1999). Even when the umbrella woman is fully visible, many observers fail to notice her. In fact, 50% of observers failed to notice a person in a gorilla outfit who stopped in the middle of the display and thumped her chest at the viewer before leaving the screen.

Based on these sorts of selective looking studies, Neisser (1979) concluded, "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). Our recent work has attempted to gain insight into this issue by combining the dynamic and sustained aspects of selective looking experiments (Becklen & Cervone, 1983; Neisser & Dube, 1978, cited in Neisser, 1979; Simons & Chabris, 1999) with the more precise, controllable computerized inattentional blindness task (Mack & Rock, 1998). We find that expectations alone cannot account for the detection of or blindness to an unexpected object.

Controlled studies of sustained inattentional blindness

Many factors may influence whether or not someone will notice an unexpected object when they are absorbed in a demanding task. For example, distinctive or salient features might pop into awareness in the same way that they do when subjects are actually searching for them in a field of distracters (e.g., Treisman

& Gelade, 1980). Spatial proximity to the focus of sustained attention could also influence conscious detection; unexpected objects appearing close to the focus of attention might be noticed more readily. Furthermore, the observers attention set might influence noticing, as would be predicted if the contingent involuntary orienting hypothesis were applied to explicit capture (Folk, et al., 1992). In this section, we discuss studies that explore each of these hypotheses in turn. These studies engage subjects in an ongoing, attentionally demanding task and then test whether or not observers notice an unexpected stimulus.

In one version of our task (Most, et al., 2001), four white objects and four black objects move on random paths in a rectangular computer window for 15 seconds. As they move, each object occasionally "bounces" off one of the display's edges, and the observer's task is to count the total number of bounces made by either the white or black objects (as indicated by the experimenter). During the first two trials, nothing unexpected occurs. However, on the third, critical trial, an additional, unexpected object enters the right side of the display, travels in a linear path behind a fixation point, and exits the left side of the display, remaining visible for a total of 5 seconds (see Figure 2). After this critical trial, observers are asked whether or not they saw anything other than the original eight items in the display. Even salient unexpected objects go unnoticed. For example, in one experiment, almost 30% of observers failed to notice a bright red cross that was fully visible for 5 seconds (Most, et al., 2001, Experiment 3).

This example by itself illustrates the power of expectations: observers did not expect an additional object, and many failed to notice it even though it was the only red item in the display. However, an alternative explanation for this failure to notice is that the unexpected object fell outside the focus of attention. Perhaps it did not appear in close enough proximity to any of the target items to be detected. Indeed, observers were looking for target bounces at the edges of the display when the unexpected object traversed the middle of the display. To explore this possibility, we modified the task so that observers counted the number of times that the target set of items (black or white Ls and Ts) came into contact with a horizontal line bisecting the display. With this task, we could vary the proximity of the unexpected object (a gray cross) to the attended region by varying its distance from the line. We found a small effect of proximity in this experiment, suggesting that spatial location is relevant to noticing. However, 47% of observers still failed to detect the unexpected item when it traveled on the line, which was presumably the locus of attention (Most, Simons, Scholl, & Chabris, 2000b).

Although spatial proximity to the attended region appears to play some role in noticing, a more important determinant is the relationship between the unexpected object and the observer's goal-orientation in the primary task. Noticing was strongly influenced by the similarity of the unexpected item to the objects that the observers were attending and ignoring. The more similar the unexpected object was to the target items, and the less similar it was to the distracter items, the more likely

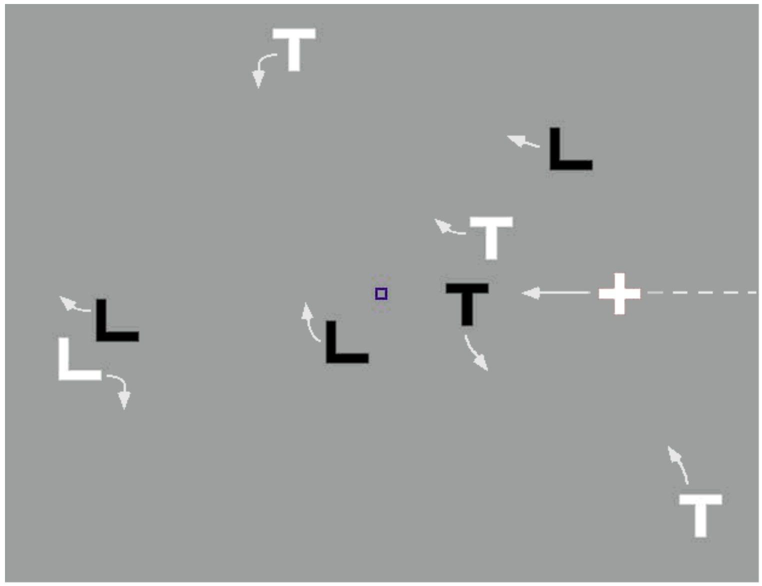

Figure 2. A critical trial in a sustained inattentional blindness task (adapted from Most et al., 2001). On each trial, the black and white L's and T's move on random paths, bouncing of the edges of the display, and subjects count the number of bounces made by either the black or white items. On a critical trial, an additional object (here, a white cross) enters from the right, travels in a linear path behind a fixation point, and exits to the left. (Arrows were not present in the experimental display.)

it was to be detected. For example, when observers attended to white L's and T's and ignored black ones, 94% saw an unexpected white cross on the critical trial but only 6% saw an unexpected black cross. Detection was intermediate with gray crosses. Furthermore, when observers were attending to the black shapes and ignoring the white ones, these noticing rates were reversed (Most, et al., 2001, Experiment 1). Even though the unexpected cross always had a unique shape and motion, these distinctive features did not lead to detection; however, variations in luminance influenced detection.

Why did variations in luminance so strongly influence noticing? One possibility is that luminance affected noticing because luminance is a privileged stimulus dimension for the visual system, often implicated in scene segmentation and motion perception (Marr, 1982). Alternatively, luminance might have influenced noticing because it was the only dimension distinguishing the attended from the ignored items. This possibility raises the intriguing hypothesis that observers established an attention set on the basis of the task demands, and that the attention set allows some classes of items to enter into conscious awareness while keeping others out.

To test this possibility directly, we designed a new version of this task in which the moving, bouncing items in the display were 2 black circles, 2 white circles, 2 black squares, and 2 white squares. Depending on the condition, observers counted the total number of bounces made by all the white shapes (both circles and squares), all the black shapes (both circles and squares), all the circles (both black and white), or all the squares (both black and white). Thus, the critical dimension could be either luminance or shape (depending on the instructions), and the display items across all four conditions were identical. In all conditions, the unexpected object was an additional black circle, which entered the display, traveled on a unique linear path, and exited the display. As in our earlier experiment (Most, et al., 2001, Experiment 1), observers who attended to the black shapes were more likely to notice the additional black circle than those who attended to the white shapes. More importantly, the effect seems to be driven by the nature of the critical dimension: observers who attended to all the circles were more likely to detect the additional black circle (82% noticing) than those who attended to the squares (6% noticing; Most, Clifford, Scholl, & Simons, 2000a). The magnitude of this difference in noticing was comparable to that for luminance-based attention sets.

Given the strong effect of top-down control settings on noticing rates, perhaps variations along feature dimensions unrelated to the attention set will fail to influence conscious awareness. For example, if observers are discriminating attended from ignored items on the basis of shape, will variations in color, however extreme, fail to affect noticing? In a study designed to explore this question, observers attended to black squares while ignoring black circles, and the unexpected object was either a black triangle or a white triangle. In other words, shape was the dimension relevant to the attention set but the two unexpected items differed from each other only in luminance, an irrelevant dimension. Even though luminance was irrelevant, it still influenced noticing rates: 68% noticed the white triangle and 38% noticed the black (Most, et al., 2000a). Thus, features can influence noticing even when they are unrelated to the critical, attended dimension. However, as in the case of the red cross, more than 30% still failed to notice the white triangle, the only white item in the display, suggesting that even extreme salience does not completely override the attentional selection required by the primary task.[3]

Interim Summary

Do some features automatically capture awareness in the absence of expectations? Or does explicit capture depend more on what the observer brings to the situation? Explicit capture likely requires more processing than does implicit capture because the former may depend on the active construction of a conscious percept (Neisser, 1976). Because an individual's expectations and schemas guide this process, it is reasonable to expect that attention sets will play an important role and, in fact, this is exactly what we found in our studies. When subjects were engaged in an attentionally demanding task that required them to establish an attention set, unexpected stimuli consistent with that set were much more likely to be noticed than set-inconsistent stimuli (Most, et al., 2000a; Most, et al., 2001; see also Simons & Chabris, 1999). Stimulus variations along irrelevant dimensions had only a limited effect on noticing, and even salient, but irrelevant features failed to override completely the selectivity imposed by the attention set (Most, et al., 2000a; Most, et al., 2001). Perhaps surprisingly, spatial proximity of an unexpected object to the focus of sustained attention appeared not to play a large role in noticing (Most, et al., 2000b).

If conscious detection requires a relatively extended period of sustained attention, then it might well rely on a different attention mechanism than does implicit capture. The relatively reflexive shifts revealed by implicit measures appear strongly linked to a transient component of attention, whereas explicit capture likely requires the diversion of sustained attention. The next section considers how the distinction between sustained and transient components of attention may aid in the integration of the implicit capture and explicit capture literatures.

Integrating Implicit and Explicit Attention Capture

Implicit measures of capture are based on performance, whereas inattentional blindness is a measure of awareness. However, to say that studies of implicit capture and inattentional blindness assess different aspects of attention, and to leave it at that, seems rather hollow. A more satisfying reconciliation would show how these two literatures can be integrated. In this brief discussion, we attempt an integration by returning to the notion of a perceptual cycle (Neisser, 1976). This notion posits a repeated and sustained visual exploration of the environment, which eventually produces conscious awareness. The following anecdote illustrates the framework. As one of us was working on the manuscript for this chapter, he noticed a darting motion in his peripheral vision. Presumably the motion had induced a transient shift of attention. Further exploration revealed a color discontinuity with the carpeting along with ongoing motion signals, leading to a tentative interpretation of the information: some kind of animal in the room. But what kind of animal? An insect? Further inspection revealed that the source of the motion was a mouse (a description of the author's subsequent reaction is beyond the scope of this chapter). The following evening, while again working on this manuscript, the author was distracted by a color discontinuity in his peripheral vision. The immediate reaction, upon an initial interpretation of it as another mouse, was quickly followed by further visual analysis, which revealed the source of the scare to be a 1969 copper penny. In both cases, the properties of the stimulus were combined with a schema that then guided subsequent visual exploration. Had the objects been present only for an instant, an orienting response might have occurred, but this orienting quite likely would not have produced a conscious percept. Furthermore, had the author not seen the original mouse, his schema for what should appear in his office likely would not have included a mouse, and he would have been unlikely to initially interpret the coin as an animal. In fact, without the prior influence of the mouse on his schema, he might not have noticed the coin at all.

Neisser hypothesized that information with "no temporal dimension…can lead to an orienting response, but…cannot specify the identity or the meaning of events and has no phenomenal impact" (Neisser, 1979, p. 214). Although the original perceptual cycle model captures some intuitions about how conscious perception might proceed, the model does not explicitly incorporate different forms of orienting. An updated version of this model might provide a useful framework for considering how implicit and explicit forms of capture relate to each other and to orienting in general. Given that implicit capture requires no awareness of a cue and is more closely aligned with reflexive shifts of attention than with voluntary shifts, implicit capture studies might help to illuminate the kinds of stimuli (e.g., onsets, unique colors) capable of triggering a new perceptual cycle in the absence of expectations. Like repeatedly striking a match, each transient shift caused by such stimuli can potentially kindle the cyclical process leading to awareness. However, a new or modified perceptual cycle will proceed only if attention, like the spark of the match, is sustained. This possibility is consistent with our finding that distinctive unexpected items, while not always noticed, are detected more often than less salient stimuli (Most, et al., 2000a). Figure 3 presents our modified version of the perceptual cycle, reframed in terms of recent work on attention.

In this model, information from or about the visual scene initially establishes a schema for the sorts of objects that belong in the scene. This initial schema is likely to be fairly crude. When engaged in selective processing of the scene, an individual may adopt an attention set based on his or her schema. The attention set determines which specific objects or features the observer will attend to and then guides sustained attention to those aspects of the scene consistent with the attention set. As a result of the new information gained through sustained attention to the scene, the schema is fleshed out and the attention set is then updated again. As this process is repeated, perception of the scene is gradually enriched. The key question is what happens when a new cue appears in the scene, something that might capture attention. When such a signal occurs, it has the potential to disrupt sustained attention, thereby redirecting attention to the signal itself. Even when such signals do not fully disrupt sustained attention, they could still influence performance. That is, they could implicitly capture attention by inducing a shift of transient attention. Some stimuli, either due to consistency with the attention set or to the strength of the signal might either become part of the ongoing perceptual cycle or initiate a new one. Through repeated cycles of exploration and accommodation into a schema, such stimuli might reach awareness.

This model of the perceptual cycle allows for sustained shifts of attention as a function of the observer's schema and attention set. It also allows for transient shifts of attention in response to a new signal in the scene. Implicit capture is attributed to a transient signal that may or may not completely disrupt the perceptual cycle. Explicit capture results from a signal that succeeds in disrupting or being incorporated into the cycle, thereby becoming a focus of sustained attention. Of course, this model is necessarily incomplete in that it cannot readily encompass all of the claims in the implicit and explicit capture literatures, and it cannot account for contradictory claims within them. Also, the mechanisms underlying the formation and operation of attention sets are not clearly understood. The model does have the advantage that it refocuses capture research on the components of attention (e.g., types of attention shifts), rather than on the features that may or may not automatically draw attention. Notably, it predicts that all attention capture, including explicit capture, results from a transient shift. That is, explicit capture will not occur in the absence of implicit capture. This is an empirically testable hypothesis, although one that has not yet been addressed systematically. Although this model is necessarily vague, it provides a potentially valuable framework that accommodates both implicit and explicit capture.

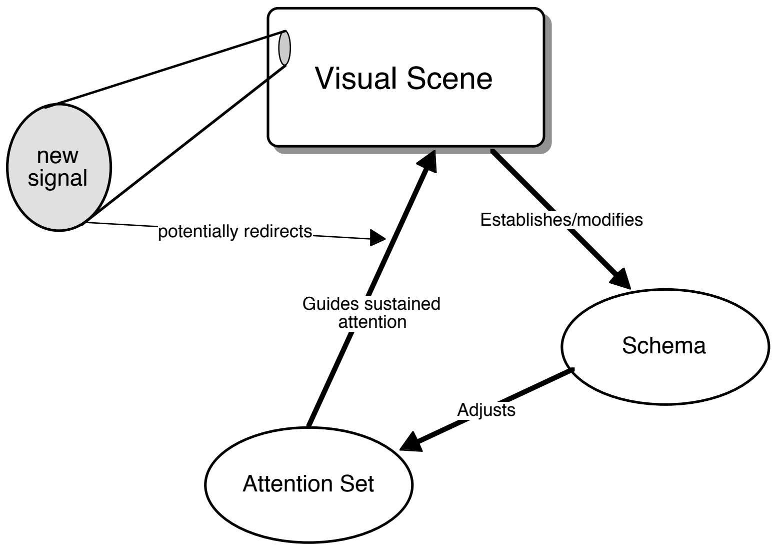

Figure 3. A modified version of Neisser's (1976) perceptual cycle model. When observers are engaged in selective processing, crude information from a visual scene (or from task instructions) initially establishes a schema for what is likely to be in the scene. This schema then contributes to an attention set which guides sustained attention as the observer inspects the scene. This inspection yields more information about what is in the scene, which, in turn, leads to modification of the schema to incorporate the new information. Unless interrupted or redirected, this cycle repeats, eventually leading to awareness of the attended aspects of the scene. This part of the model is comparable to Neisser's original proposal. Importantly, when a new signal appears, it can cause a reflexive shift of attention to a different aspect of the scene, thereby disrupting sustained attention. In so doing, it might produce evidence for implicit attention capture. However, unless it is incorporated into the current perceptual cycle or triggers a new one, it will not garner additional sustained attention and will not reach awareness.

Conclusion

What is "attention capture"? Here we have distinguished between implicit and explicit measures of capture, with the former focusing on effects of an irrelevant stimulus on performance and the latter focusing on the effects of an unexpected stimulus on awareness. Although both approaches have been common in the capture literature, relatively few studies have yet explored the relationship between implicit and explicit capture (but see Gibson, this volume). Our review of this distinction highlights the need for studies that directly compare different forms of orienting while simultaneously measuring effects on awareness of the cue. Although the distinction between implicit and explicit capture helps to classify the current results, neither literature in isolation can resolve the fundamental question of whether or not a stimulus can draw attention regardless of the goals, schemas, and expectations of an observer.

In attempting to address this question, the capture literature has often focused on the distinction between exogenous and endogenous capture. There *are* times when objects and events affect our behavior and/or enter into conscious awareness without our having *explicitly* decided to attend to them. However, the impossibility of determining the observer's attention set with sufficient precision (Folk, et al., 1993) precludes any strong claim that a stimulus has automatically drawn attention. Rather than emphasizing the types of cues that automatically draw attention, perhaps we can more effectively operationalize capture in terms of the nature of the shift itself. A transient shift of attention is likely to be a relatively reflexive response to a stimulus, and it has a number of characteristics that seem consistent with attention capture. Furthermore, such shifts can be measured without regard to the observer's attention set.

This treatment of capture has the advantage that it is readily measured and that it can be distinguished from sustained shifts of attention, which are more likely to be under voluntary control. Moreover, it returns the emphasis of capture research to the components of attention rather than the nature of the stimulus. However, it does not distinguish between effects on behavior and effects on awareness. Perhaps a slightly broader definition can accommodate both forms of capture: when a person is engaged in a primary task and has no *explicit intention* to process additional stimuli, awareness of an unexpected object constitutes explicit attention capture and a shift of attention to a stimulus without awareness of it constitutes implicit attention capture.

The main goal of this chapter was to integrate findings using implicit measures of attention capture with those using explicit measures. In the process, we have argued that implicit and explicit measures actually reflect different phenomena that, while intimately linked, may be dissociated from each other. Transient orienting responses can occur in the absence of awareness; whether or not awareness of unexpected stimuli can occur without an initial transient shift of attention is a question for further research. By thinking of the function of capture in terms of a perceptual cycle, we can combine both implicit and explicit capture into a single framework. If a person is engaged in a hazardous task requiring sustained and focused attention, anything more than a transient shift of attention to an unexpected object could result in disaster (Nakayama & Mackeben, 1989). On the other hand, if the unexpected object is also of critical importance or is related to the task, then it would be appropriate to incorporate it as a focus of sustained attention. Implicit capture resulting in a transient shift of attention might allow the perceptual system to rapidly evaluate whether or not sustained attention should be directed to a stimulus. This shift might affect performance, but if the eliciting stimulus is not centrally relevant for the current task it will not reach awareness; particularly salient stimuli might also trigger a new perceptual cycle, but even highly salient stimuli often go unnoticed if they are irrelevant to the current task. When the transient shift reveals a stimulus to be consistent with the observer's attention set, sustained attention is reallocated and the stimulus becomes part of a perceptual cycle. Explicit capture of awareness results from the integration of a stimulus into the current perceptual cycle or from the formation of a new cycle. By thinking of capture in terms of the perceptual goals of the organism rather than in terms of the nature of the stimulus itself, we can gain a better appreciation for how different forms of capture are linked and for the functional roles they play.

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Footnotes

1. A reasonable objection to this notion is that we often are aware of very brief stimuli. For example briefly flashed stimuli are often seen, and it is not uncommon to be able to make out whole scenes during a flash of lightning (Neisser, 1976). Two points, however, defuse the effectiveness of this objection. First, even when stimuli appear briefly, subjects often expect to see them, and such expectations may serve to facilitate the processing required for conscious awareness. Second, although it is true that brief stimuli are often perceived, it is also true that these stimuli tend to persist in iconic memory, thereby allowing processing to continue well after the actual items have disappeared (Neisser, 1976; Sperling, 1960).

2. These findings are consistent with implicit evidence for capture that even abrupt onsets do not capture attention when observers know the spatial location of the target in advance (Yantis & Jonides, 1990). It would be worthwhile to investigate whether inattentional blindness still occurs when subjects are uncertain about where the cross would appear. However, the data do suggest that observers are equally bad at detecting the additional stimulus when it appears on one of the arms of the cross as when it appears in one of the quadrants (Mack & Rock, 1998). Thus, failure to detect it might not have been dependent on prior knowledge of the target's location.

3. Ongoing experiments are exploring whether unexpected objects with sudden onsets are noticed more than those that appear gradually. Preliminary data from our lab suggest that even sudden onsets fail to capture awareness much of the time.

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