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ATTENTION AND UNIT FORMATION: A BIASED COMPETITION ACCOUNT OF OBJECT-BASED ATTENTION

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ABSTRACT

Because the visual system cannot process all of the items present in a visual scene, some stimuli must be selected over others to prevent the visual system from becoming overloaded. Visual attention allows some stimuli or events to be processed instead of others. Most research on attentional selection has focused on spatial or location-based attention, in which the locations occupied by stimuli are selected for further processing. Recent research, however, has demonstrated the importance of objects in guiding attentional selection. Because of the long history of spatial attention research, theories of spatial attention are more mature than theories of other visual processes, such as object segregation and object attention. In the present chapter, we outline a biased competition account of object segregation and attention, following similar accounts that have been developed for visual search (Desimone & Duncan, 1995). In the biased competition account, there are two sources of visual information that allow an object to be processed over other objects: bottom-up information carried by the physical stimulus and top-down information based on an observer's goals. We use the biased competition account to combine many diverse findings from both behavioral and neurobiological studies of object attention.

Until the mid-1980s, the majority of research on selective visual attention studied spatial attention and the processes by which stimuli were selected on the basis of their location. Distinctions on topics such as the movement of the spatial focus (does it move smoothly through space or does it jump from place to place?) and the shape of the spatial window (is it a spotlight, a zoom lens, or a gradient?) were important to the theoretical perspectives that dominated the literature. However, the tide began to change with increasing demonstrations that objects may be the recipients of visual attention. With increasing demonstrations of so-called “object-based” attention, the strong spatial (or location-based) account fell from favor. Although there was initial debate over whether attention selects objects or locations, many researchers studying visual attention would agree that both forms of selection are possible because it is unlikely that there is a single attentional “bottleneck” or limitation (e.g., Allport, 1993; Haimson & Behrmann, in preparation; Luck & Vecera, 2000; Vecera & Luck, 2000).

Once the object-based versus location-based debate has been put aside, other interesting questions regarding the nature of attentional selection arise. For example, what processes form the objects that are selected? How are object-based selection and location-based selection combined to produce coordinated behavior? What are the neural mechanisms that underlie these forms of attentional selection? In this chapter we attempt to answer these questions by reviewing the recent object-based attention literature, including behavioral and neurobiological studies. Because space-based selective attention has been studied longer and more intensively than object-based selection, theoretical accounts of spatial attention are more mature than those of object attention (for theories of spatial attention see Desimone & Duncan, 1995; Mozer & Sitton, 1998; Sperling & Weichselgartner, 1995; Treisman, 1988; Wolfe, 1994). Because there are few theoretical account of object attention, our goal here is to illustrate the types of attentional phenomena that theories of object-based attention must explain and to outline a “biased competition” account of object-based attentional selection. Following previous work (Vecera, in press), we extend the biased competition account of visual search (Desimone & Duncan, 1995) to the selection of objects by attentional processes (also see Behrmann & Haimson, 1999; Haimson & Behrmann, in preparation; O’Craven, Downing, & Kanwisher, 1999). Our account is intended to provide a framework for organizing the object-based attention literature and, hopefully, generating questions for future research (Vecera, in press).

In what follows, we first discuss the visual processes relevant for object attention. We next outline generally the biased competition account of visual search presented by Desimone and Duncan (1995), and then apply the principles of biased competition to behavioral results that support object-based selection. We then discuss the cognitive neuroscience of object-based attention, focusing primarily on neuropsychological patients and neurophysiological studies. We summarize these results and discuss their relation to the biased competition account that we outline for the behavioral studies of object attention.

WHAT IS AN OBJECT?

Before reviewing findings and accounts of object-based attention, we must be clear what the term "object" means. In the context of attentional selection, "objects" refer to perceptual groups or units (see Logan, 1996, for example). These perceptual groups are formed through the application of the well-known gestalt principles of organization, principles such as proximity, similarity, good continuation, closure, connectedness, and so forth. Multiple theoretical accounts and many empirical results suggest that gestalt principles operate early in visual processing at a preattentive level (e.g., Julesz, 1984; Neisser, 1967; Treisman & Gelade, 1980). Further, a single perceptual group may have a hierarchical organization. A perceptual group may contain parts, and there are perceptual principles that can be used to define the parts of a perceptual group (e.g., Hoffman & Richards, 1984; Hoffman & Singh, 1997; Vecera, Behrmann, & Filapek, in press; Vecera, Behrmann, & McGoldrick., 2000). These perceptual grouping principles allow visual space or spatiotopic features to be organized. We refer to this perceptual grouping definition of "object" as a "grouped array" representation. The grouped array is an array-format, or spatiotopic, representation that codes features in specific retinal locations, similar to Treisman's (1988) feature maps. Various gestalt grouping principles organize this array into coherent chunks of visual information that correspond to objects or shapes. (Also see the next section of this volume for computational models of unit formation and grouping.) The spatial representations that underlie object-based attention may be shared with spatial attention (see Valdes-Sosa et al., 1997, for relevant results, which we discuss below).

Our definition of "object" points out a close connection between object segregation processes and object-based attention processes. Object segregation refers to the visual processes that determine which visual features combine to form a single shape and which features combine to form other shapes. Object segregation is synonymous with perceptual organization, the term used in conjunction with the gestalt principles of visual organization (e.g., Wertheimer, 1923/1958). The ability to perform figure-ground segregation and distinguish foreground shapes ('figures') from background regions also involves segregation processes (e.g., Rubin, 1915/1958), although figure-ground segregation may follow earlier image segregation processes (Vecera & O'Reilly, 1998). An example of object segregation appears in Figure 1, which contains two perceptual groups that are formed by the gestalt principles of proximity and good continuation.

The features are individual line segments that are organized into two distinct shapes—two lines, a straight line and a squiggly line. Note that these two "objects" (lines) are approximately equal in their salience. Neither object appears to grab attention more effectively than the other object. However, in such a display, empirical evidence indicates that one of these objects could be selectively attended.

The fact that the two objects in Figure 1 have approximately equal salience indicates that the

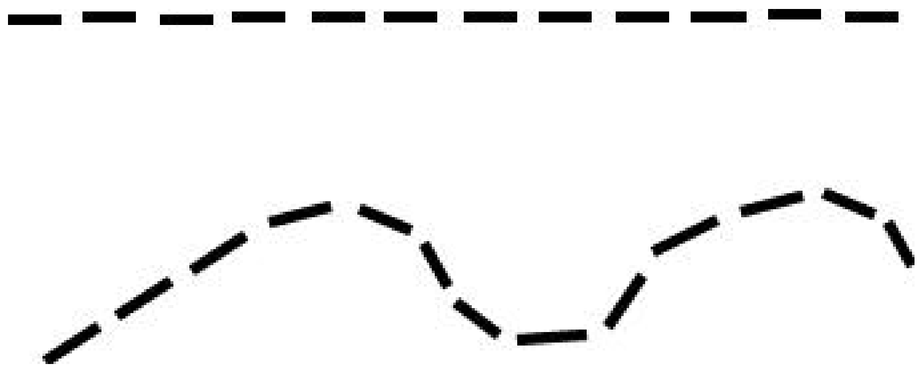

Figure 1. An example of object segregation in which gestalt proximity and good continuation form two perceptual groups (two lines). The small straight lines of line the top group together because they are closer to one another than the small lines of the bottom line.

human visual system must be capable of somehow creating a processing bias favoring one of theseobjects over the other. Object-based attention (that is, directing attention to one of these objects) may provide a mechanism for favoring either the straight line or squiggly line in Figure 1. Object-based attention refers to the visual processes that select a segregated shape from among several segregated shapes. As we noted above, object segregation and object-based attention likely are interrelated—before a shape can be selected, the features of the shape first must be segregated from features of other shapes to some extent. In Figure 1, before an observer could attend to the squiggly line, the features of that line must be grouped together (and grouped separately from the features of the straight line). Further, object-based attention is more efficient when it is directed to a single object; that is, observers can select either the straight line or the squiggly line with relatively little effort. In contrast, it is more difficult to divide object-based attention across multiple objects; if an observer needed to attend to both lines, object-based selection would be more effortful. Object-based attention either would have to shift between the two lines or would need to be divided between the two lines. Either shifting or division of attention cause performance to decline; this declining performance is the basis of many object-based attentional effects reported in the literature (e.g., Baylis & Driver, 1993; Behrmann, Zemel, & Mozer, 1998; Duncan, 1984, 1993a, 1993b; Egly, Driver, & Rafal, 1994; Vecera, 1994; Vecera & Farah, 1994). Many of these object-based attentional effects are influenced by the spatial position of objects, indicating that object-based attention may involve the selection of grouped locations (Vecera, 1994; Vecera & Farah, 1994). However, the coordinate system of these grouped locations is poorly understood, and not all forms of object selection may involve attending to grouped locations (Vecera & Farah, 1994; Lee & Chun, in press).

In sum, any account of object-based attention needs to explain (1) the segregation processes that provide the input to object attention and (2) the object selection effect, in which one object and all of its features are more readily attended than multiple objects (or multiple features on different objects). We now turn to the key ideas behind the biased competition account that we will discuss in conjunction with behavioral studies of object attention. Because visual scenes contain many objects that compete with one another for attention, the visual system must allocate processing to one object over others. This allocation is achieved by biasing processing toward one object. This bias provides a resolution for the competition between objects. For example, the two objects in Figure 1 compete with one another for attention, yet observers can selectively process either of the lines, even though neither line has an 'inherent' processing advantage. The biased competition account attempts to explain how some objects are selected over others (also see Vecera, in press).

BIASED COMPETITION AND VISUAL SEARCH

The biased competition account we discuss relies heavily on the biased competition account of visual search outlined by Desimone and Duncan (1995; also see Cohen & Huston, 1994; Harter & Aine, 1984, for similar accounts). Visual search refers to the collection of visual processes that allow us to "find what we are looking for" (Wolfe, 1998) by using spatial attention to combine the features of objects (e.g., Treisman, 1988; Treisman & Gelade, 1980). Thus, visual search involves spatial selective attention. In a typical visual search task, several visual stimuli are present and an observer searches for a target among the distracting stimuli (e.g., find the black vertical bar among black horizontal bars and white vertical bars). Searching for a friend's face (the target) in a restaurant containing many people (the distractors) would be an example of real world visual search. Note that we are using the visual search paradigm to introduce the principles of biased competition. We are not endorsing any particular theoretical view or model of visual search. Similar biased competition ideas can be applied to other experimental paradigms (e.g., simple spatial cuing with peripheral and central precues), and we focus on visual search to illustrate the biased competition account discussed by Desimone and Duncan (1995).

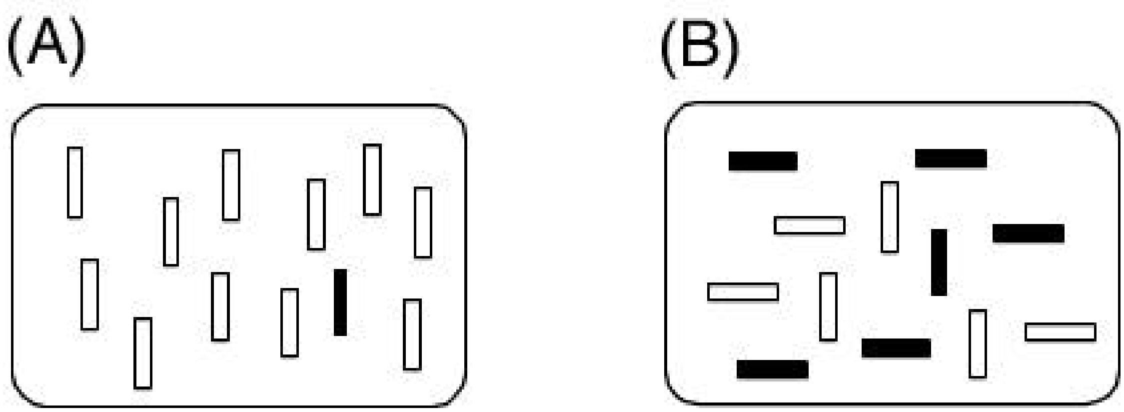

Figure 2. Sample visual search displays in which subjects search for a black vertical line. (A) An efficient feature search in which the target pops out from a homogeneous background. (B) An inefficient conjunction search in which the target does not pop out because the distractors share both black and vertical features with the target.

There are two important results from the visual search paradigm. First, targets that are highly salient (i.e., quite different from the background distractors) "pop out" and grab attention immediately and effectively (Figure 2A). These "feature searches" are performed efficiently in that the number of irrelevant distractors does not influence the time to search. Second, targets that are formed by a conjunction of features that are shared with the distractors require effortful search (Figure 2B). These inefficient conjunction searches are highly dependent upon the number of distractors present in a display; as the number of distractors increases, response times also increase (see Wolfe, 1998, for a comprehensive review of visual search).

How can these two results, which appear to be quite different, be explained? Desimone and Duncan's (1995) biased competition model provides an answer. There are two general principles of their account. First, multiple visual stimuli compete for attention. Second, the competition for attention is biased toward some stimuli over others. This biasing comes from two sources of information: bottom-up sources that arise from sensory stimuli present in a scene and top-down sources that arise from the current behavioral goals. Visual search performance requires both bottom-up stimulus sources and top-down control sources to be considered and balanced against one another, each source of information providing constraints on visual processing.

In the biased competition account of visual search, the display presented in a visual search task provides the bottom-up information that is searched through; this information indicates where objects are located and which features are present at each location. In efficient visual search (Figure 2A), the target may pop out from the distractors because of a possible bottom-up bias to orient attention to local inhomogeneities (e.g., Sagi & Julesz, 1985), which may involve a preference for orienting to novel items in a display. The abrupt appearance of a new object or shape also captures attention in an efficient manner (Yantis & Jonides, 1984; see Yantis, 1998, for a review), suggesting that abrupt onsets bias bottom-up attentional orienting. Thus, efficient visual search is almost exclusively driven by bottom-up input to the visual system, allowing salient targets to pop out and control spatial attention. In some search tasks, however, bottom-up pop out may involve top-down parameters: Some search targets only pop out if they are task-relevant and are the target of a visual search (Yantis & Egeth, 1999).

Under Desimone and Duncan's (1995) account of visual search, inefficient visual search may arise when there is no unique bottom-up stimulus characteristic to influence attentional allocation. Such a conjunction search (Figure 2B) may depend heavily on the top-down control of spatial attention in which items in a scene are examined in a sequential or sequential-looking manner. The primary source of top-down control in Desimone and Duncan's (1995) account is the target's description or identity—what is referred to as a "target template" (also see Duncan & Humphreys, 1989). Visual search must be sensitive to the goals of an observer; that is, an observer must be able to search for targets that may not be biased by the bottom-up input to the visual system. The target template is based on the visual features of the target (e.g., "black and vertical" in Figure 2). In visual search experiments, the target template typically is based on an experimenter's instructions ("search for a black, vertical bar") that is stored in visual working memory for the duration of the task or trial (e.g., Duncan & Humphreys, 1989; but see Woodman, Vogel, & Luck, in press). The target template acts to weight the incoming bottom-up stimulus information to allow attention to be biased toward one bottom-up input over another. In a less efficient conjunction search (Figure 2B), no single piece of bottom-up information is unique to the target item, so the bottom-up biases are less effective in guiding attention to the target. Top-down constraints are required to resolve the competition among the bottom-up inputs and bias attention toward the black, vertical line.

This brief overview of Desimone and Duncan's (1995) account highlights the two primary sources of attentional control in visual search—bottom-up and top-down sources. The biased competition model has proven useful in describing a range of behavioral, neurobiological, and neuroimaging data from experiments that rely on spatial attention, which suggests that the general approach of combining stimulus information and goal-related information may provide an accurate description of many attentional phenomena. How well could a biased competition approach explain the results from the emerging literature on object-based visual attention? We address this question in the subsequent sections by outlining a biased competition framework for object-based attentional control.

BIASED COMPETITION AND OBJECT-BASED ATTENTION

Bottom-Up Biases in Object Attention

In multi-object scenes, objects or regions compete with one another in two respects. The first type of competition occurs within object segregation processes and the perceptual regions formed by these processes. The outcome of this competition is a perceptual group that is more salient than other groups. Figure-ground segregation provides an ideal example: Symmetric figures, which are perceived as lying in the foreground, are more salient and shape-like than asymmetric backgrounds. In some displays, however, there may not be a salient group that "wins out" over other groups. This could occur, for example, in scenes that contain two asymmetric regions; because neither region has the bottom-up cue of symmetry, neither has a processing advantage over the other. The second type of competition occurs within object-based attentional processes; the outcome of this competition is the selection of one perceptual group or figure over another. Object attention is likely to be necessary when there are no salient regions defined by object segregation cues, as when two asymmetric regions abut in a figure-ground display. Directing object-based attention to one of these regions would allow that region to be selected and become attentionally more salient than the unattended region. Although these two sources of competition are highly interrelated, they tend to be discussed as separate in the visual cognition literature. Our main focus here will be on object-based attention and the sources of bottom-up information that bias the allocation of object attention.

Most of the object-based attention literature can be characterized as a search for the image grouping cues that influence attentional allocation in a bottom-up manner. Several studies, for example, have used Eriksen's flanker task to determine the stimulus cues that guide attentional selection of objects. The flanker task was one of the earliest paradigms developed to study spatial selective attention (e.g., Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1973). Observers are instructed to report a target letter appearing at a location (e.g., at the fixation point); the target letter is surrounded, or flanked, by non-target letters which are either compatible with or incompatible with the response to the target. For example, observers are instructed to determine if a target letter is an H or a T; the target letter is either flanked by compatible letters (e.g., H flanked by other Hs) or by incompatible letters (e.g., H flanked by Ts). The flankers influence how the target is processed: Flankers compatible with the target letter speed target identification and flankers incompatible with the target slow target identification.

The attentional selection involved in the flanker task can be biased by several object-grouping effects. Perhaps the earliest demonstration of object-grouping in the flanker task came from Driver and Baylis (1989), who reported that targets and flankers that moved together were processed as a single perceptual group (but see Kramer et al., 1991, for a failure to replicate). Driver and Baylis' (1989) results suggest that attention is biased to process simultaneously items moving in a common direction. These observations were extended to other bottom-up cues by Baylis and Driver (1992), who demonstrated that targets and flankers that were the same color were processed as a single group and that targets and flankers that were grouped through good continuation were processed simultaneously. In a similar manner, Kramer and Jacobson (1991) showed that connectedness biased attentional selection in a flanker task. A target that was physically connected to the flankers was attended as a single unit or group; a target that was not connected to the flankers could be selectively attended with little influence from the surrounding flankers. As with other gestalt cues, connectedness cues bias attention to select items that are physically connected to one another (see Palmer, 1992, 1999, for a discussion of the connectedness grouping cue).

A bottom-up bias over object selection also has been observed in spatial cuing tasks. Observers are given advance information about a target's location by a spatial precue, and responses to targets are typically more accurate and faster when the cue and target appear at the same location (validly cued target) than at different locations (invalidly cued targets; see Posner, 1980; Posner et al., 1980). Egly and colleagues used a spatial cuing task to study object-based attention (Egly et al., 1994; also see Vecera, 1994). In this task, depicted in Figure 3, observers viewed two rectangles. The rectangles were perceptual groups formed by closure and common region. One end of one of these shapes was cued, and a target appeared after the cue. Observers were instructed to detect the onset of the targets, and the targets could appear in one of three locations: at the spatially cued location (Figure 3A), in the opposite end of the cued object (Figure

3B), or in the uncued object (Figure 3C). The targets that appear at the uncued location in the cued object are the same spatial distance from the cued region as the targets that appear in the uncued object. Using this task, Egly et al. reported that observers showed a spatial cuing effect; observers were faster to detect targets at the spatially cued location than at either of the uncued locations. More important, observers exhibited an object effect by detecting targets appearing in the cued object faster than targets appearing in the uncued object. These results indicate that closure and

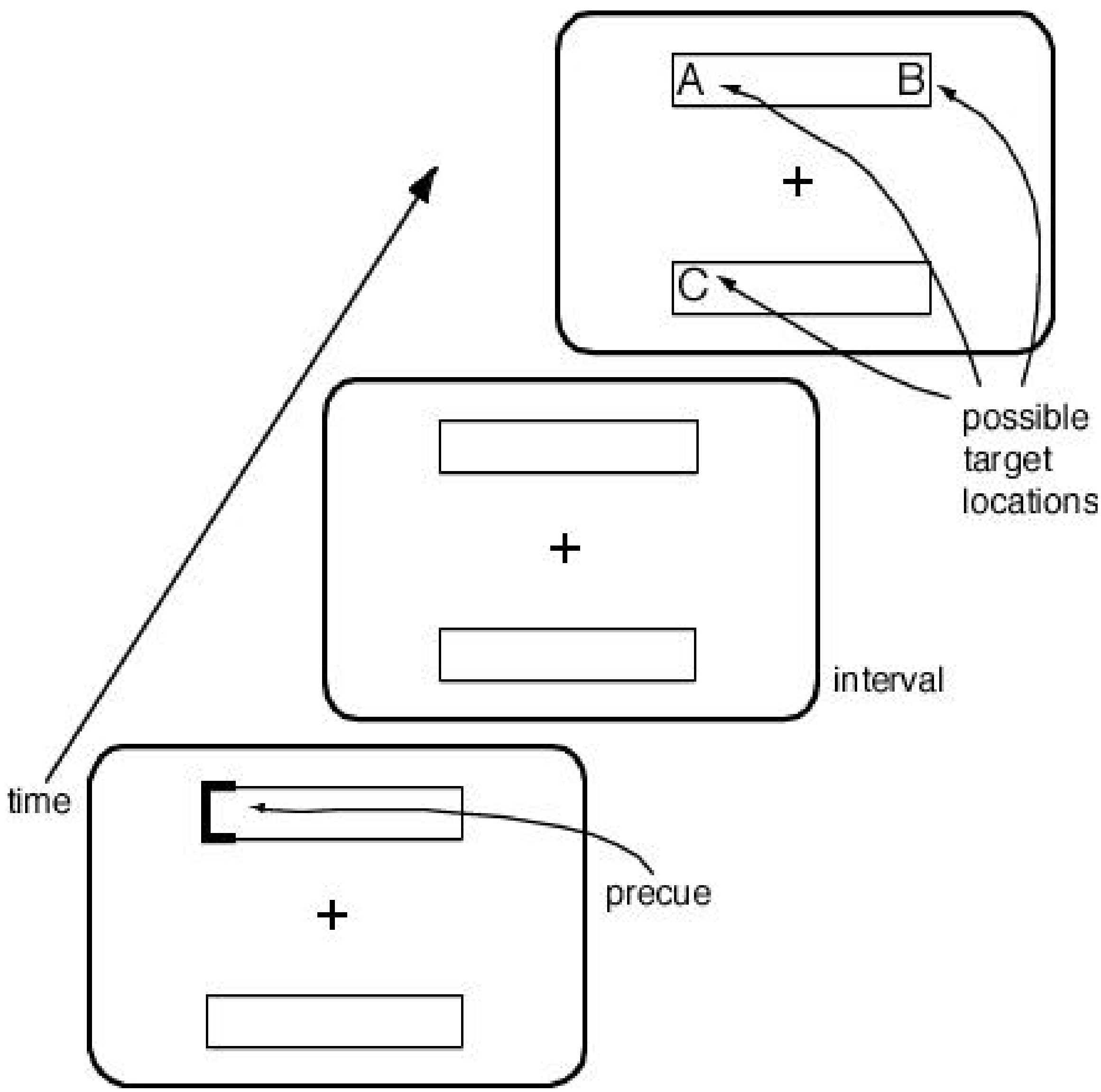

Figure 3. Egly et al.'s (1994) cuing task which was developed to study object-based attention. Two rectangles appear, and the end of one is precued with a peripheral precue. After a delay, a target appears at one of three locations: (A) a validly cued target; (B) an invalidly cued target that appears in the cued object; (C) an invalidly cued object that appears in the uncued object. Subjects are faster to detect invalidly cued targets appearing in the cued rectangle faster than those appearing in the uncued rectangle.

connectedness bias the allocation of spatial attention. When spatial attention is summoned to a cued location, attention can spread or move more easily within a closed region than between closed regions. We should note the possibility that this task also may involve top-down information under a biased competition account; we discuss this possible top-down effect later.

Finally, bottom-up biases in attention exist for the segregation of an object into parts. Bottom-up image cues that allow an object to be decomposed into its parts, such as minima of curvature cues (Hoffman & Richards, 1984; Hoffman & Singh, 1997; Singh & Hoffman, this volume), influence attentional selection. Some of our recent research demonstrates that observers are more accurate reporting features from a single part of an object than from multiple parts of an object (Vecera, Behrmann, & Filapek, in press; Vecera, Behrmann, & McGoldrick, 2000). These part-based attentional costs do not appear to be caused by selection with a simple spatially-based attention mechanism such as a "spotlight" because changing the physical separation between the parts of an object influences attention very little, if at all (Vecera, Behrmann, & Filapek, in press). The cost of dividing attention between two parts did not increase as the spatial separation of the parts increased. In some experimental paradigms, attention appears to select the parts themselves, and not the visual space occupied by the parts.

Information contained in a visual scene—bottom-up information—appears to both define perceptual groups and bias some groups to be more easily perceived than others. Once these segregation processes have operated, perceptual groups then bias the allocation of visual attention. In general, features or stimuli that group together based on the gestalt principles bias attentional selection. Attention must obey those perceptual units formed by gestalt grouping processes, allowing attention to shift more easily within a group than between groups, for example.

Although object attention obeys the boundaries and groups formed by grouping processes, object attention is not guided entirely by these bottom-up biases. Visuomotor behavior would be severely limited if humans only recognized, attended, and acted upon objects defined by bottom-up criteria. Visual attention must be modulated by information that is relevant to current behavior or goals. This modulation of attention comes in the form of top-down inputs that can bias the competition among perceptual groups or objects. In the next section, we review some of the sources of top-down information that may influence or guide object attention.

Top-Down Biases in Object Attention

In many cases, visual scenes do not contain an isolated, perceptually salient region that is uniquely relevant to the current behavior, such as searching for a coffee cup on a cluttered desk. Instead, there may be multiple regions or objects that have equal salience or, in the worst case, there may be an irrelevant object that is more salient than the object relevant to a current goal. For example, if an observer's current goal is to drink from the coffee cup, an error message abruptly appearing on the computer monitor would conflict with the goal-relevant object (the coffee cup). Top-down sources of information are needed either to bias attention to one of many equally salient objects or groups or to overcome a salient but behaviorally-irrelevant object or group. What sources of top-down information influence object attention, and what evidence is there for these top-down influences? There are at least three sources of top-down information in object attention tasks: (1) object recognition processes, (2) perceptual "set" processes, and (3) endogenous spatial attention processes. We discuss these sources in turn (see Vecera, in press, for a more detailed discussion).

Top-down biases from object recognition processes. Object representations stored in long-term visual memory represent familiar objects, such as a familiar face or a word. Behavioral studies have shown that familiar objects can provide top-down feedback to object attention processes. For example, Vecera & Farah (1997) demonstrated that familiar objects (upright letters) are selected by object attention more rapidly than less-familiar objects (rotated letters).

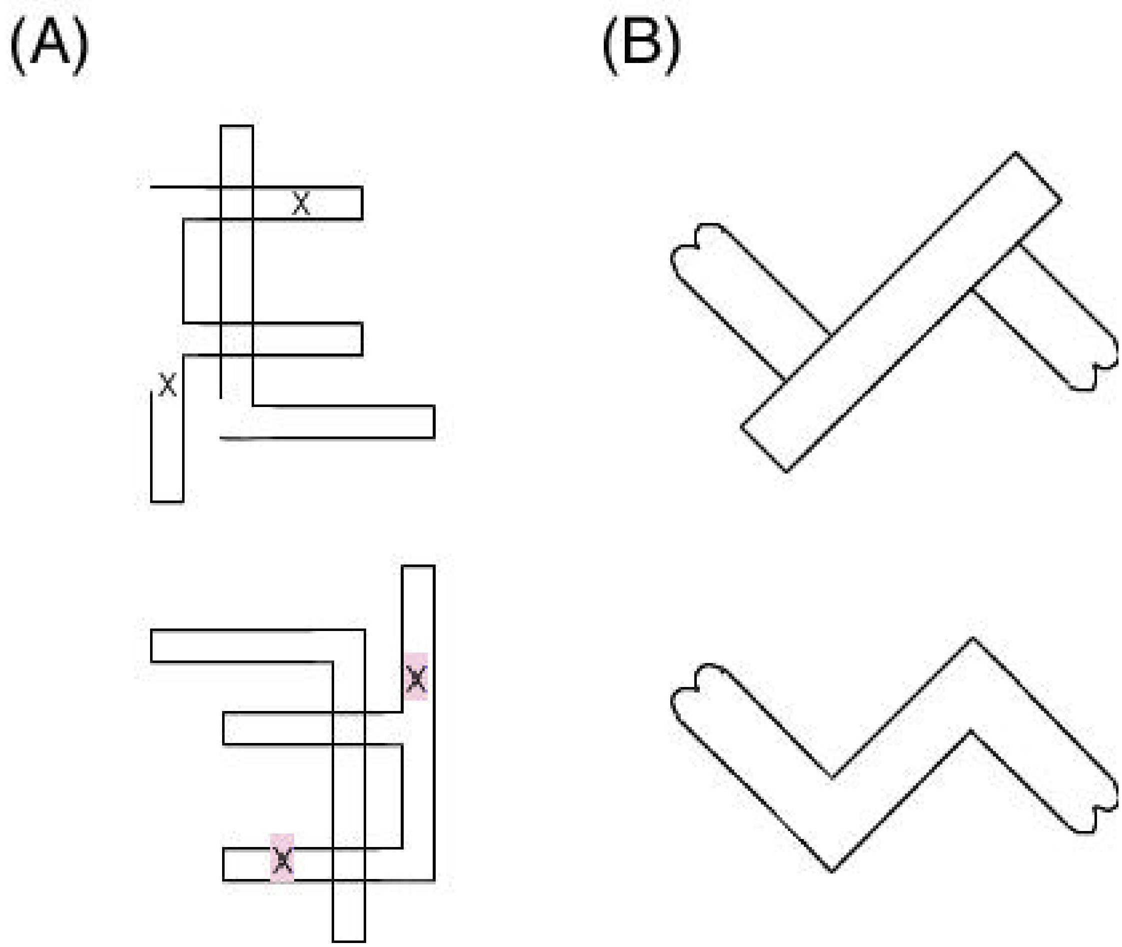

Figure 4. (A) Stimuli used by Vecera and Farah (1997) to study familiarity effects in object segregation and object-based attention. Familiar objects, such as upright letters, are selected and processed faster than less-familiar objects, such as upside down letters. (B) The Z-shaped displays used by Zemel et al. (submitted) to study the effects of learning on object attention. In the top panel, bottom-up cues typically lead to the perception of mis-aligned ends as being on different objects. However, if subjects see Z-shaped stimuli in the course of the experiment, as shown in the bottom panel, they interpret mis-aligned object ends (top) as being on a single object.

Observers viewed displays that contained two overlapping transparent letters, such as those shown in Figure 4A and were asked to determine if two small Xs were on the same shape or on different shapes. This task requires observers to first segregate the two regions from one another and then to orient attention to the Xs in order to determine if the Xs are either on the same shape or on different shapes. Vecera and Farah's (1997) results suggested an object-based attention effect in this task: Observers were faster to respond when the Xs were on the same object than when they were on different objects. There also was an effect of object familiarity; reaction times were faster to the familiar upright letters than to the less-familiar, rotated letters (also see Kimchi & Hadad, submitted, for similar results). Further, in their final experiment, Vecera and Farah (1997) showed that object familiarity can override bottom-up stimulus cues such as connectedness and common region. Two unconnected regions could be grouped together and attended if those unconnected regions formed a familiar, upright letter. Thus, object attention appears to be influenced by shape familiarity in a top-down manner, and top-down familiarity cues can, in some cases, override bottom-up cues.

The influence of shape familiarity on object attention also was demonstrated by Zemel and colleagues (Zemel, Behrmann, Bavelier, & Mozer, submitted). In a series of studies, observers were shown an initially ambiguous display such as that shown in the top panel of Figure 4B. Naive observers who were required to decide whether the bumps at the end of the Z-shaped display were the same or different were slow at making this decision compared with the situation in which the bumps appeared at the end of a single, continuous bar (bottom panel of Figure 4B), suggesting that the Z-shaped displays were processed as two objects. Half the observers were then exposed to a stimulus display which is consistent with a single-object interpretation of the Z-display whereas the other half were only exposed to the fragments and no linking stimulus. When the observers were tested on the ambiguous displays again, only those subjects who had seen the linking Z displays, and not those who saw the fragments, showed reaction times to make the bump judgements as quickly on the unusual novel displays as on the single continuous bar. These data provide further support for the idea that experience with or familiarity of visual input can influence the segregation and perceptual organization of displays.

Perceptual set. Another mechanism for top-down bias signals in object attention comes from "perceptual set." Perceptual set loosely refers to the expectancies or goals held by an observer, which typically is established by the task-relevant instructions provided by an experimenter in a laboratory setting. For example, an observer could be instructed to report the shape of a red object that could appear anywhere in the display or report the identity of the object that appears at the 3 o'clock position in a cluttered array. In general, any type of task instruction provided by an experimenter may establish a specific perceptual set. Of course, in everyday behavior, there is no experimenter to establish perceptual set, and set must be established by the individual's current goals. In visual search tasks, for example, the target template may be akin to perceptual set. In object attention tasks, perceptual set may be a more general form of a "target template" because perceptual set refers to several possible types of information that observers can use to guide their behavior. Admittedly, the notion of perceptual set is vague and, therefore, the mechanisms that underlie perceptual set may be difficult to study. Nevertheless, several studies have shown that instructions provided by an experimenter can influence the manner in which objects are attended, supporting the notion that top-down information can bias bottom-up object selection.

A now-classic example of the influence of perceptual set on object selection comes from Neisser and Becklen (1975), who had observers view two spatially overlapping films that were played simultaneously. One film contained two sets of hands playing a "hand game" and the other film contained a basketball game. Because the films were spatially overlapped and because both films were approximately equally salient, there were few, if any, bottom-up cues to favor one film clip over the other. However, Neisser and Becklen (1975) instructed observers to attend to one film or both films. Not only could observers use this instruction to monitor the films, observers also showed an object-based (or film-based) attentional effect; observers were better able to monitor a single film (e.g., the basketball game only) than to divide their attention across both film clips. The experimenter's instructions allowed observers to selectively attend one of the two films, and attention was directed more effectively to a single event (i.e., film clip) than to multiple events.

Duncan's (1984) study of object-based attention also may demonstrate an influence of perceptual set. Observers viewed two overlapping objects, a box and a line, and each of these objects varied on two attributes. Observers reported pairs of attributes, which were located on either the same object (e.g., report the two attributes of the box) or on different objects (e.g., report one attribute of the box and one attribute of the line). The specific attributes to be reported were told to the observers at the beginning of the experiment (or at the beginning of a block of trials in Vecera and Farah, 1994, who used a similar procedure). The instructions provided to the observer biased attention toward the relevant attributes; thus, the observers' perceptual set influenced the allocation of attention to either one object or two. Using this paradigm, Duncan (1984) found that observers were more accurate reporting attributes from the same object than from different objects, thereby showing an object-based effect on attentional selection (also see Vecera & Farah, 1994).

Recent results reported by Baylis and Driver (Baylis, 1994; Baylis & Driver, 1993) also show the effects of perceptual set on object attention. Observers viewed figure-ground stimuli that contained three regions (Figure 5A) in which the central region was one color (e.g., red) and the two flanking regions were another color (e.g., green). Observers were asked to attend to two of the bent edges in the display and to report which apex was above the other. To manipulate whether observers attended one or two objects, Baylis and Driver (1993; Baylis, 1994) manipulated perceptual set by instructing each observer to pay attention to either the color red or the color green. On some trials, the central region was red, and observers attended to a single object; on other trials, the two flanking regions were red and observers attended to two objects. Observers were faster to compare the apices when one object was attended than when two objects were attended. This object-based effect occurred even though the apices were identical between the

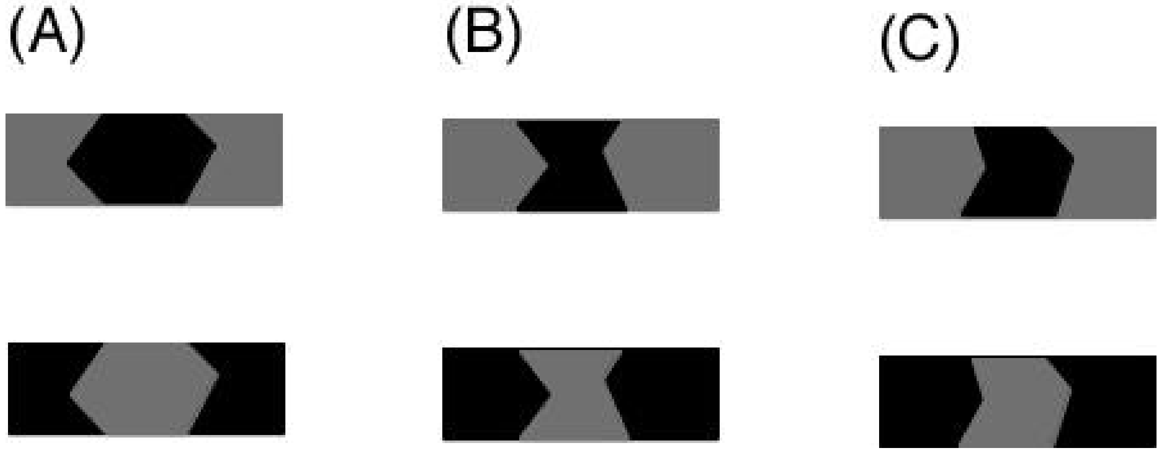

Figure 5. Stimuli in which perceptual set can create top-down effects in object-based attention tasks. (A) Stimuli used by Baylis and Driver (1993). If observers are instructed to perceive the black region, then the top panel involves attending to one object (the central black region) and the bottom panel involves attending to two objects (the flanking black regions). (B) Stimuli used by Gibson (1994) to show that a reversal of convexity reverses the object attention effects observed by Baylis and Driver (1993). (C) Ambiguous stimuli that do not contain convexity cues from Baylis (1994). See text for additional details.

central and flanking regions in a subset of the trials. Thus, object-based attention can be influenced by perceptual set: Observers responded faster and more accurately if perceptual set, based on the experimenter's instructions, biased selection of a single region than multiple regions.

Although Baylis and Driver's (1993) results appear consistent with a top-down biasing influence from perceptual set, there is a potential difficulty with their findings. This difficulty, pointed out by Gibson (1994), resulted in a theoretical exchange in the literature regarding the nature of perceptual set, bottom-up cues, and object-based attention (see Baylis, 1994; Gibson, 1994). This theoretical exchange can be understood better when viewed from the perspective of the biased competition that we have been outlining. The confound in the Baylis and Driver stimuli is visible in Figure 5A: The stimuli in Figure 5A contain a bottom-up cue to segregation—the central region was always convex and the two adjacent regions were always concave. Gibson (1994) correctly noted that convexity is a salient determinant of figure-ground segregation and, therefore, Baylis and Driver's (1993) results could have been caused by easier segregation of the central region, not object-based attention to a single region. That is, the convex region may have "popped out" to observers, allowing the apices of the central, convex region to be reported faster than the apices of the flanking, concave regions.

Gibson (1994) conducted a study in which he reversed the convexity in the stimuli by making the two flanking regions convex and the central region concave (Figure 5B). Interestingly, Gibson (1994) found that reversing the convexity also reversed the so-called object attention effect: Observers who viewed the stimuli in Figure 5B were faster to compare the apices when the two flanking regions were perceived as figure than when the central region was perceived as figure, a reversal of Baylis and Driver's (1993) results. Gibson's (1994) results suggest that salient bottom-up information, such as convex regions, may capture attention more effectively than less salient bottom-up information (concave regions). Object-based attention can be applied to multiple regions more effectively than to a single region, provided there is stimulus information (e.g., convexity) that favors the multiple-region interpretation of the scene over the single-region interpretation. In subsequent research, however, Baylis (1994) demonstrated an object-based effect in displays that had equal convexity between the central region and adjacent regions (Figure 5C). It is easier to select a single region than multiple regions when bottom-up cues are equated with one another and the only influence on object-based attention is perceptual set.

This exchange on the role of perceptual set in object attention is more than a minor disagreement about a stimulus confound when viewed from a biased competition account. The Baylis/Gibson exchange clearly shows that both bottom-up information and top-down perceptual set information can influence object attention. If bottom-up information, such as convexity, favors a two-object interpretation of a scene, attention may more easily select two objects than one object (Gibson's, 1994, results). However, bottom-up information alone does not guide object attention because equating all bottom-up cues allows perceptual set to have a continuing influence on object attention, which selects a single region more easily than two regions (Baylis', 1994, results).

Finally, Chen (1998) recently reported that object-based attentional effects were influenced by subjects' organization of a stimulus. Subjects viewed stimuli that could be perceived as either two objects (two V-shaped objects) or as one object (a single X-shaped object). Chen (1998) found that the instructions given to the subjects influenced object-based effects. Specifically, the subjects who were told they would see two V-shaped objects showed object-based effects; these subjects were faster to discriminate stimuli presented on a precued V shape than those stimuli presented on an uncued V shape. However, the subjects who were told to perceive the display as containing a single X showed no differences in discriminating stimuli on one region of the X shape or another region of the X shape. Subjects' perceptual set—the instructions provided by the experimenter—influenced how subjects organized and attended the displays.

<u>Top-down biases from spatial attention</u>. The studies that have used perceptual set to bias observers raise the issue of the mechanism that underlies perceptual set. Perceptual set can be viewed as an expectancy effect or a task demand imposed by the experimenter, but what are the visual processes involved in expectation or task demand? One possibility is that perceptual set involves the voluntary (or endogenous) control of spatial attention (e.g., Shulman, 1992; Tsal, 1994). Observers may voluntarily allocate their spatial attention to the region in the scene that is consistent with the instructions provided by the experimenter. For example, in Baylis and Driver's (1993) studies discussed above, observers who were instructed to attend to the red region may have shifted spatial attention to the red region, biasing this region to be perceived as figure. This account of perceptual set does find some empirical support in studies that show that overt attention—that is, eye fixation location—can influence the interpretation of a scene (e.g., Peterson & Gibson, 1994; Peterson & Hochberg, 1983). A voluntary spatial attention view of perceptual set suggests that spatial attention more generally may provide another top-down biasing signal in the

biased competition account. There are a handful of studies that can be interpreted as demonstrating a top-down bias from spatial attention to object attention.

Perhaps one of the most straightforward tasks that shows how a spatial precue (and spatial attention) can influence object selection is the cued detection task developed by Egly et al. (1994) that was discussed earlier (see Figure 3). Recall that the target usually appears at the cued location (Figure 3A); when the target appears at an uncued location it may appear within the cued object (Figure 3B) or in the other, uncued object (Figure 3C). The important result is that observers are faster to respond to targets appearing in the uncued end of the cued rectangle than at either end of the uncued rectangle. The object selection demonstrated in this paradigm may involve a top-down component in addition to the bottom-up cues of closure and common region that define the two rectangles as separate objects. The spatial precue likely allows spatial attention to bias attention in a top-down manner: Because the two rectangles are identical, there is no bottom-up bias to favor attention to one object over the other (as in the two lines in Figure 1). Therefore, if there was no spatial precue, each object should have an equal chance of being attended, and presumably object attention would select one of the two objects randomly. The spatial precue acts to bias processing toward the cued object, allowing observers to respond faster to targets appearing in the cued object than in the uncued object. The processing bias for the cued object remains even when the object moves its position (e.g., Lamy & Tsal, 2000).

The top-down role of spatial attention on object selection has been demonstrated more recently in a series of studies reported by Lavie and Driver (1996), who investigated the combined roles of spatial attention and object attention by using spatial precues with an object-based attention task. Observers viewed two overlapping lines (objects) and discriminated features that appeared on the same line (same object) or different lines (different objects). In their final study, Lavie and Driver (1996) precued the adjacent ends of the <u>different</u> objects, as shown in Figure 6. The spatial precue summoned attention to a subregion of the display that contained features from the different objects. This spatial precue abolished object-based attention; that is, observers were just as fast to report features on the same object as features on different objects. Because spatial attention was restricted to a subregion of the display, the entirety of both objects was no longer in a spatially attended region. Lavie and Driver (1996) concluded that object attention only occurs within a spatially attended region.

Although Lavie and Driver's (1996) results suggest a top-down influence from spatial attention to object attention processes, their explanation does not necessarily appeal to the mechanisms of biased competition. However, a biased competition account can readily explain the results from Lavie and Driver's (1996) final study without the need to suggest that object attention only occurs within a spatially attended region. An additional piece of procedural information is needed to explain Lavie and Driver's (1996) results with a biased competition account: The spatial precues used in their study were highly predictive. On 70% of the trials, observers were precued to attend to different objects. The top-down inputs from spatial attention were highly predictive and may have biased observers to adopt a spatial orienting strategy in which the objects were effectively

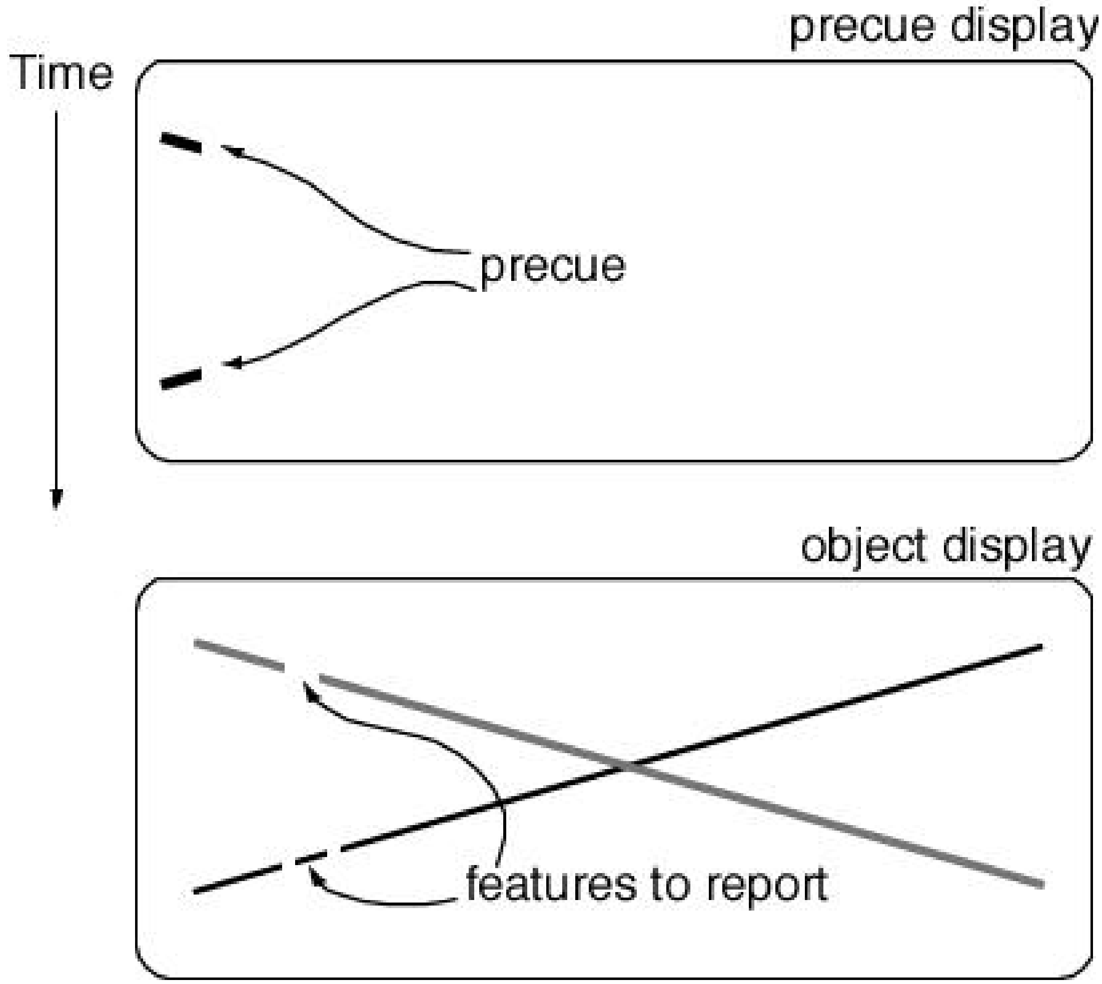

Figure 6. The spatial cuing procedure used by Lavie and Driver (1996) to argue that object-based attentional effects only occur within a spatially attended region. The ends of two different objects are cued (top), and subjects are asked to determine if two features are the same or different. The features most frequently appear near the cued regions; that is, the features are usually on different objects. When different objects are consistently precued, object-based attention effects disappear in this task.

ignored. The perceptual set established by a frequent spatial precue was to attend to different objects.

It follows from a biased-competition account that less-predictive spatial precues, in which the top-down inputs are weaker than those used by Lavie and Driver (1996), may not abolish object-based attention. Gilds & Vecera (submitted) tested this possibility by allowing the bottom-up object segregation cues to compete against non-predictive spatial precues. When the spatial precue was valid on 50% of trials (compared to 70% of the trials in Lavie & Driver, 1996), observers were faster to respond to features on the same object than on different objects. The spatial precue did not abolish the object-based effect, unlike what Lavie and Driver (1996) found using highly predictive spatial precues. Thus, object attention may no occur only within a spatially attended region; instead, both bottom-up and top-down factors influence object attention and the <u>strengths</u> of the top-down inputs also must be considered. Highly predictive (i.e., strong) spatial precues may allow observers to favor a spatial-selection strategy over an object-selection strategy, as in Lavie and Driver's (1996) results. These strategies may be established by observers' perceptual set, and perceptual set may be established through the statistical regularities of a task.

Summary

Both bottom-up, stimulus-driven cues and top-down, goal-driven cues can influence object attention. The allocation of object-based attention within a scene is dependent upon the cooperation and competition of bottom-up and top-down cues. Presumably, both sources of information influence behavior in important ways. For example, our visual systems need to be sensitive to bottom-up cues because these cues contain information regarding salient information in the external world. However, to maintain flexible behavior that is not entirely stimulus driven, visual processing must be modified by an observer's goals.

In the foregoing review, we have interpreted only behavioral results within the biased competition framework. In addition to the behavioral results, there are many recent results from cognitive neuroscience that also appear to support a biased competition account of object attention, such as findings that demonstrate neurons in primary visual cortex are sensitive to both figure-ground relations (e.g., Lamme, 1995; Zipser et al., 1996) and object-based attention (e.g., Roelfsema et al., 1998). In the next section, we discuss the cognitive neuroscience of object-based attention, including neuropsychological and neurophysiological approaches. Our goal in the next section is to show that the biased competition account of object attention provides a framework for results from different methodologies.

COGNITIVE NEUROSCIENCE OF OBJECT-BASED ATTENTION

Two important avenues of research in cognitive neuroscience have contributed to our understanding of object-based attention. The first avenue involves studies of humans with damage to the visual system, usually acquired in adulthood as a consequence of stroke, tumor, or trauma. The second avenue involves the study of nonhuman primates and includes behavioral studies as well as single neuron recording studies of awake, behaving animals.

Neuropsychology of Object-Based Attention

Data obtained from individuals with deficits following brain damage traditionally have provided an important source of evidence for theories of visual processing and, more recently, for theories of object-based attention. Two patient populations are of particular interest for the current purpose: patients with agnosia following lesions to the ventral or occipito-temporal cortical visual pathway and patients with hemispatial neglect following lesions to the dorsal or occipito-parietal pathway. We consider each neuropsychological deficit in turn.

Visual agnosia. The data from patients with visual agnosia is particularly relevant for understanding the processes involved in object segregation or the derivation of perceptual groups. Visual agnosia refers to an inability to identify or recognize even common objects presented in the visual modality, with intact semantics and recognition of objects through other sensory modalities. This disorder includes, at one end of the spectrum, a fairly low-level deficit such as the inability to extract featural elements from a display and, at the other end of the spectrum, a rather higher-level deficit such as the failure to assign meaning to an object despite the derivation of an intact percept (see Farah, 1990; Humphreys & Riddoch, 2000a, for reviews of this literature). Of particular relevance for the present discussion are a group of agnosic patients who mostly have available to them the features or elements in the display but who are unable to group these features into a meaningful and rich percept. These patients have problems with processes involved in perceptual organization, including figure-ground segregation, binding shapes from featural forms and binding surface properties to shapes. The consequence of the failure to individuate an object, part of an object or even a group of objects is that attention can not be biased to select specific object/s for further processing as no candidates are available. The standard behavioral effects associated with object-based attention, such as the facilitation of features of a single object, are consequently not obtained with these patients.

The absence of these object-based attention effects is exemplified in the performance of patient, JW, whom we have studied in some depth over the past few years (Vecera & Behrmann, 2000; Vecera & Behrmann, 1997). JW was in his late thirties when he suffered a severe cardiac event, the result of which was an anoxic encephalopathy (deprivation of oxygen from the brain). Although no focal masses or obvious infarcts are visible on neuroimaging, multiple hypodensities are seen in both occipital lobes on CT scan as well as more minor hypodensities in the right parietal lobe. A mild upper left visual field cut is present although this has no adverse effect on his performance in the tasks we conducted. JW appears to be unable to integrate contours as manifest in his inability to trace around the edges of two overlapping rectangles. He also performs at chance on the Efron (1968) shape matching task in which the subject is required to match two rectangles which vary in shape but are equal in area. Although JW is able to group elements in an image to some extent, based on Gestalt properties such as similarity or proximity, his ability to organize an image based on good continuation, closure or symmetry is poor. JW’s visual disorder impairs his ability to recognize objects, even those that are encountered frequently, as well as faces and letters (for review of similar patients, see (Heider, 2000).

Most relevant for the current purpose is that JW does not benefit from within-object cueing, as evident in his performance on an Egly et al. (1994) object-based attention cuing task (Vecera & Behrmann, 1997). As mentioned previously, this task involves a precue followed by a target which appears either in the cued location (valid condition), in a location on the cued object but at the opposite end of the cued location (invalid, within-object condition) or in a location on the noncued object that is equidistant to the within-object location (invalid, between-object location). Normal subjects matched to JW (as well as the controls in the original experiment; Egly, Driver, & Rafal, 1994) detect the presence of the target most rapidly in the valid condition. The more important result is that they also detect the target faster in the within-object than in the between-object condition, reflecting the benefit accrued from sharing a location on the same object as the cue. This is the facilitation afforded by object-based attention. JW also shows fastest performance in the valid condition, reflecting normal spatial orienting. Unlike the control subjects, however, he showed no difference between the within- and between-object conditions. The absence of the object-based attention advantage likely reflects the failure on JW's part to establish the two objects as separate perceptual groups and to benefit from this segregation. JW's failure to organize the image perceptually precludes any benefit from the cued object. The finding that JW was still able to orient to spatial locations (fastest performance in the valid condition) reflects the separation of spatial- and object-based attentional processing. That JW had preserved the ability to deploy spatial attention is verified in another experiment using the same paradigm but in which the distance between the two objects is manipulated. JW again showed fastest performance on the valid condition. Consistent with characteristics of spatial-based attention, when the distance between the rectangles was reduced, JW detected the target faster in the invalid, between object condition than in the invalid, within-object condition as the former is spatially closer to the cue than the latter. Taken together, these findings illustrate how a deficit in the analysis and assembly of features can impair the subsequent operation of object-based attention when the image is not fully or correctly segmented. Spatial attention, however, is not dependent on perceptual grouping and operates independently and apparently normally.

The inability to organize an image perceptually is also the hallmark feature of integrative agnosia. This label was coined by Riddoch and Humphreys (1987) specifically to distinguish between patients who can perform feature analysis but who fail to integrate the features from other patients who are agnosic but with different underlying problems. As with JW, these patients also do not show object-based attention effects because they fail to organize the incoming image perceptually. Their perceptual performance however, is slightly better than that of JW who does not always have the elemental features in a display available to him. This is reflected in his less-than-normal performance on search tasks for some elementary features. In some cases, for example, searching for a target line feature which is less than 45 degrees different from the background distractor, JW does not show popout or normal target detection as the number of distractors increase (Mapelli and Behrmann, unpublished observations). In contrast, integrative agnosic patient, HJA, described in detail by Riddoch and Humphreys (Humphreys & Riddoch, 1987; Riddoch & Humphreys, 1987) is able to perform popout visual search for a feature that differs from the distractors in orientation. It is only when the target requires a conjunction of features or when the distractors differ from each other and require some form of grouping that performance is most obviously impaired (Humphreys & Riddoch, 2000b; Humphreys et al., 1994).

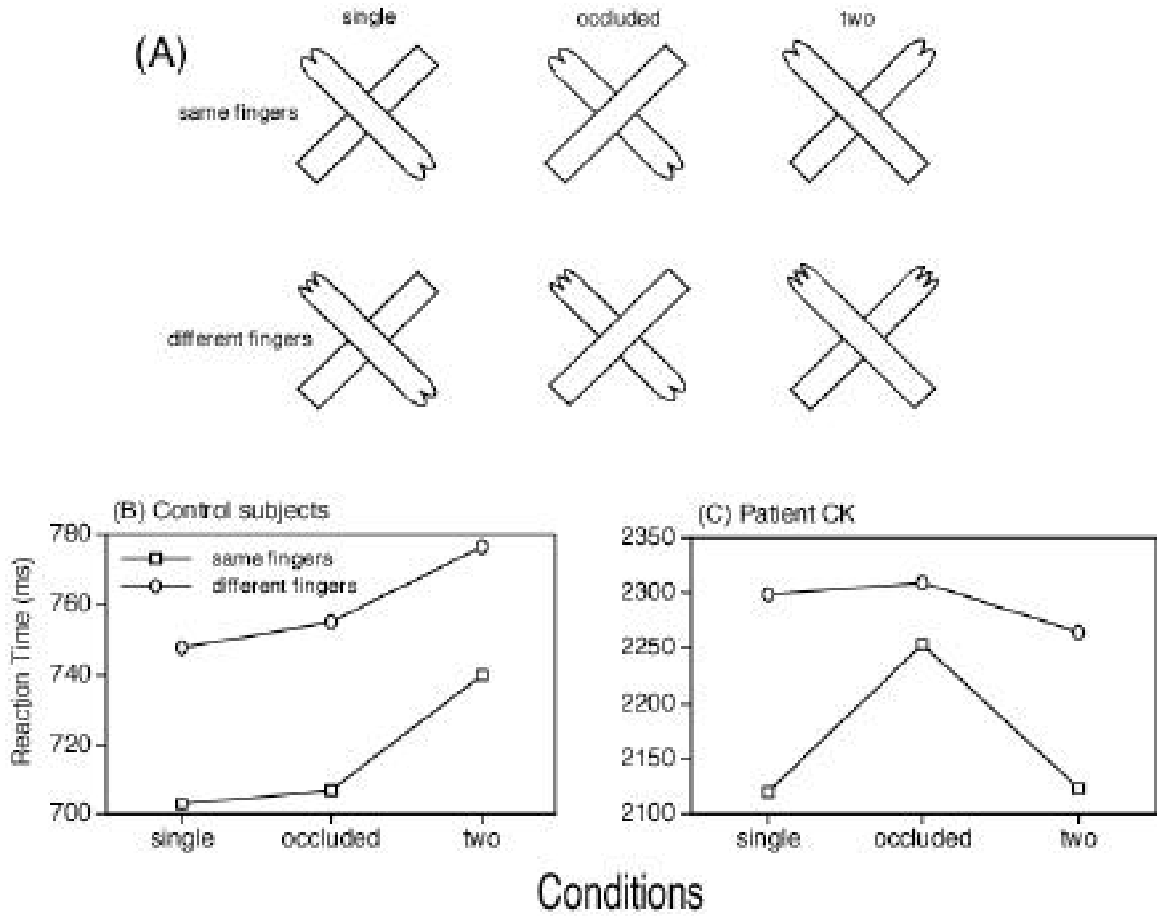

Figure 7. (A) Examples of displays from Behrmann et al.'s (1998) object attention task. Same and different judgements, shown in columns, are made to bumps appearing at ends of a single, unoccluded object, of two different objects or of a single, occluded object. (B) Reaction time data obtained from normal subjects (left panel; data from Behrmann et al., 1998) and patient CK (right panel) on the single, occluded and two object conditions for same and different trials.

CK, a patient whom we have studied, exhibits performance similar to HJA. Like HJA, he fails to recognize common objects and is severely alexic. CK fails at figure-ground segregation tasks and his performance is poor when objects overlap compared with when they are depicted in isolation (Behrmann, Moscovitch, & Winocur, 1994). Critically, CK does not show a single-object advantage, namely, the ability to process the features of a single object in parallel. For example, we tested him on a paradigm in which subjects are required to decide, as quickly as possible, whether the number of bumps appearing at two of the four possible ends of overlapping rectangle are the same or not (Behrmann, Zemel, & Mozer, 1998; Behrmann, Zemel, & Mozer, 2000). As shown in Figure 7A, there are three conditions in this task, shown in the three rows, all of which are crossed with same/different judgements, as reflected in the columns. In the first, the single object condition, the bumps appear at the ends of a single, unoccluded objects. In the second condition, the bumps appear at the end of two different objects and, in the third condition, the bumps appear at the ends of an occluded object. Whereas the normal subjects are equivalently fast to make the bumps decision on the single and occluded object, and both of these conditions are faster than the two-object condition, especially for ‘same’ judgements, this was not so for CK. Aside from the enormous intercept differences between the controls and patient CK, CK shows no difference between the single and the two object condition, reflecting the absence of the single-object benefit (Figure 7B). Interestingly, his performance for ‘same’ occluded objects is disproportionately slow, suggesting that he has difficulty integrating or processing in parallel the spatially discontinuous component parts. Taken together, the data from the agnosic patients reveals the failure of perceptual organization or object derivation. In the absence of candidate objects or groups of objects, attention cannot be biased preferentially to enhance the features of the possible objects and, thus, object-based attention no longer operates normally.

Visual hemispatial neglect. Hemispatial neglect refers to a deficit in which patients do not orient to or report information appearing on the side of space opposite the side of the brain lesion. Thus, following a lesion to the right hemisphere, patients may only draw information on the right, ignoring corresponding information on the left, may only eat from the right side of the plate and may only dress or apply make-up to the right side of the body (see Bisiach & Vallar, 2000; Vallar, 1998, for review of the phenomena). These patients, like those with agnosia as reviewed above, have a problem in deriving a coherent percept and, consequently, have disorders of object-based attention. In the case of hemispatial neglect, the problem arises specifically because these patients do not process or represent adequately the information occurring on the contralesional side. The question is what consequences this spatial deficit has for object-based attention.

The failure to represent contralesional information has recently been thought of as a failure to select information on the contralesional side as a consequence of a biased spatial competition mechanism. Neglect is thought to arise from a gradient of spatial attention or bias such that, following brain damage, fewer neurons are available to represent information on the contralesional than on the ipsilesional side. The consequence of this is that information on the ipsilesional side is activated so much more strongly than contralesional information that it invariably wins in a winner-take-all outcome. This imbalance as a function of neuronal distribution occurs not only between the two hemifields but also within a single hemifield, giving rise to better performance even for stimuli on the relative left of the right visual field. This theoretical interpretation of neglect has received much support not only from studies which describe the distribution of neurons in parietal cortex (Duhamel & Hamed, personal communication; Rizzolatti, Berti, & Gallese, 2000) and from neuropsychological studies of patients (Cate & Behrmann, 2000; di Pellegrino, Basso, & Frasinetti, 1998; di Pellegrino, Basso, & Frassinetti, 1997), but also from studies which explore the nature of the competition which manifests after parietal damage (Cohen, Romero, Servan-Schreiber, & Farah, 1994; Mozer, 1999; Pouget & Driver, 2000).

Of most interest to the present issue is that contralesional information can be detected under some circumstances. For example, in those cases where contralesional information can be grouped with the corresponding ipsilesional information, selection of information on the left is possible and extinction of the contralesional information can be overridden. It is the knowledge about objects and their structure that offsets the negative bias associated with the contralesional information. For example, Ward, Goodrich, and Driver (1994) showed that when the contralesional item could be grouped with the ipsilesional information on the basis of Gestalt factors such as similarity (for example, a bracket on the left and a bracket on the right) or symmetry, report of the left-sided stimulus improved by roughly 50% compared to when the left sided information could not be grouped with a simultaneous right sided stimulus. The same pattern was obtained when the two items formed a familiar configuration (for example, an arrow made of a left arrowhead and a right horizontal bar). This modulation of extinction of the contralesional information has suggested that, in the context of a competitive mechanism, the negative bias for the contralesional information is reduced such that contralesional and ipsilesional information form a single group and cooperate rather than compete.

The reduction of extinction through grouping has now been replicated in several studies with parietal patients and better processing of the contralesional information has been shown when the left-sided information can be grouped by bottom-up factors such as color and proximity field (Driver & Halligan, 1991) or brightness or collinear edges (Gilchrist, Humphreys, & Riddoch, 1996; Rorden, Mattingley, Karnath, & Driver, 1997). A reduction in contralesional extinction is also seen when the left information is grouped with the right information by a global outline (Farah, Wallace, & Vecera, 1993). We also see modulation of poor left-sided processing when the contralesional information forms the left side of an illusory contour (Kanizsa-type figure), of a partially occluded figure (Mattingley, David, & Driver, 1997; see also Driver, Baylis, & Rafal, 1992) or of any well-configured object or whole (Gilchrist et al., 1996; Humphreys & Riddoch, 1994).

Low-level mechanisms of edge assignment may also influence the neglect outcome, with attention being allocated exclusively to those shaped regions to which an edge has been assigned. When viewing ambiguous 2D displays comprising adjacent regions separated by a common vertically oriented articulated contour, the region on the left is perceived as being figure and is matched or copied better than the region to the right (Driver, Baylis, & Rafal, 1992; Marshall & Halligan, 1994; Mattingley, Price, & Driver, 2000; Peterson, Gerhardstein, Mennemeier, & Rapcsak, 1998). Performance, however, was also influenced by the familiarity of the object in that the region on the left was picked as figure with even greater frequency when the contralesional information corresponded to a high denotative (familiar) object (Peterson et al., 1998). Interestingly, even when the dividing contour depicted a high denotative object, the low denotative region on the left was still identified as figure despite the fact that the patient could identify the high denotative shapes when they appeared to the right (Mattingley et al., 2000). This finding attests to the robust and powerful influence of edge assignment in modulating what is neglected and what is perceived.

Temporal processes can also influence extinction. Recent data from the study of patient GK, who has bilateral parietal lesions, suggests that extinction may arise from the temporary binding of the information (Riddoch, Humphreys, & Nys, 2000). In their study, they demonstrated that GK could report two stimuli when the onset of the stimuli was common (but not the offset) and the display duration was short (300 ms and less) but not when it was above 500 ms. The term 'anti-extinction' was adopted by the authors to indicate the recovery of the extinguished contralesional information. In this case, the temporal similarity between the contralesional and ipsilesional stimuli, rather than their common form characteristics, was sufficient for them to be equally activated and reported. Although common onset suffices for anti-extinction effects, when it is pitted against other object-segmentation cues such that the contralesional and ipsilesional information appear to belong to different objects, the advantage of common onset is overridden and extinction is, once again, observed.

Top down lexical effects also play a role with less extinction for known, familiar objects than for unknown objects (Ward & Goodrich, 1996; Ward et al., 1994) and for left-sided stimuli that form a unified lexical representation with the right-sided item (for example, COW BOY as opposed to COW SUN; Behrmann, Moscovitch, Black, & Mozer, 1990; Brunn & Farah, 1991).

Taken together, these findings suggest that visual elements may enter into grouping prior to or simultaneous with the distribution of spatial attention. The extent to which the elements cohere and form a robust perceptual group may determine whether neglect is observed or not.

Physiology of Object-Based Attention

In contrast to the focus on parietal lobe involvement in neuropsychological studies of object selection, physiological studies have implicated several other cortical areas in object attention. Neurophysiological studies from behaving monkeys have implicated primary visual cortex (V1) and the supplementary eye fields (SEF) in coding objects for attentional orienting. Human electrophysiological studies have suggested shared mechanisms between object-based and space-based selection, consistent with attentional selection from a grouped spatial array (Vecera, 1994; Vecera & Farah, 1994) that involves both object segregation processes and object attention processes.

Over the past few years, a potential conundrum has arisen in neurophysiological studies of visual attention (Posner & Gilbert, 1999): Does visual attention operate at the level of primary visual cortex, or V1? Many earlier studies failed to find V1 attention effects in this area (e.g., Luck et al., 1997; Moran & Desimone, 1985), but more recent studies of appear to show attention effects in this visual area (Gandhi et al., 1999; Motter, 1993; Roelfsema et al., 1998). Object-based attentional orienting may provide an explanation for when V1 attentional effects will be observed—attention may operate at the level of V1 when objects are selected. V1 may provide a neural substrate for a grouped-array representation.

In an important study, Roelfsema and colleagues demonstrated object-based attentional effects in area V1. Specifically, Roelfsema et al. (1998) demonstrated that attending to one of two objects in a display results in enhanced firing for neurons whose receptive fields contain features of the attended object. Monkeys viewed scenes containing two objects (simple curves); one of the objects was connected to the fixation point, and monkeys were trained to attend to this object. The monkeys' task was to make an eye movement from the fixation point to the opposite end of the attended curve. Segments of the curves fell within receptive fields of V1 neurons. The neuronal responses were larger when a receptive field contained a segment of the attended curve than a segment of the unattended curve. This object-based attentional modulation in area V1 is important because previous studies of spatial attention were equivocal in finding V1 attentional modulation. Neurons in V1 may exhibit attentional modulation when an object can act as the recipient or focus of attention; neurons in V1 may not appear to exhibit attentional modulation with blank displays or nonorganized cluttered displays. Objects may need to be present to receive the top-down feedback from spatial attention processes.

Beyond the object-based effects observed in primary visual cortex, neurophysiological studies also have suggested that object-based effects can occur in the oculomotor system. Olson and Gettner (1995, 1999) showed that neurons in the supplementary eye fields (SEF), located on the dorsomedial surface of the frontal lobes, represent object-centered spatial selectivity for the direction of eye movements. SEF neurons seem to code for spatial positions within an object, such as the left side of the object. Olson and Gettner trained monkeys to make eye movements to the onset of a visual target. The target appeared in one of three conditions: alone in an otherwise blank display, at the left end of an object (a rectangle), or at the right end of an object. The absolute direction of the eye movement was identical in all three conditions; that is, the monkeys' eyes moved in exactly the same direction and same distance across these conditions. Although the eyes moved identically, a subset of SEF neurons fired at higher rates when eye movements were executed to a specific region of the object, regardless of object's absolute spatial location. For example, some neurons responded vigorously to eye movements to the right side of the object; the same eye movement that landed on the left side of the object resulted in a smaller neuronal response. Thus, SEF neurons code for locations within an object; how these locations are coded (e.g., in a grouped array or in another representation) is unknown.

Finally, several recent studies have investigated object selection by using event-related potential (ERP) studies with humans. Kramer and colleagues (Weber, Kramer, & Miller, 1997) took issue with the late, object-based visual working memory selection explanation of Duncan's (1984) results offered by Vecera and Farah (1994). Instead, Weber et al. hypothesized that selection in this task may occur at the perceptual level from a grouped array representation. To determine if object selection in Duncan's task occurred from a spatiotopic array, Weber et al. had subjects perform a version of this task while ERPs were recorded from scalp electrodes. Two overlapping objects were presented to the left or right of fixation, and subjects reported pairs of attributes from these objects. The attributes appeared either on the same object or on different objects. On two-thirds of the trials, a task-irrelevant probe stimulus followed the presentation of the object stimuli. Task irrelevant probes have been used extensively to study spatial attention (see

Hillyard et al., 1998; Luck, 1998; Luck & Vecera, in press; Vecera & Luck, in press, for reviews). Early ERP components, specifically the P1 and N1 components, are generated by task irrelevant probes, and the voltage amplitudes of these components are larger when the probes appear at attended locations than at unattended locations (Luck, 1998).

Weber and colleagues reasoned that if attention was selecting from a grouped spatial array, then probes that appeared at the location of the two overlapping stimuli should evoke larger responses when subjects report attributes from the same object than from different objects. The results appeared to support this predicted outcome. Behaviorally, subjects were more accurate reporting attributes from the same object than from different objects. The irrelevant-probe evoked P1 components had larger amplitudes in the same-object condition than in the different-object conditions. However, this P1 effect is correlational with the object effect observed in the behavioral data, and, therefore, the P1 effect could be due to other variables. For example, the P1 effect could have been caused by the abrupt onset of the objects; abrupt onsets are known to capture spatial attention (Yantis, 1998; Yantis & Jonides, 1984). The capture of spatial attention by the abrupt appearance of the objects may have been modulated indirectly by the same-object and different-objects conditions. Specifically, in the same-object condition, spatial attention could have been captured and allocated to a smaller region in the object display; in the different-objects condition, spatial attention could have been captured and allocated to a larger region of the object display. The size of the spatial focus may not cause the object effect observed in the behavioral data but may produce differences in the amplitude of the P1 component.

Although some aspects of Weber et al.'s data may not support grouped-array selection, results presented by Valdes-Sosa et al. (1997) are very compelling. Valdes-Sosa et al. had subjects view displays containing two superimposed surfaces that occupied the same spatial location and rotated in opposite directions; subjects' subjective impressions were to see two separate moving surfaces, or objects. Subjects were asked to selectively attend to one of the two surfaces. Either the attended surface and the unattended surface moved in a linear (i.e., non-rotational) motion. These motion onsets were used to generate ERPs. Motion changes to the attended surface produced early ERP components with larger amplitudes than stimuli presented on the unattended surface. Specifically, changes on the attended surface generate larger P1, N1, and N2 components compared to changes on the unattended surface. The P1 and N1 components typically are modulated by spatial attention (see Hillyard et al., 1998; Luck, 1998), suggesting a spatial component in Valdes-Sosa et al.'s data that occurred despite the spatial overlap between the two objects. The similarity of these effects to the spatial attention effects described above suggest that some object-based effects may be generated by neural processes shared with spatial attention. Attentional selection may be occurring from a grouped spatial array in which motion segregation cues allow the two dot surfaces to be separated from one another on the basis of a bottom-up image cue—common motion. This stimulus cue may have allowed the two dot surfaces to be segregated in depth, which then permitted object-based attention to select one surface over the other.

Connections to Biased Competition

The biased competition framework we outlined earlier may lend some conceptual organization to the results from neuropsychological patients and single-unit recordings just reviewed. Different populations of neuropsychological patients appear to have become insensitive to particular object attention cues. For example, patient JW (Vecera & Behrmann, 1997), who had visual form agnosia, was unable to make use of bottom-up image cues for segregating the visual field and attending to objects. In contrast, patients with hemineglect may be able to make use of bottom-up information, but attentional processes, which may influence object segregation in a top-down manner, appear to be disrupted in these patients.

The neurophysiological results we reviewed also can be interpreted within the biased competition framework we have outlined. Most of the studies conducted to date have investigated the bottom-up control of object-based attention. Olson and Gettner's (1995, 1999) research demonstrates that oculomotor control is influenced by shapes in the visual environment. Roelfsema et al.'s (1998) curve tracing results suggest that attentional processes are influenced by the structure of the images that are being searched. But, the curve that is selected in the curve-tracing task is due to behavioral goals (i.e., where the monkey must move its eyes), a top-down factor, pointing to both bottom-up and top-down influences in Roelfsema et al.'s (1998) task. A similar conclusion comes from Landman et al. (2000, cited in Lamme et al., 2000), who discussed recent results from their lab demonstrating different time courses for bottom-up and top-down processing components. Landman et al. (2000) discuss the results of research in progress that presented monkeys with a multi-object scene while multiunit recordings were made from area V1. Based on previous research (e.g., Lamme, 1995), V1 appears to play a role in segregating an object from the background (figure-ground segregation). In the multi-object displays, object segregation occurred temporally early and did not depend upon the number of objects in the display. However, a temporally later component of the physiological response did depend on the number of objects in the display, indicating an object-based attentional component. Image-based bottom-up cues to object segregation appear to influence processing early, followed by top-down attentional factors. Finally, Valdes-Sosa et al.'s (1997) electrophysiological results suggest that stimulus cues, namely common motion, can establish perceptual groups that are then selected by attention; the attentional selection observed in this task bears a striking similarity to spatial selection. Thus, Valdes-Sosa et al.'s findings may be interpreted as an early object segregation process influencing later attentional processes in a bottom-up manner.

SUMMARY & CONCLUSIONS

Visual scenes typically contain many objects that compete for attention. Some of these objects may be more salient than others, and some of these objects may be more relevant for a current behavioral goal than others. Object salience and goal or task relevance characterize the two main influences on object attention under the biased competition framework we have proposed here. In this chapter, we outlined a biased competition framework for object-based attentional selection. The strength of this framework is that it provides a conceptual structure for interpreting the many behavioral results regarding object-based attentional selection. We admit that the framework may ultimately be unfalsifiable, but the framework is useful to the extent that it (1) organizes previous research, (2) suggests directions for future research (e.g., studying the control parameters that influence top-down and bottom-up aspects of object attention), and (3) generates more specific, falsifiable theories of object selection. We also reviewed several recent findings on the neural mechanisms that may be involved in object-based attention, and these results also may be accommodated within the biased competition framework.

We would like to conclude by pointing out that the general principles of our biased competition framework are consistent with the principles of parallel distributed processing (PDP) models and that the biased competition view could be instantiated concretely in a PDP models. Our own efforts at computational modeling (e.g., Mozer, Zemel, Behrmann, & Williams, 1992; Vecera & O'Reilly, 1998, 2000) are consistent with the idea that there are multiple cues to object segregation and attention. The theoretical usefulness of the biased competition account we have presented will be determined by this account's ability to guide the development of future computational models as well as future experimental studies.

REFERENCES

Allport, A. (1993). Attention and control: Have we been asking the wrong questions? A critical review of twenty-five years. In D. E. Meyer & S. Kornblum (Eds.), *Attention and Performance XIV* (pp. 183-218). Cambridge, MA: MIT Press.

Baylis, G. C. (1994). Visual attention and objects: Two-object cost with equal convexity. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 208-212.

Baylis, G. C., & Driver, J. (1992). Visual parsing and response competition: The effect of grouping factors. *Perception & Psychophysics*, *51*, 145-162.

Baylis, G. C., & Driver, J. (1993). Visual attention and objects: Evidence for hierarchical coding of location. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 451-470.

Behrmann, M., & Haimson, C. (1999). The cognitive neuroscience of visual attention. *Current Opinion in Neurobiology, 9*, 158-163.

Behrmann, M., Moscovitch, M., Black, S. E., & Mozer, M. C. (1990). Perceptual and conceptual factors in neglect dyslexia: Two contrasting case studies. *Brain*, *113*, 1163-1183.

Behrmann, M., Moscovitch, M., & Winocur, G. (1994). Intact visual imagery and impaired visual perception in a patient with visual agnosia. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1068-1087.

Behrmann, M., Zemel, R., & Mozer, M. C. (1998). Object-based attention and occlusion: Evidence from normal subjects and a computational model. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1011-1036.

Behrmann, M., Zemel, R., & Mozer, M. C. (2000). Occlusion, symmetry, and object-based attention: Reply to Saiki (2000). *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 1497-1505.

Bisiach, E., & Vallar, G. (2000). Unilateral neglect in humans. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology*. North-Holland, Amsterdam: Elsevier Science.

Brunn, J. L., & Farah, M. J. (1991). The relation between spatial attention and reading: Evidence from the neglect syndrome. *Cognitive Neuropsychology*, *8*, 59-75.

Cate, A., & Behrmann, M. (2000). *Hemispatial neglect: Spatial and temporal influences*. Manuscript submitted for publication.

Chen, Z. (1998). Switching attention within and between objects: The role of subjective organization. *Canadian Journal of Experimental Psychology*, *52*, 7-16.

Cohen, J., Romero, R., Servan-Schreiber, D., & Farah, M. J. (1994). Mechanisms of spatial attention: The relation of macrostructure to microstructure in parietal neglect. *Journal of Cognitive Neuroscience, 6*, 377-387.

Cohen, J. D., & Huston, T. A. (1994). Progress in the use of interactive models for understanding attention and performance. In C. Umiltá & M. Moscovitch (Eds.), *Attention and Performance XV* (pp. 453-476). Cambridge, MA: MIT Press.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*, 193-222.

di Pellegrino, G., Basso, G., & Frasinetti, F. (1998). Visual extinction as a spatio-temporal disorder of selective attention. *NeuroReport*, *9*, 835-839.

di Pellegrino, G., Basso, G., & Frassinetti, F. (1997). Spatial extinction on double asynchronous stimulation. *Neuropsychologia*, *35*, 1215-1223.

Driver, J., Baylis, G. C., & Rafal, R. D. (1992). Preserved figure-ground segregation and symmetry perception in visual neglect. *Nature*, *360*, 73-75.

Driver, J., & Halligan, P. W. (1991). Can visual neglect operate in object-centered coordinates: An affirmative study. *Cognitive Neuropsychology*, *8*, 475-496.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General*, *113*, 501-517.

Duncan, J. (1993a). Similarity between concurrent visual discriminations: Dimensions and objects. *Perception & Psychophysics, 54*, 425-430.

Duncan, J. (1993b). Coordination of what and where in visual attention. *Perception, 22*, 1261-1270.

Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, *96*, 433-458.

Efron, R. (1968). What is perception? *Boston Studies in Philosophy of Science, 4*, 137-173.

Egly, R., Driver, J., & Rafal, R. D. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General, 123*, 161-177.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*, 143-149.

Eriksen, C. W., & Hoffman, J. (1973). The extent of processing of noise elements during selective encoding from visual displays. *Perception & Psychophysics, 14*, 155-160.

Farah, M. J. (1990). *Visual Agnosia*. Cambridge, MA: MIT Press.

Farah, M. J., Wallace, M., & Vecera, S. P. (1993). "What" and "where" in visual attention: Evidence from the neglect syndrome. In I. H. Robertson & J. C. Marshall (Eds.), *Unilateral neglect: Clinical and Experimental Studies* (pp. 123-138). Hove, UK: Erlbaum.

Gandhi, S. P., Heeger, D. J., & Boynton, G. M. (1999). Spatial attention affects brain activity in human primary visual cortex. *Proceedings of the National Academy of Sciences, 96,* 3314-3319.

Gibson, B. S. (1994). Visual attention and objects: One versus two or convex versus concave? *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 203-207.

Gilchrist, I. D., Humphreys, G. W., & Riddoch, M. J. (1996). Grouping and extinction: Evidence for low-level modulation of visual selection. *Cognitive Neuropsychology*, *13*, 1223-1249.

Gilds, K. S., & Vecera, S. P. (submitted). *The influence of spatial attention on object-based selection*. Manuscript submitted for publication.

Goldsmith, M. (1998). What's in a location? Comparing object-based and space-based models of feature integration in visual search. *Journal of Experimental Psychology: General*, *127*, 189-219.

Haimson, C., & Behrmann, M. (in preparation). *Objects in attention: The many faces of object-based selection*.

Harter, M. R., & Aine, C. J. (1984). Brain mechanisms of visual selective attention. In R. Parasuraman & D. R. Davies (Eds.), *Varieties of Attention* (pp. 293-321). Orlando, FL: Academic Press.

Heider, B. (2000). Visual form agnosia: Neural mechanisms and anatomical foundations. *Neurocase*, *6*, 1-12.

Hillyard, S. A., Vogel, E. K., & Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: Electrophysiological and neuroimaging evidence. *Philosophical Transactions of the Royal Society of London*, *353B*, 1257-1270.

Hoffman, D. D., & Richards, W. (1984). The parts of recognition. *Cognition*, *18*, 65-96.

Hoffman, D. D., & Singh, M. (1997). Salience of visual parts. *Cognition*, *63*, 29-78.

Humphreys, G. W., & Riddoch, M. J. (1987). *To See but not to See: A Case-Study of Visual Agnosia*. Hillsdale, NJ: Erlbaum.

Humphreys, G. W., & Riddoch, M. J. (1994). Attention to within-object and between-object spatial representations: Multiple sites for visual selection. *Cognitive Neuropsychology, 11,* 207-241.

Humphreys, G. W., & Riddoch, M. J. (2000a). Knowing what you need but not what you want: Affordance and action-defined templates in neglect. *Behavioral Neurology*.

Humphreys, G. W., & Riddoch, M. J. (2000b). Neuropsychological disorders of visual object recognition and naming. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology* (Vol. 4,). North-Holland: Elsevier Science.

Humphreys, G. W., Riddoch, M. J., Donnelly, N., Freeman, T., Boucart, M., & Muller, H. M. (1994). Intermediate visual processing and visual agnosia. In M. J. Farah & G. Ratcliff (Eds.), *The Neuropsychology of High-Level Vision* (pp. 63-101). Hillsdale, New Jersey: Lawrence Erlbaum.

Julesz, B. (1984). A brief outline of the texton theory of human vision. *Trends in Neurosciences*, *6*, 41-45.

Kimchi, R., & Hadad, B. (2000). *Influence of past experience on perceptual grouping*. Manuscript submitted for publication.

Kramer, A. F., & Jacobson, A. (1991). Perceptual organization and focussed attention: The role of objects and proximity in visual processing. *Perception & Psychophysics*, *50*, 267-284.

Kramer, A. F., Tham, M.-P., & Yeh, Y.-Y. (1991). Movement and focused attention: A failure to replicate. *Perception & Psychophysics*, *50*, 537-546.

Lamme, V. A. F. (1995). The neurophysiology of figure-ground segregation in primary visual cortex. *Journal of Neuroscience*, *15*, 1605-1615.

Lamme, V. A. F., Supér, H., Landman, R., Roelfsema, P. R., & Spekreijse, H. (2000). The role of primary visual cortex (V1) in visual awareness. *Vision Research, 40*, 1507-1521.

Lamy, D., & Tsal, Y. (2000). Object features, object locations, and object files: Which does selective attention activate and when? *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 1387-1400.

Landman, R., Lamme, V. A. F., & Spekreijse, H. (2000). Gradual transition from preattentive to attentive components in a neural correlate of figure-ground segregation in monkey V1. *Investigative Ophthalmology and Visual Science*, *40* (Suppl. S200).

Lavie, N., & Driver, J. (1996). On the spatial extent of attention in object-based visual selection. *Perception & Psychophysics*, *58*, 1238-1251.

Logan, G. D. (1996). The CODE theory of visual attention: An integration of space-based and object-based attention. *Psychological Review*, *103*, 603-649.

Luck, S. J. (1998). Neurophysiology of selective attention. In H. Pashler (Ed.), *Attention* (pp. 257-295). East Sussex, UK: Psychology Press.

Luck, S. J., Chelazzi, L., Hillyard, S. A., & Desimone, R. (1997). Neural mechanisms of spatial selective attention in areas V1, V2, and V4 of macaque visual cortex. *Journal of Neurophysiology*, *77*, 24-42.

Luck, S. J. & Vecera, S. P. (2000). Attention: From tasks to mechanisms. To appear in H. Pashler & S. Yantis (Eds.), *Steven's Handbook of Experimental Psychology*.

Marshall, J. C., & Halligan, P. W. (1994). The yin and yang of visuo-spatial neglect: A case study. *Neuropsychologia*, *32*, 1036-1057 .

Mattingley, J. B., David, G., & Driver, J. (1997). Pre-attentive filling in of visual surfaces in parietal extinction. *Science*, *275*, 671-674.

Mattingley, J. B., Price, M. C., & Driver, J. (2000). *Figure-ground segmentation of ambiguous 2D displays: Clues to object-based visual neglect*. Paper presented at the Cognitive and Neural Bases of Spatial neglect, Como, Italy.

Moran, J., & Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science*, *229*, 782-784.

Motter, B. C. (1993). Focal attention produces spatially selective processing in visual cortical areas V1, V2 and V4 in the presence of competing stimuli. *Journal of Neurophysiology*, *70*, 909-919.

Mozer, M. C. (1999). Explaining object-based deficits in unilateral neglect without object-based frames of reference. In J. A. Reggia, E. Ruppin, & D. Glanzman (Eds.), *Disorders of Brain, Behavior, and Cognition: The Neurocomputational Perspective* (pp. 99-119). Amsterdam: Elsevier.

Mozer, M. C., & Sitton, M. (1998). Computational modeling of spatial attention. In H. Pashler (Ed.), *Attention* (pp. 341-393). Hove, UK: Psychology Press.

Mozer, M. C., Zemel, R. S., Behrmann, M., & Williams, C. K. I. (1992). Learning to segment images using dynamic feature binding. *Neural Computation*, *4*, 650-665.

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

Neisser, U., & Becklen, R. (1975). Selective looking: Attending to visually specified events. *Cognitive Psychology*, *7*, 480-494.

O'Craven, K. M., Downing, P. E., & Kanwisher, N. (1999). fMRI evidence for objects as the units of attentional selection. *Nature*, *401*, 584-587.

Olson C. R., & Gettner, S. N. (1995). Object-centered direction selectivity in the macaque supplementary eye field. *Science*, *269*, 985-988.

Olson C. R., & Gettner, S. N. (1999). Macaque SEF neurons encode object-centered directions of eye movements regardless of the visual attributes of instructional cues. *Journal of Neurophysiology*, *81*, 2340-2346.

Palmer, S. E. (1992). Common region: A new principle of perceptual grouping. *Cognitive Psychology*, *24*, 436-447.

Palmer, S. E. (1999). *Vision Science: From Photons to Phenomenology*. Cambridge, MA: MIT Press.

Peterson, M. A., Gerhardstein, P. C., Mennemeier, M., & Rapcsak, S. Z. (1998). Object-centered attentional biases and object recognition contributions to scene segmentation in left and right hemisphere patients. *Psychobiology*, *26*, 557-570.

Peterson, M. A., & Gibson, B. S. (1994). Object recognition contributions to figure-ground organization: Operations on outlines and subjective contours. *Perception & Psychophysics*, *56*, 551-564.

Peterson, M. A., & Hochberg, J. (1983). Opposed-set measurement procedure: A quantitative analysis of the role of local cues and intention in form perception. *Journal of Experimental Psychology: Human Perception and Performance*, *9*, 183-193.

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

Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, *109*, 160-174.

Posner, M. I., & Gilbert, C. D. (1999). Attention and primary visual cortex. *Proceedings of the National Academy of Sciences*, *96*, 2585-2587.

Pouget, A., & Driver, J. (2000). Relating unilateral neglect to the neural coding of space. *Current Opinion in Neurobiology*, *10*, 242-249.

Riddoch, M. J., & Humphreys, G. W. (1987). A case of integrative visual agnosia. *Brain*, *110*, 1431-1462.

Riddoch, M. J., Humphreys, G. W., & Nys, G. (2000). *Characteristics of anti-extinction and extinction effects*. Paper presented at the Cognitive and Neural Bases of Spatial neglect, Como, Italy.

Rizzolatti, G., Berti, A., & Gallese, V. (2000). Spatial neglect: Neurophysiological bases, cortical circuits and theories. In F. Boller & J. Grafman (Eds.), *Handbook of Neuropsychology*. North-Holland, Amsterdam: Elsevier Science.

Roelfsema, P. R, Lamme, V. A. F, & Spekreijse, H. (1998). Object-based attention in the primary visual cortex of the macaque monkey. *Nature*, *395*, 376-381.

Rorden, C., Mattingley, J. B., Karnath, H.-O., & Driver, J. (1997). Visual extinction and prior entry: Impaired perception of temporal order with intact motion perception after unilateral parietal damage. *Neuropsychologia*, *35*, 421-433.

Rubin, E. (1915/1958). Figure and ground. In D. C. Beardslee & M. Wertheimer (Eds.), *Readings in Perception* (pp. 194-203). Princeton, NJ: Van Nostrand. (Original work published 1915.)

Sagi, D., & Julesz, B. (1984). Detection versus discrimination of visual orientation. *Perception, 13*, 619-628.

Shulman, G. L. (1992). Attentional modulation of a figural aftereffect. *Perception*, *21*, 7-19.

Sperling, G., & Weichselgartner, E. (1995). Episodic theory of the dynamics of spatial attention. *Psychological Review*, *102*, 503-532.

Treisman, A. (1988). Features and objects. The fourteenth Bartlett memorial lecture. *Quarterly Journal of Experimental Psychology*, *40A*, 201-237.

Treisman, A., & Gelade, G. A. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*, 96-136.

Tsal, Y. (1994). Effects of attention on perception of features and figural organisation. *Perception*, *23*, 441-452.

Valdes-Sosa, M., Bobes, M. A., Rodriguez, V., & Pinilla, T. (1998). Switching attention without shifting the spotlight: Object-based attentional modulation of brain potentials. *Journal of Cognitive Neuroscience*, *10*, 137-151.

Vallar, G. (1998). Spatial hemineglect in humans. *Trends in Cognitive Sciences*, *2*, 87-96.

Vecera, S. P. (1994). Grouped locations and object-based attention: Comment on Egly, Driver, & Rafal (1994). *Journal of Experimental Psychology: General*, *123*, 316-320.

Vecera, S. P. (in press). Toward a biased competition account of object-based segregation and attention. *Brain and Mind*.

Vecera, S. P., & Behrmann, M. (1997). Spatial attention does not require preattentive grouping. *Neuropsychology*, *11*, 30-43.

Vecera, S., & Behrmann, M. (2000). *What are the inputs to object recognition processes? Considerations from apperceptive agnosia*. Manuscript submitted for publication.

Vecera, S. P., Behrmann, M., & Filapek, J. C. (in press). Attending to the parts of a single object: Part-based selection limitations. *Perception & Psychophysics*.

Vecera, S. P., Behrmann, M., & McGoldrick, J. (2000). Selective attention to the parts of an object. *Psychonomic Bulletin & Review*, *7*, XXX-XXX

Vecera, S. P., & Farah, M. J. (1994). Does visual attention select objects or locations? *Journal of Experimental Psychology: General*, *123*, 146-160.

Vecera, S. P., & Farah, M. J. (1997). Is visual image segmentation a bottom-up or an interactive process? *Perception & Psychophysics*, *59*, 1280-1296.

Vecera, S. P., & Luck, S. J. (2000). Attention. To appear in V. S. Ramachandran (Ed.), *Encyclopedia of the Human Brain*. San Diego: Academic Press.

Ward, R., & Goodrich, S. (1996). Differences between objects and nonobjects in visual extinction. *Psychological Science*, *7*, 177-180.

Ward, R., Goodrich, S., & Driver, J. (1994). Grouping reduces visual extinction: Neuropsychological evidence for weight-linkage in visual selection. *Visual Cognition*, *1*, 101-129.

Weber, T. A., Kramer, A. F., & Miller, G. A. (1997). Selective processing of superimposed objects: An electrophysiological analysis of object-based attentional selection. *Biological Psychology*, *45*, 159-182.

Wertheimer, M. (1923/1958). Principles of perceptual organization. Translated in D. C. Beardslee & M. Wertheimer (Eds.), *Readings in Perception* (pp. 115-135). Princeton, NJ: Van Nostrand. (Original work published in 1923.)

Wolfe, J. M. (1998). Visual search. In H. Pashler (Ed.), *Attention* (pp. 13-73). East Sussex, UK: Psychology Press.

Woodman, G. F., Vogel, E. K., & Luck, S. J. (in press). Visual search remains efficient when working memory is full. *Psychological Science*.

Yantis, S. (1998). Control of visual attention. In H. Pashler (Ed.), *Attention* (pp. 223-256). Hove, UK: Psychology Press.

Yantis, S., & Egeth, H. E. (1999). On the distinction between visual salience and stimulus-driven attentional capture. *Journal of Experimental Psychology: Human Perception & Performance*, *25*, 661-676.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 601-621.

Zemel, R. S., Behrmann, M., Bavelier, D., & Mozer, M. C. (submitted). *Experience-dependent perceptual grouping and object-based attention*. Manuscript submitted for publication.

Zipser, K., Lamme, V. A. F., & Schiller, P. H. (1996). Contextual modulation in primary visual cortex. *Journal of Neuroscience*, *16*, 7376-7389.

AUTHOR NOTES

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