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Sustained Inattentional Blindness:
The Role of Location in the Detection of Unexpected Dynamic Events

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ABSTRACT: Attempts to understand visual attention have produced models based on location, in which attention selects particular regions of space, and models based on other visual attributes (e.g., in which attention selects discrete objects or specific features). Previous studies of inattentional blindness have contributed to our understanding of attention by suggesting that the detection of an unexpected object depends on the distance of that object from the spatial focus of attention. When the distance of a briefly flashed object from both fixation and the focus of attention is systematically varied, detection appears to have a location-based component. However, the likelihood that people will detect an unexpected event in sustained and dynamic displays may depend on more than just spatial location. We investigated the influence of spatial location on inattentional blindness under precisely controlled, sustained and dynamic conditions. We found that although location-based models cannot fully account for the detection of unexpected objects, spatial location does play a role even when displays are visible for an extended period.

1. Introduction

One central issue in the study of visual attention involves the question of whether attention is solely location-based or whether it can also be affected by non-spatial factors. Each view encompasses several variants. For example, location-based models of attention include the "spotlight" model (Posner, 1980; see Cave & Bichot, 1999, for a review), in which attention acts to "illuminate" whatever falls within an attended region, and the "zoom lens" model (Eriksen & St. James, 1986), in which attention can be directed either at broad areas in coarse detail or at small areas in fine detail. Models based on other visual attributes include those suggesting that discrete objects or features within a scene can be directly attended, unmediated by a spatial spotlight (e.g., Baylis & Driver, 1993; Duncan, 1984; see Scholl, in press, for a review). Recent studies of inattentional blindness have explored whether the detection of an unexpected object can inform us about the nature of attention (Mack & Rock, 1998; Newby & Rock, 1999). Specifically, does detection depend on the spatial proximity to the focus of attention? In this paper, we also explore the role of proximity to the focus of attention in the detection of unexpected objects, but unlike previous studies, we use a dynamic, sustained inattentional blindness task (Most et al, in press). This task is well-suited to exploring on-going perceptual events under controlled conditions.

Location-based models might predict that the probability of noticing an unexpected object will be affected by the distance of the object from the focus of attention (Newby & Rock, 1999). If an unexpected object appears near the focus of attention, then observers will be much more likely to see it than if it appears far away from the focus of attention. However, detection should not be affected by the similarity of the unexpected object to the other objects in the display. Evidence for an object-based component to selection comes from findings that multiple features are more readily processed when they are part of a single object than when they are part of multiple objects, even when the features are the same distance apart in both cases (e.g., Duncan, 1984; Watson & Kramer, 1999). Feature-based models argue that attention is preattentively directed to simple features in the display (e.g., red or bright) in addition to objects or regions. For example, if observers were attending to the red objects in a display, a new red object would be noticed but a new black object might not be. Accordingly, feature-based models might predict that unexpected objects will be detected provided that they are featurally similar to objects already being attended, regardless of their position in the display (Most et al, in press). This view also predicts that people may *not* necessarily see unexpected objects that have *different* properties from already-attended objects, even if the unexpected object appears in close proximity to the focus of attention.

Recently, the "inattentional blindness" paradigm has contributed to our understanding of the effects of spatial proximity on the detection of unexpected objects (Mack & Rock, 1998; Newby & Rock, 1998). "Inattentional blindness" (IB) refers to the finding that observers who are engaged in attentionally demanding tasks often fail to see unexpected objects or events. In a typical task, observers viewed a cross that appeared in a computer display for 200 milliseconds before it was replaced by a patterned mask. They were asked simply to judge whether the horizontal or the vertical arm of the cross was longer. On a "critical trial," an additional unexpected object appeared simultaneously with the cross, usually in one of the quadrants defined by the cross's arms. The dependent measure was whether or not observers retrospectively reported having consciously seen the unexpected object. Depending on the particular variant of

this task, between 25% and 75% of the observers failed to notice the unexpected object (Mack & Rock, 1998).

Mack and Rock (1998), inspired partly by "spotlight" metaphors of attention (Posner, 1980), hypothesized that unexpected events occurring anywhere within a contiguous "zone of attention"-where the zone's diameter was roughly defined by the length of the cross's arms-would more likely be seen than unexpected events occurring outside this zone. If this hypothesis is correct, then objects appearing within one of the quadrants of the cross should be seen just as frequently as objects appearing *on* one of the cross's arms. Their results showed that 80% of observers saw the unexpected object (put another way, the level of inattentional blindness, IB, was 20%) both when the unexpected object appeared on an arm of the cross and when it appeared in one of the cross's quadrants. In further experiments, observers were far less likely to detect an unexpected object that appeared outside the region defined by the horizontal and vertical extent of the cross (or of a rectangle that was sometimes substituted for the cross) than to detect an object that appeared within that region. Taken together, these findings seem to support a location-based model of attention over an object-based model, as well as supporting the idea of a contiguous "zone of attention" (Mack & Rock, 1998).

However, these findings do not eliminate the possibility that increasing levels of IB were due to the increasing distance from the center of attention, rather than to the qualitative difference between appearing within or outside the "zone of attention." Extending this work, Newby and Rock (1998) directly examined the effect of distance on detection rate by parametrically increasing the distance of the unexpected object from the center of the cross. Furthermore, by having the attended cross appear away from fixation, they were able to vary the distance of the unexpected object from the center of the cross while keeping its distance from fixation constant. Under these conditions, distance from the center of attention, and not from fixation, accounted for the resulting rate of noticing: when the object appeared further away from the focus of attention (i.e., the cross), fewer observers saw it than when it appeared at the center of focal attention. However, their evidence did not support the notion of a bordered "zone of attention." Instead, the decrease in detection rate with distance occurred in a continuous fashion, with no sudden drop-off beyond the region defined by the cross.

Although the evidence from these IB studies suggests a role for spatial proximity in mediating the likelihood of detecting an unexpected object, these effects might not generalize to the perception of realistic, dynamic scenes; the displays used in these studies typically involved briefly presented and masked static stimuli. It is noteworthy, then, that studies involving more sustained and dynamic displays may support models in which attention can be directed at discrete objects, features, or event sequences in addition to spatial locations. For example, extending other work on "selective looking" (Becklen & Cervone, 1983), Simons and Chabris (1999) conducted a series of experiments in which observers watched a video of two teams of basketball players-one team clad in white shirts, the other in black shirts-each passing a basketball among themselves. The observers were instructed to count the number of passes made by either the white team or the black team. Partway through this task, either a woman with an umbrella or a person in a gorilla costume unexpectedly walked through the center of the action, remaining clearly visible for about five seconds before exiting the display. The observers were then asked if they had seen the unexpected object. Thirty-five percent of the observers failed to notice the woman with the umbrella, even though her presence was obvious to anyone not engaged in the counting task. Perhaps more startling, given its more unusual nature, even more people failed to notice the gorilla (56%). In both cases the unexpected figure moved through the

same spatial locations that were being occupied by the attended basketball players. Thus, an appeal to solely spatially based models of attention cannot explain the high degree of IB. If, however, we assume that attention was focused on objects in the scene rather than on locations, IB should be relatively unaffected by the spatial proximity of the unexpected object to the other objects.

These studies of selective attention also provide evidence for the role of featural similarity in detection. Although a surprising number of observers failed to notice the gorilla in all conditions, more observers saw it when they were attending to the black team than when they were attending to the white team (Simons & Chabris, 1999). Because the gorilla was black and observers had been instructed to attend to the other black objects in the display, it may have naturally drawn attention upon entering the screen. Although these data seem to support a feature-based component to selection, the sorts of complex, naturalistic videos used in these studies are not optimal for a systematic exploration of the influence of either of these factors on detection. For example, the background in these video studies was not homogenous in either color or luminance, and the spatial locations of the moving objects were not well controlled.

In the current studies, we investigate the role of spatial location using a variation of a recently developed "sustained" IB paradigm (Most et al., in press). In the original version of this paradigm, observers viewed a computer display in which four white and four black shapes moved on random paths and periodically "bounced" off the edges of the display. Observers were instructed to fixate on a central point and to count the number of bounces made by either the white shapes or the black shapes during each 15-second trial. On a "critical trial" an unexpected shape (a cross) entered the middle of the display from the right, traveled on a linear path across the fixation point, and exited the left side of the display, remaining clearly visible for 5 seconds as it did so. The luminance of the unexpected cross was either white, light gray, dark gray, or black, and the rate at which observers consciously detected the cross appeared to be almost entirely dependent on these luminance differences. When the cross was the same luminance as the attended set of objects, 94% of observers saw it, but when it was the same luminance as the ignored set, only 3% saw it. The more similar the cross was in luminance to the attended set of objects and the less similar it was to the ignored objects, the more likely observers were to notice it. Thus, these studies also support a feature-based component to attentional selection.

However, these selective looking studies leave open the possibility that location still plays at least some role. For example, detection rate might increase when the unexpected object appears in the location where observers direct their attention. Accordingly, a few alternative predictions could be made. First, in accord with work supporting a "spotlight" version of a location-based model, observers might be equally likely to detect the unexpected object when it appears anywhere within the region through which the attended objects move. However, they should be less likely to detect it when it appears outside that region (Mack & Rock, 1998). A second possibility is that observers will be most likely to detect the unexpected object when it appears in close proximity to another object representing the focus of attention, with detection rate continually decreasing as the object appears further away from it. These two alternative predictions suggest some role for location in the detection of unexpected objects. A third alternative prediction is that location will play no role in mediating detection rate; if the allocation of attention is entirely object-based (or 'spatially-invariant'; Vecera & Farah, 1994), then the detection rate for the unexpected object should be the same regardless of where in the display the object appears.

2. Method

2.1. Participants

143 observers were tested in exchange for candy. Data from 27 observers were subsequently excluded for reasons noted below. Of the remaining 116 observers, 64 were male and 52 were female (Mean age = 20.4 years).

2.2. Materials and Procedure

Stimuli were presented using custom software written with Micro M-L's Vision Shell C libraries <http://www.mlink.net/~ml> on a Macintosh G3 PowerBook with a 14.1" active matrix display. Head position was not fixed and observers sat at a comfortable distance from the display (on average, approximately 35 cm). All of the events on each trial took place within a gray 12.7 x 15.5 cm display window (luminance = 32.1 cd/m2) with a 1 pixel wide blue horizontal line dividing it in half. A small fixation point was located on the center of the line. Within this window, four black (luminance = 1.2 cd/m2) and four white (luminance = 88.0 cd/m2) L and T shapes (1 cm x 1 cm block letters) each moved independently on random paths at a variable rate ranging from 2-5 cm/s. Their range of motion extended from 5.5 cm above the horizontal line to 5.5 cm below the horizontal line, a region occupying 87% of the vertical extent of the display window, and the objects were smoothly repulsed as they approached the limits of this region. The objects could occlude each other as they passed. Periodically, each black and white shape "touched" the horizontal line, usually as it crossed from one half of the display to the other. Each trial lasted for a total of 15 seconds, and each observer completed 5 trials.

Observers were instructed both in writing and by the experimenter to fixate on the central point on the line and to keep a silent tally of the total number of times that the black shapes touched the line during each 15-second trial. A "touch" was counted every time a shape came into contact with the line, whether it crossed it or not and regardless of how long it remained in contact with the line. Following each trial, observers typed the number of touches they had seen into the computer in response to a prompt.

The first two trials contained no unexpected event. Five seconds into the third trial (the "critical trial"), a cross with the same horizontal and vertical extent as the L's and T's entered from the right side of the display, moved horizontally in a linear path across the center of the screen, and exited the left side of the display, remaining visible for 5 seconds (see Figure 1). The luminance of the cross was light gray (49.3 cd/m2), and depending on the experimental condition, its path was either on the blue horizontal line (On-Line; n=17), 2.4 cm above or below the line (Near; n=16 in each), 4.8 cm above or below the line (Far; n=17 for above, n=16 for below), or 5.9 cm above or below the line (Very Far; n=18 for above, n=16 for below). In the Very Far conditions, the path of the unexpected object did not overlap with other moving objects in the display, which were constrained by the gradual repulsion to a region closer to the center of the display. Because observers were not forewarned about the cross, its appearance was unexpected. After this critical trial, observers were given a printed questionnaire on which they were asked to report (1) whether or not they had seen anything other than the black and white Ls and T's, and (2) if they had seen something else, to describe it.
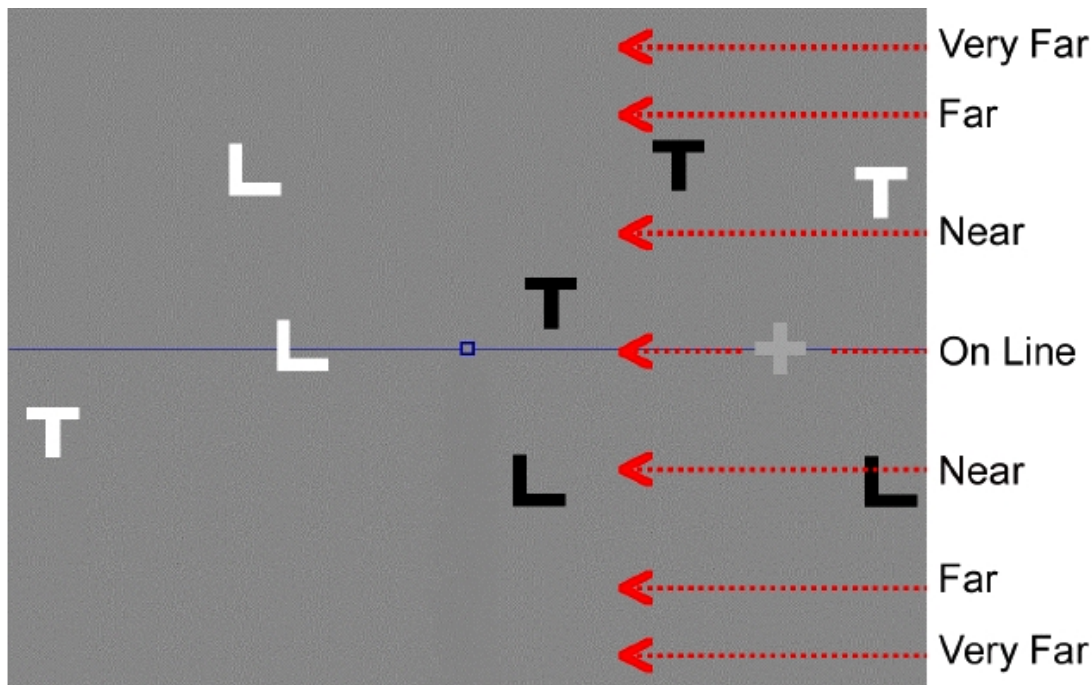
Figure 1.
A single frame of the dynamic display. The arrows and labels shown here were not present in the experimental display. They have been added to indicate the direction and vertical distance from the horizontal line that the gray cross (seen here in the On-Line condition) travelled in each condition. The movement of the black and white L's and T's was constrained to the region extending from between the Far and Very Far conditions above the line to between the Far and Very Far conditions below the line.

Observers then completed a fourth trial on which the cross again appeared, travelling on the same path. Although they were not explicitly told to look for the cross, the questionnaire had alerted them to the possibility that a novel object could appear mid-trial. Therefore, this trial tested perception under "divided attention" conditions. After completing this trial, observers filled out a second questionnaire, identical to the first.

On the fifth trial, observers again focused on the central fixation point, but this time were instructed simply to watch the display without counting the number of times the black shapes touched the line. Having read the previous questionnaires, observers were now alert to the possibility that another object could appear. Furthermore, their attention was not otherwise engaged, so this trial tested perception under "full attention" conditions. After this trial, observers completed a questionnaire identical to the first two.

After completing all five trials, observers answered follow-up questions designed to gather demographic information and to determine if they had been familiar with this or other related experiments prior to participation (e.g., Simons & Chabris, 1999; Most et al, in press). Because we wanted observers to have no reason to expect another object to appear in the display during the first critical trial, data from observers who were familiar with studies of IB were excluded from the analyses. The experiment required 5 to 10 minutes to complete, and observers were debriefed afterward.

3. Results

Of the 143 observers, 27 were excluded from the final data analysis for the following reasons: previous knowledge of IB or related research (8), failure to see the unexpected event in the full attention trial (2)<u><1></u>, computer error (1), experimenter error (14), or ambiguity of response (2).

For each given distance away from the horizontal line, the rate of detecting the unexpected cross was virtually identical on the critical trial regardless of whether it travelled above or below the line (Near: chi-square(1)= .13, p = .72; Far: chi-square(1)= .08, p = .78; Very Far: Fisher Exact Test<u><2></u>, p = .19; combined: chi-square=.83, p=.36) (see Figure 1 and the left half of Table 1). Therefore, the above- and below-line conditions for each distance were collapsed in all of the analyses reported below.

Table 1.
Percentage of observers who noticed the unexpected event when it appeared on the line and at each distance above or below the line. Detection rates for the full-attention trial are not included here because, for that trial, all participants included in the analysis saw the unexpected event.

Distance from Line	Observers Noticing the Unexpected Object (%)			
	Critical Trial		**Divided Attention**	
On-Line	47% (n=17)		65% (n=17)	
	Above Line	**Below Line**	**Above Line**	**Below Line**
Near	44% (n=16)	38% (n=16)	75% (n=16)	63% (n=16)
Far	29% (n=17)	25% (n=16)	59% (n=17)	69% (n=16)
Very Far	28% (n=18)	13% (n=16)	61% (n=18)	56% (n=16)

The most striking result in the current studies was that less than half the observers (47%) noticed the unexpected object in the On-Line condition, even though the object always stayed on what was presumably the focus of attention and was clearly visible for 5 seconds. Consistent with the findings of Mack and Rock (1998) and Newby and Rock (1998), our results also demonstrate a role for distance from the focus of attention (i.e., the region around the horizontal line). The farther the unexpected cross was from the horizontal line, the fewer the observers who noticed its appearance on the critical trial (see Figure 2), with detection dropping to only 21% noticing

overall in the Very Far condition. If we regard the region in which the attended and distractor objects moved as the "zone of attention" (Mack & Rock, 1998), then in the Very Far condition, the unexpected object was outside this zone. As can be seen in Figure 2, the detection rate decreases as the unexpected object appears further and further away from the line. However, the difference between the Far and Very Far conditions-which straddled the borders of this "zone"-was not significant (chi-square(1)= .41, p = .52). The only significant planned pair-wise comparison was between the On-Line and Very Far conditions (chi-square(1)= 3.83, p = .050). Thus, our results are consistent with the findings of Newby and Rock (1998) but not with those of Mack and Rock (1998); the detection rate did not drop discontinuously in the Very Far condition.
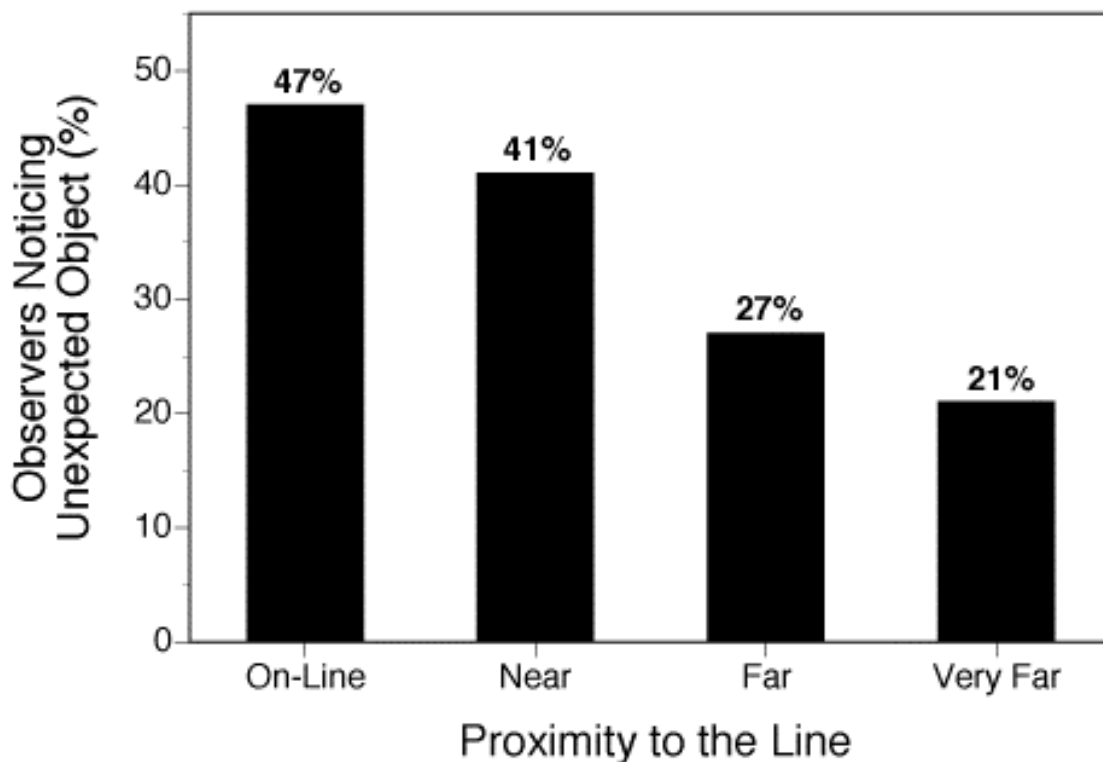

Figure 2.
Percentage of observers in the critical trial who reported seeing the unexpected object as a function of distance from the line. The distance the unexpected object was from the line: On-Line 0 cm; Near 2.4 cm; Far 4.8 cm; Very Far 5.9 cm. Note: the distance between conditions was not evenly spaced.

Importantly, accuracy in the counting task on the critical trial, averaging across all conditions, did not differ significantly between those who did not notice the unexpected stimulus (Mean error = 11.6%, SD = 9.4%) and those who did (Mean error = 12.3%, SD = 13.9%), t(114) = -.29, p = .77). In other words, observers who noticed the unexpected object on the critical trial were no more or less accurate than those who did not. (Across all conditions, the average number of actual line-touches on the critical trial was 14.13.) Performance of noticers and non-noticers was also comparable on the second trial, before any unexpected objects appeared (Mean error for noticers = 9.6%, SD = 10.0%; Mean error for non-noticers = 10.9%, SD = 11.7%; t(114) = .59, p = .56), suggesting that differences in the ability to perform the primary task cannot account for

differences in the likelihood of detecting the unexpected objects. The difference in accuracy rate between the On-Line (Mean error = 10.8%, SD = 11.1%) and Very Far (Mean error = 10.6%, SD = 7.3%) conditions was also not significant, with t(49)= .08, p = .94.

4. Discussion

When they were engaged in an attentionally demanding counting task, more than half the observers in this study failed to notice a distinctive but unexpected object that moved along the center of attention for 5 seconds. In contrast, the object was almost always detected when observers were not engaged in an attentionally demanding task. This finding of inattentional blindness for an unexpected, dynamic object is consistent with earlier experiments using sustained IB paradigms (e.g., Most et al., in press). However, in these earlier studies, observers were required to count the number of bounces that shapes made off the edges of the display, while the unexpected object traversed the middle of the display. Therefore, the primary task did not require observers to attend to the area in which the unexpected object moved. In the experiments reported here, more than half of the observers missed the unexpected object on the critical trial even though it appeared right on the line, which-because of the nature of the task- was presumably the center of attention.

In addition, observers became less likely to detect the unexpected object as its path was moved further and further from the line. These results are consistent with some forms of location-based models of attention. While they are not consistent with a "spotlight" model, they are consistent both with models in which detection rate decreases with distance from fixation and with those in which detection decreases with distance from an attended object. Findings by Newby and Rock (1998) suggest that the former possibility-detection mediated by distance from fixation-may be insufficient, as distance from an attended object appeared to play a larger role than distance from fixation in their studies.

Interestingly, our own previous work has provided evidence that while spatial factors may influence the likelihood of detection, appeals to solely location-based models may be too extreme. As described earlier, in a similar sustained IB study (Most et al., in press), observers who attended to either white or black items in a display were more likely to detect an unexpected object when it was similar in luminance to the attended items and dissimilar to the ignored items.

That high levels of IB were found using the current paradigm is significant and perhaps a bit startling. In earlier static paradigms the unexpected object was typically presented very briefly and was immediately followed by a mask. In contrast, in the sustained paradigm, the unexpected object is moving and visible for five seconds. Despite this difference, we found levels of IB that were even more pronounced than those that were obtained with brief, static displays. This may be due to the dynamic task being more difficult or engaging than the static task, or to its requiring more diffuse allocation of attention.

Whatever the underlying cause of the greater levels of IB, the results of the current study underscore the effectiveness of this paradigm for investigating what kinds of unexpected events people will detect under sustained and dynamic conditions. Under these conditions, strong forms of either location-based or feature-based models appear to be too extreme. Rather, spatial location plays a role in conjunction with the non-location-based aspects of attention to influence

levels of inattentional blindness under sustained and dynamic conditions.

Notes

[1]. Because observers should see the object in the full attention trial (Mack & Rock, 1998), we used the full attention trial as a control to ensure that observers could understand and follow task instructions. Accordingly, observers who failed to see the cross on this trial were replaced and their data excluded from further analysis. Only two observers failed to see the cross on this trial.

[2]. A Fisher Exact Test was used because of low expected frequencies in this condition.

Acknowledgments

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