Opinion

Object-based attention: strategy versus automaticity

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This article begins with a description of space- and object-based guidance of attentional selection. It goes on to discuss the most influential, two-rectangle, paradigm for demonstrating the existence of space- and object-based attentional effects. The article then considers two different mechanisms, attentional spreading and attentional prioritization, that can potentially explain how object representations come to guide attentional selection. Finally, it discusses several empirical findings that have emerged in support of the two different mechanisms. It concludes by putting forth a new framework for investigating object-based effects.

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INTRODUCTION

How does the human visual system sort through the massive amounts of sensory input, which it samples almost continuously, to arrive at the coherent perception of a scene? This process of searching through the environment for information is a ubiquitous component of sensory processing and it reflects a remarkable ability of the perceptual system to dynamically select information that is relevant for the current goal of the organism. Such perceptual selectivity, referred to as *attention*, is central to cognition. Since most of what we consciously perceive will ultimately depend on where we direct our attention, understanding the attentional mechanism is an important first step toward revealing the neural mechanisms that support conscious awareness.

One of the key elements to understanding attentional selection is to know *what* representations guide this process. Until the early 1980s, it was widely assumed that attention is typically directed to regions in space, in a manner analogous to a graded spotlight that illuminates a local convex region.[1–5] It should be considered, however, that spatial locations are usually occupied by objects and are rarely empty. It is thus reasonable to assume that, in addition to using space-based representations, the perceptual system has evolved to use object-based representations for attentional guidance. Starting in the early 1980s, evidence began to accumulate that some tasks engage a selective mechanism that operates on an object-based, rather than a location-based, representation.[6–10]

THE TWO-RECTANGLE PARADIGM

A large body of evidence in support of object-based attentional selection has been derived from the two-rectangle paradigm, originally developed by Egly et al. (1994).[11,15] In this paradigm, two adjacent rectangles, oriented either vertically or horizontally, are presented to the observer (Figure 1(a)). After a brief delay, one end of one of the rectangles is illuminated briefly—an event that cues the observer to direct their attention to a specific location while maintaining fixation at the center of the display. After another brief delay, a target is presented either in the location previously occupied by the cue (the *valid cued* location), in the opposite end of the cued rectangle (an *invalid same-object* location), or in the other rectangle (an *invalid different-object* location) at the same distance from the cue as the *invalid same-object* location. This paradigm yields two main findings. First, items in the *validly cued* location are detected faster and more accurately than items presented in any other location (Figure 1(b)). This result implies that the spatial distance between the cued location and the target affects the quality of one's perceptual representation[4,12,13] and is consistent with space-based attentional orienting. Second, and more relevant for the current purpose, is the finding that

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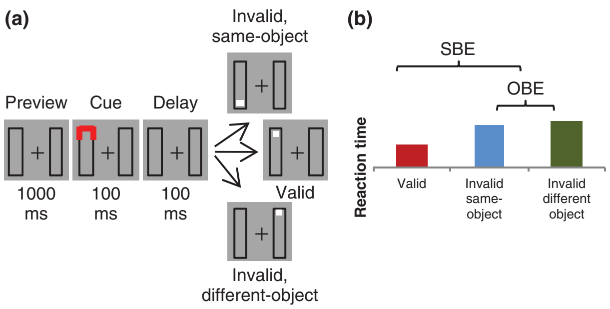

FIGURE 1 | (a) Example of a typical two-rectangle experiment. Note that the same-object and the different-object target locations are equidistant from the cue. (b) Idealized pattern of results (reaction time) for targets appearing in the same location as the cue (valid), in the same-object as the cue (same-object) and in the object that was not cued (different-object). Space-based effect (SBE), object-based effect (OBE).

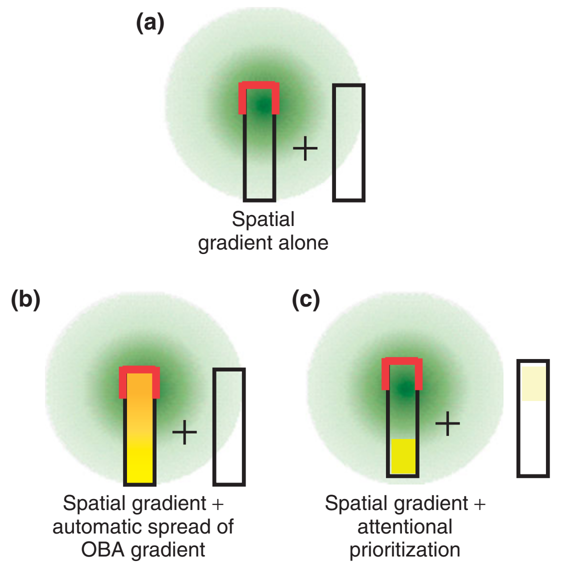

FIGURE 2 | (a) Spatial gradient following a sensory cue. Here, and in other panels, lighter color indicates greater sensory strength. (b and c) Two mechanisms. (b) *Attentional spreading:* spatial gradient along with a superimposed object gradient. (c) *Attentional prioritization:* spatial gradient along with the prioritization map. Higher priorities assigned to a within-object location. Spatial gradient is denoted by green colors; object-based effects (OBE) are denoted by yellow colors.

items in the *invalid same-object* location are detected faster and more accurately than objects in the *invalid different-object* location [difference labeled as object-based effect (OBE) in Figure 1(b)]. The latter finding reflects the contribution of object-based attention to the quality of perception,[14–17] indicating that other dimensions (e.g., spatial locations) of objects are facilitated by virtue of being part of the cued object. This paradigm has been extended in several subsequent studies investigating the role of object-based attention in visual perception,[16,18–24] rendering the findings, for the most part, robust and replicable.

TWO MECHANISMS

Having repeatedly demonstrated the robustness of the empirical OBE, more recent research has focused on elucidating the mechanism driving this effect. At least two possible mechanisms for attentional modulation of perceptual efficiency can be invoked to account for the same-object benefit observed in the two-rectangle paradigm. It is important to note that in the context of the widely used two-rectangle paradigm, both mechanisms predict the same behavioral result—fastest reaction times (RT) for targets presented in the valid location, followed by same-object targets, and finally, slowest RTs for different-object targets.

Attentional Spreading Hypothesis: Automatic

The first mechanism, termed *the attentional spreading hypothesis* (sometimes referred to as sensory enhancement), suggests that once attention is attracted to a spatial location, two *automatic* processes take place. First, the spatial gradient is constructed centered on the cued location (Figure 2(a)), falling off with distance from the center of the attended region. This gradient accounts for distance effects as measured by both speed and accuracy in cued-attention paradigms,[4] as well as for reduced strength of a representation as measured by various neuroimaging techniques.[16,22,24] Second, another automatic gradient is constructed representing the spatial spread of top down facilitation, respecting object boundaries (Figure 2(b)) so that representations within an attended object are stronger than representations outside the attended object. It should be noted that although there is a straightforward explanation for distance effects in this account, as a result of the retinotopic organization of early vision and of the increasing size of receptive fields in successive stages of the visual pathway,[25] there is no correspondingly obvious explanation of how scene segmentation could affect attentional control signal and thereby influence the spread of attention in an object-based fashion. Despite the lack of clarity of *how* such object-based gradients are constructed, an important property of this object-based *attentional spreading* is its *automaticity*. In other words, whenever spatial attention is attracted to a particular location, if that location is occupied by an object, that object will automatically benefit perceptually. It should be noted that even though the supposition that object-based attention is *automatic* (*or mandatory*) has been implicitly supported by many studies, there have been relatively few and largely inconclusive studies providing evidence for or against it. A rare exception is a recent study by Yeari and Goldsmith,[26] clearly articulating the automaticity assumption[27,28] in the context of their investigation.

Attentional Prioritization Hypothesis: Flexible

The second mechanism, proposed by Shomstein and Yantis,[29] offers an alternative explanation of OBEs. In what has been termed the *attentional prioritization hypothesis*, the authors argue that OBEs are attributed to a flexible attentional prioritization mechanism. Specifically, once attention is attracted to a spatial location a combination of two processes take place: one *automatic* and one *flexible* (*or strategic*). First, the same automatic spatial gradient is constructed following a spatial cue (Figure 2(b)), which results in the expected distance effects as described in the spreading account. The second, flexible gradient is assigned according to a particular strategic plan that is most efficient given the contingencies of the environment and the current goal of the organism. With all things being equal, the organism simply assigns higher attentional priority to locations within an already attended object via grouping by common region[30] rather than to other locations (Figure 2(c)). Given that attentional priority determines the efficiency with which certain information will be selected, unattended parts of an attended object will enjoy an advantage over other objects and locations in a scene, thus giving rise to OBEs.

It is possible to view this account in the context of Wolfe's Guided Search, suggesting that the order of search is governed by attentional priorities. These priorities are affected not only by local feature contrast and by similarity to a target template,[31,32] but also by object structure. It should be noted that although attentional prioritization can be described as an ordering of search, a strictly serial search need not be warranted. An equally plausible implementation would be display-wide parallel processing with different rates of information selection according to an attentional priority map.[33–35]

EMPIRICAL TESTS: AUTOMATIC OR STRATEGIC?

Within the context of a typical two-rectangle paradigm, these two hypotheses predict the same behavioral pattern of performance, thus early studies of object-based attention could be interpreted as being consistent with either *attentional spreading* or *attentional prioritization*. However, the two hypotheses lead to differing predictions under certain circumstances and in order to test such circumstances it is beneficial to summarize the key predictions of each mechanism. *Attentional spreading* predicts that subsequent to attentional selection of one part of an object there is a mandatory, or automatic, spread of attention to the other parts of the object. On the other hand, a*ttentional prioritization* predicts that the benefit for the unattended part of an attended object will be observed if and only if there are no alternative strategies available (e.g., uncertainty about the location of the upcoming target).

Shomstein and Yantis[29] created a set of circumstances in which attentional spreading and attentional prioritization yield different predictions. Participants identified a central target while attempting to ignore flanking distractors that appeared on the same or a different object. An important element of this design was that the spatial location of the target was known with 100% certainty. According to attentional spreading, attention 'spreads' within the attended object so that the flanking letters located in that object should benefit perceptually, thus causing more interference as compared to objects elsewhere. Therefore, this account predicts that the time to identify the target letter will depend on the identity (or more precisely, on the response compatibility) of the flanking letters to a greater degree when they appear in the attended object (Figure 3(a)) than when they appear in the unattended object (Figure 3(b)). In contrast, the *attentional prioritization* account predicts that because the target location is known with 100% certainty, only one location should be examined in order to perform the task, so the priority of other locations in the scene should remain near zero. This account consequently predicts that flanker interference will not depend on whether the flankers occupy the same or different object as the target (although the absolute spatial separation between the target and flankers may well affect performance due to spatial 'leakage' of attention). The predictions of the *prioritization* account, and not of the *attentional spreading* account, were satisfied; there was no modulation of flanker effect size by whether flankers appeared on the same- or different-object.

Recently, however, the attentional prioritization hypothesis and the role of attentional certainty in particular have come under scrutiny. Studies by Chen and Cave,[28,36] for example, suggested that the reason OBEs do not manifest under conditions of 100% attentional certainty is not due to the successful establishment of a priority map with central location

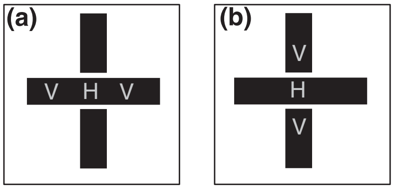

FIGURE 3 | Displays used by Shomstein and Yantis 29 to demonstrate absence of object-based effects (OBEs) when target location was known in advance (i.e., target always appeared in the center). (a) Same-object flankers; (b) different-object flankers.

being the only location benefiting from attentional prioritization, as was initially argued by Shomstein and Yantis.[29] Instead, they argue this is due to the type of representational display that was employed. In particular, Chen and Cave[28,36] suggested that the three rectangles arranged into a cross-like configuration (Figure 3(a) and (b)), used by Shomstein and Yantis[29] were interpreted not as three independent objects, but rather as a single multipart object (i.e., a cross). To demonstrate that such an alternative interpretation of the display could result in the absence of OBEs, the authors first replicated the original finding observed by Shomstein and Yantis.[29] Then, the researchers went on to ensure that participants did in fact perceive the three rectangles as three independent objects by decomposing the three-rectangle display into component pieces: on some trials participants were presented with either the full display (three rectangles), with two smaller rectangles alone, or with one long rectangle alone. By manipulating how much of the display was shown, OBEs (evidenced by greater interference of flankers appearing on the same-object, as compared to flankers appearing on a different-object) were present even when target location was known in advance with 100% certainty. Chen and Cave[28,36] concluded that object representations guide attentional selection if the display is interpreted as consisting of different objects even when the location of the upcoming target is known in advance.

Several important factors must be considered when interpreting the findings of Chen and Cave[28,36] because although the observed findings seem inconsistent with attentional prioritization at first glance, they can nevertheless be integrated rather seamlessly. Attentional prioritization argues that target location certainty eliminates OBEs because it allows for attention to narrowly focus and prioritize a spatial location, which effectively filters out irrelevant object representations. In Chen and Cave's[28] manipulation, some trials contained the full cross (three objects), while some trials only contained pieces of the display (either two short rectangles or one long rectangle). They suggest that the trials with a partial display affected attentional selection on trials with a complete display, such that when the full cross appeared, participants interpreted the three-rectangle display as consisting of three different objects (rather than as interpreting it as a single cross-like display). However, it should be noted that even though participants were 100% certain about the location of the upcoming target in that paradigm, a different type of uncertainty was introduced into the display—that of configural uncertainty. In other words, from trial to trial participants were presented with three different configural displays. Therefore, even when the target's location was known in advance, the lack of certainty about the completeness of the display was enough to alter attentional allocation. Namely, this uncertainty placed an emphasis back onto the objects, resulting in an inability to successfully filter out object representations thus leading to an OBE. In a follow-up experiment, Chen and Cave[36] presented participants with a similar cross-like pattern along with a cue that indicated precisely where the two to-be-compared target letters will appear. The authors again found OBEs (faster RTs for same object targets as compared to different object targets) with positional certainty. It should be considered, however, that in this paradigm attention was split between two targets so that even when the target locations were certain, attention was focused on *multiple* locations at once thus necessarily reducing certainty. Prioritizing multiple locations is what occurs under conditions of target location *uncertainty*.

Additionally, Chen and Cave's results can be reconciled with the attentional prioritization hypothesis by framing their findings within Goldsmith and Yeari's[37] attentional focus hypothesis. The attentional focus hypothesis is very much related to attentional prioritization. Goldsmith and Yeari[37] suggested that when attention is spread across the display (i.e., diffuse attentional focus), objects contribute to attentional guidance. Focused attention (i.e., narrow attentional focus), on the other hand, allows for the objects to become irrelevant so they are successfully filtered out and do not guide attention. Perhaps, as the authors suggest, the changing of the display configuration on a trial by trial basis led to a *diffuse* state of attention (or attentional uncertainty), which would lend itself to OBEs. Further investigation is necessary to determine what accounts for the discrepancy between results reported by some investigators[29,37,38] and not others:[27,28,36] whether it is certainty (configural or positional) or whether the cue creates a diffuse spread of attention that is not conducive to attentional prioritization.

Another recent study conducted by Richard et al.[27] argued that while OBEs are indeed observed under conditions of 100% certainty, this outcome is due to the perception that the targets are part of (i.e., belong to) the object shape. The authors contend that Shomstein and Yantis[29] did not observe OBEs with a 100% target certainty paradigm because the target letters (Ts and Ls) were interpreted as being 'placed' on top of the object, rather than being perceived as parts of the object.[27] While this alternative interpretation is interesting and is supported by several experiments,[27] it does not explain why Shomstein and Yantis observed OBEs in that same study when the factor being manipulated was the predictive value of the cue (i.e., the target location is no longer certain) and not aspects of the physical display. In addition, Richard et al.[27] account falls short of explaining why in other studies that employ identical target types as Shomstein and Yantis[29] OBEs were not observed when target location is known in advance and *are* observed when target location is determined randomly.[38] Again, further experiments will have to be conducted in order to reconcile these apparently opposing interpretations.

Most recently, Drummond and Shomstein[38] conducted an experiment that employed the traditional two-rectangle method (rather than a cross-like display; Figure 1) to examine whether certainty of target location would eliminate OBEs. The primary goal of this set of experiments was to address the Chen and Cave[28] concern that the cross-like display used in earlier investigations was interpreted as a single cross-like object rather than a set of three independent objects. In this experiment, using the two-rectangle paradigm, it was observed that when certainty increased, OBEs were eliminated. These results strongly suggest that that certainty results originally observed by Shomstein and Yantis[29] were not due to using the cross-like display. Rather, it was certainty alone that predicted object-based guidance of attention. Additionally, this experiment employed the same type of targets used by Shomstein and Yantis,[29] thereby addressing concerns raised by other investigators regarding the interpretation of targets as not being part of the object.[27]

In a series of four experiments, certainty of target location was manipulated such that under some circumstances the location of the target was known in advance (100% certainty) while at other times target location was unpredictable. Consistent with the attentional prioritization hypothesis, it was observed that OBEs depended solely on certainty of the forthcoming target location. These results suggest that a flexible attentional prioritization, not an automatic spreading of attention, gives rise to object-based guidance of attentional selection.

CONCLUSION

This article began with a description of two types of representations, space- and object-based, that guide attentional selection and the two-rectangle paradigm that has been most influential for the purposes of demonstrating the existence of these effects. It then went on to describe the two possible mechanisms that give rise to OBEs, *attentional spreading* and *attentional prioritization*, and the empirical evidence for each. While the *attentional prioritization* hypothesis seems to be the most parsimonious, its explanatory power (and that of the *attentional spreading*) is weekend somewhat by the shortcomings of the employed approach.

The first major shortcoming of most recent investigations focused on understanding the mechanisms of object-based attention is an almost exclusive reliance on paradigms that turn OBEs 'on' or 'off'. For example, Drummond and Shomstein[38] and Shomstein and Yantis[29] show that objects cease to exert their influence on attentional guidance when location of the target is known in advance with 100% certainty, and Chen and Cave[28] manipulate configurations of displays and positional certainty to either elicit or wipe out OBEs . An inherent problem with these particular studies and those like it is that the critical predictions on which arguments are based are null results. While initially useful, the time is ripe to move beyond this reasoning and on to stronger forms of inference.

The second major shortcoming is that investigations have been restricted to only one domain of uncertainty—spatial.[23,24,27–29,36,38,39] It is evident that uncertainty is not unique to spatial maps, but can also be configural (e.g., target location is known in advance but the object that will contain it varies), or temporal, just to name a few. Again, while valuable, there is now urgency to move beyond spatial contributions to investigate object-based attentional guidance.

A simple, reconciliatory, and powerful approach that has the power to predict when object representations guide attentional control (i.e., OBEs) is needed. We propose such an approach here and call it the *uncertainty hypothesis*. Given that the goal of the attentional system is select sensory stimuli by reducing uncertainty in the input,[40–43] this logic can be extended as follows: if uncertainty is high (e.g., the location or the timing of the target is unknown) the visual system integrates all the available information embedded in the environment to guide attentional selection, thus yielding OBEs. If, however, uncertainty is low, then resources can be most efficiently allocated to only the relevant information in the environment, thus reducing OBEs.

This is somewhat reminiscent of the attentional load hypothesis, initially used to reconcile late vs. early theories of attentional selection.[44,45] In the context of object-based attentional selection, if uncertainty is high, then objects are used to guide attentional selection thereby eliciting OBEs. If, on the other hand, uncertainty is low, then object representations are not useful to guide attention thus resulting in the absence of OBEs. An important feature of *uncertainty* is that it is integrated across all domains of attentional orienting (spatial, featural, configural, temporal, endogenous, exogenous, etc., thereby addressing the second major shortcoming). Additionally, uncertainty is a continuum, thus rather than turning OBEs 'on' and 'off', it would allow for parametric manipulations (addressing the remaining major concern listed above). Studies testing this new hypothesis are currently under way and the results are very promising.

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