The role of similarity in inattentional blindness:
Selective enhancement, selective suppression, or both?

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Abstract

When people selectively pay attention to one set of objects and ignore another, unexpected stimuli often go unnoticed. Noticing rates are higher when the unexpected object matches the features of the attended items and lower when it matches those of the ignored items. No prior studies have fully disentangled these aspects of similarity; in previous work, the unexpected object fell on a continuum between the attended and ignored objects, so increasing the similarity to one set of objects necessarily decreased it to the other. We designed an inattention blindness task in which we held similarity to the attended set constant and varied it with respect only to the ignored set, or vice versa. In Experiment 1, objects that were more similar to the attended set were noticed more often and objects that were more similar to the ignored set were noticed less often. Experiment 2, using a different set of unexpected objects, replicated the result that similarity to the ignored set affected noticing, but showed no effect of similarity to the attended set. In both experiments, the pattern of noticing rates differed for similarity with respect to the attended and ignored items, suggesting that suppression of ignored objects functions independently of enhancement of attended objects.

Introduction

When absorbed in a task, people are often oblivious to unexpected objects and events—a phenomenon known as inattention blindness (Neisser & Becklen, 1975; Mack & Rock, 1998; Simons & Chabris, 1999). They are more likely to notice some unexpected objects than others, however, especially those that match attended stimuli and differ from ignored ones (e.g. Most, Scholl, Clifford, & Simons, 2005). In a typical study of sustained inattention blindness, the attended and ignored objects often fall on opposite ends of the same continuum, differing from each other in shape, color, or luminance. As the appearance of the unexpected object shifts along that continuum, noticing rates change; when attending to white objects and ignoring black ones, for example, subjects typically notice a white unexpected object but not a black one (Most, Simons, Scholl, Jiminez, Clifford, & Chabris, 2001).

A few studies have sought to disentangle the influence of similarity to the attended and ignored items by equating the similarity of the unexpected objects to one of these sets. For example, if subjects attended to a set of gray shapes and ignored black ones, a black unexpected object would match the ignored set and differ from the attended set; a white unexpected object would lie on the opposite end of the continuum from the black shapes, but would be just as different from gray as would a black object (gray is halfway between them). In this case, subjects rarely notice black, but often notice white; the pattern reverses when subjects attend gray and ignore white instead (Most et al., 2001). A replication of this experiment including gray unexpected objects found the same pattern: when ignoring black and attending gray, subjects noticed gray and white unexpected objects more than black ones, and when attending gray and ignoring white, they missed white but noticed gray and black (Goldstein & Beck, 2016). More generally, people tend to notice any color that differs from those which they are ignoring (Drew & Stothart, 2016; see Figure 1).

Figure 1. A summary of noticing rates for unexpected objects in prior studies of similarity in inattention blindness (citations in left column). The middle columns shows the features of the attended and ignored items in that study, and the right column shows the noticing rates for each unexpected object (shown above the bars) in that condition.

Collectively, these results support a role for similarity to the ignored items, but they do not rule out a role for similarity to the attended items. Because the stimuli fall along a single continuum, any change to the unexpected object simultaneously affects its similarity to both the attended and ignored sets. In all cases, when an unexpected object is more similar to the attended set of objects, it is also less similar to the ignored set, obscuring whether similarity or dissimilarity drives the effect.

We developed a variant of a sustained inattention blindness task in which the two possible unexpected objects vary along a dimension that affects their similarity either to the attended items or to the ignored items, but not to

both. That approach allows us to disentangle the effects of similarity to the attended objects and the ignored objects.

Experiment 1

Unlike previous studies of the effects of similarity on noticing, the attended and ignored items in this experiment did not fall on a single feature dimension. Subjects attended either to white squares or to black-and-white checkerboards, so in this case, white and black unexpected objects varied in similarity only to the white squares; the checkerboards contain equal amounts of black and white.

Figure 2 details the predictions that emerge from this design. When subjects attend to the white squares and ignore the checkerboards, any difference in noticing between the white and black unexpected objects is affected only by similarity to the attended white squares; both should be equally similar to the half-white, half-black checkerboards. If subjects perform the task by selecting and enhancing the features of the attended objects in order to boost them above the distractors, then when they are attending to white squares, they should be more likely to notice a white unexpected object than a black one (Figure 2, panel A).

Conversely, when subjects attend to the checkerboards and ignore the white squares, any difference in noticing is affected only by similarity to the ignored white squares. Again, the unexpected objects are equally similar to the checkerboards, but differ in similarity to the white squares. If subjects perform the task by filtering or suppressing the ignored set of objects, then when they are ignoring the white objects, they should be less likely to notice a white unexpected object than a black one (Figure 2, Panel B). Given that the white and black unexpected objects are equally similar to the attended checkerboards, selective enhancement of the attended items should play no role in noticing.

If both similarity to the attended set and to the ignored set influence noticing, then an unexpected white circle should be noticed more often than a black one when attending to white

Figure 2. Predicted patterns of noticing rates for three hypotheses. Dot colors indicate the color of the unexpected object, and the attended object is indicated at the top of each column. **Panel A.** If only similarity to the attended set matters, then the white unexpected object should be noticed more often than black one when subjects attend white; there should be no difference in noticing rates when subjects attend checkerboards, since the checkerboard is equally similar to white and black unexpected objects. **Panel B.** If only similarity to the ignored set matters, then when subjects ignore checkerboards, there should be no effect on noticing rates because the objects are both equally similar to the ignored set. However, when subjects ignore the white squares, the white unexpected object should be detected less often than the black one because the white unexpected object is more similar to the ignored set. **Panel C.** If similarity to both the attended and ignored sets matter, then there should be a difference both in the attend-white and attend-checkerboard conditions. Plots generated with the ggplot2 package for R (Wickham, 2009).

squares and less often than a black one when ignoring white squares (Figure 2, Panel C). If subjects both enhance the attended objects and suppress the ignored objects, the effect of similarity should differ depending on which objects are the attended ones.

Consequently, by varying which objects are attended and the luminance of the unexpected object, we can separately measure the contributions of similarity to the attended and ignored items.

Methods

Our methods, procedures, target sample size, exclusion rules, stimuli, experimental code, and analysis scripts were preregistered prior to data collection (<https://osf.io/34z6t/>). Data were analyzed using R (R Core Team, 2015). We report all data exclusions, measures, and manipulations here and in the pre-registration (Simmons, Nelson, & Simonsohn, 2011).

Subjects. We recruited 644 subjects

via Amazon's Mechanical Turk service and

paid them \$.10 for completing the study. We aimed for usable data from 100 subjects per condi-

tion after exclusions (total $n=400$). Based on previous research, we anticipated a roughly 35% exclusion rate. Subjects were automatically recruited in batches of up to 40 until at least 600 had completed the study, at which point the HIT stopped posting and data collection stopped. Only workers based in the United States and who had at least 95% of all their submitted HITs approved could access the study. People who had previously completed our studies or those of our collaborators were informed that they could not participate in this study (we checked worker IDs against databases of prior participants, one of which used TurkGate; Goldin & Darlow, 2013).

Signed consent was waived by the Institutional Review Board at the University of Illinois due to the low-risk nature of the experiment. Subjects were shown an information screen prior to the experiment which provided experimenter and IRB contact information and explained that their responses would be anonymous, described how their data would be used, and noted that their participation was voluntary.

Materials and procedure. A demonstration of this task, identical to the one subjects completed but without any data collection, can be found at http://simonslab.com/mot/mot_demo.html.

The experiment was coded in Javascript (modeled after code used for previous experiments and provided by Cary Stothart, personal communication, October 9, 2015; e.g. Stothart, Boot, & Simons, 2015). Instruction screens informed subjects that they would see two sets of objects bouncing around inside a light blue window (#58ACFA; 666 x 546 pixels). Their task was to count the total number of times one of the sets of objects bounced against the edge of the blue window. The eight objects onscreen consisted of four white squares and four black-and-white checkerboards, each measuring 44 x 44 pixels. The checkerboards consisted of two white and two black cells (22x22 pixels each). Two checkerboards had black cells in the upper left and

lower right, and two had white cells in the upper left and lower right. The unexpected object could be either a white or black circle with a radius of 14 pixels (see Figure 3, panel A).

At the start of the experiment, each participant was randomly assigned to count the bounces of either the squares or the checkerboards, and they tracked the same set of objects in each trial. Subjects were instructed to keep their eyes fixed on a blue (#0000FF) fixation square (11 x 11 pixels, centered in the window) while completing the task, but eye movements were not monitored.

Figure 3. Panel A. An example of a display from Experiment 1 with a white unexpected object. The dotted arrow indicates its movement path across the screen. **Panel B.** An example display from Experiment 2, with a tessellation unexpected object.

Each trial lasted 17 seconds. The objects moved individually with randomly varying velocities, occluded one another when they crossed paths, and passed behind the fixation square as needed. Each object typically bounced off the sides of the windows 5-8 times during a trial. At the end of the trial, subjects entered their count for the bounces into a text box that restricted responses to integers between 0 and 99.

Subjects first completed two non-critical trials in which they performed the counting task. On the third, critical trial, a new object unexpectedly appeared from the right edge of the blue

window after 5 seconds, moved horizontally across the window (passing behind the other objects and the fixation square), and exited 6750ms later. After reporting their count, subjects indicated whether they noticed anything on the last trial that had not appeared in previous trials by selecting a “yes” or “no” radio button. Regardless of their answer, they then selected the object’s shape and color from a set of radio-button options (color: gray, black, white, blue, or none of these; shape: cross, square, circle, triangle, or none of these).

After the critical trial, subjects completed a “full attention” trial, identical to the critical trial, but with instructions not to count the bounces and to simply watch the display. Afterwards, they were again asked whether they had noticed an additional object and selected its color and shape.

Finally, subjects completed demographic questions (gender, age, use of vision correction, status of color vision, whether they experienced any issue with the display of the experiment, number identification for Ishihara Plate 9, and whether or not they had previous exposure to similar inattentional blindness paradigms) and received a completion code that they could enter on Mechanical Turk to receive payment.

Results and Discussion

Prior to analysis, we applied the preregistered exclusion criteria, eliminating data from subjects who: reported being younger than 18 years old; had prior experience with inattentional blindness; experienced a problem with the display of the experiment (stuttering, freezing, or other issues); skipped any questions; failed to notice the “unexpected object” on the full-attention trial, or misreported its shape or color; erred by more than 50% in their count of bounces on more than one trial; or reported needing vision correction but not wearing their contacts or glasses during the experiment. Data from 138 subjects (29% of the sample) were excluded, leaving 451 in the final analysis.

A total of 223 of the included subjects counted bounces from the white squares, with 112 experiencing a white unexpected object and 111 a black one. A total of 228 attended to the checkerboards, with 104 experiencing a white unexpected object and 124 experiencing a black unexpected one. Because condition assignment was random and we did not explicitly force the number of subjects in each condition to meet the desired threshold, the approximately equal numbers of subjects in each condition indicates that dropout rate were comparable across conditions.

Subjects were considered to have noticed the unexpected object if they answered “yes” to having noticed something new on the critical trial and correctly identified its shape, color, or both. Of 237 correct responses, 207 subjects correctly identified both the shape and the color, 6 correctly identified only the color, and 24 correctly identified only the shape. (Using a more stringent criterion requiring that subjects correctly identify both shape and color slightly reduced noticing in some conditions but did not affect the pattern of results; see Figure 4, Panel C.)

If similarity to the attended objects contributes to noticing, then when people attend to white squares, they should notice the more similar white unexpected object more often than the black one; the difference in noticing rates (white - black) should be positive. The ignored checkerboards are equally similar to both unexpected objects, so they should not contribute to any difference in noticing between white and black. Consistent with a role for the similarity to the attended items, subjects noticed the white unexpected object more than the black one (70.5% versus 48.7% for a difference of 21.9%, 95% bootstrapped CI: [20.9, 22.9]; see Figure 3, panel A).

When attending to the checkerboards, the black and white unexpected objects are equally similar to the attended set. However, the white unexpected object is more similar to the ignored white squares than is the black one. Consequently, if similarity to the ignored shapes affects noticing of unexpected objects, subjects should notice the white unexpected object less

Figure 4. Results for Experiments 1 and 2. The style of the point represents the unexpected object in that condition. **Panel A.** In Experiment 1, unexpected white circles are noticed more often than unexpected black circles when attending white squares and ignoring checkerboards, and noticed less often when ignoring squares and attending checkerboards. **Panel B.** In Experiment 2, unexpected checkerboards are noticed less often than unexpected tessellations when ignoring checkerboards and attending gray squares, but both unexpected objects are noticed at the same high rate when attending checkerboards and ignoring gray squares. Plots generated with the ggplot2 package for R (Wickham, 2009).

often than the black one. Consistent with a role for similarity to the ignored items, the difference in noticing rates was negative (20.2% noticed white and 66.9% noticed black for a difference of -46.7%, 95% bootstrapped CI: [-47.4, -45.4]). Collectively, this pattern of more noticing of white than black when attending to white squares and less noticing of white than black when attending to checkerboards implies that both similarity to the attended set and divergence from the ignored set modulate noticing rates, as predicted by the “both matter” hypothesis (Figure 2, Panel C).

While these results suggest independent enhancement of attended items and suppression of ignored items, several possible confounds remain. For one, while we eliminated a white-to-black continuum, we may have inadvertently replaced it with a “proportion white” continuum

ranging from 100% for the white squares to 50% for the checkerboards; the black unexpected object would fall at the far end, at 0% white/100% black.

Additionally, the stimuli are somewhat unbalanced. The squares are solid white, but the checkerboards contain both white and black. The presence of black constitutes a difference between the attended and ignored objects which could be used to separate them. In that case, the checkerboards would not be equally similar to both unexpected objects. For example, subjects could be “suppressing black” when ignoring the checkerboards, which would also suppress the black unexpected object. If so, the finding that white was noticed more than black when subjects attended white squares and ignored checkerboards could be due suppression of black rather than to enhancement of white.

The black unexpected object is also the only solid-black shape in the display, potentially making it more distinctive than the unexpected white object; the white circle is solid white, just as the squares are, but nothing else is solid black. Rather than being seen as equally similar to the checkerboards but less similar to white, it could be seen as dissimilar from both sets of objects because it is a “new color” or a new object category (solid black). This is of concern because subjects must use color to distinguish the objects from each other, and color is also the critical dimension of similarity.

Experiment 2 controls for these potential confounds.

Experiment 2

Experiment 2 again used checkerboards for one set of objects (with a higher spatial frequency than in Experiment 1), but replaced the white squares with mid-gray squares, ensuring that average luminance was equated between the two sets of objects. For the unexpected objects, we used patterned stimuli that varied in similarity to the checkerboards. One was a black-and-white checkerboard of a lower spatial frequency than the attended/ignored checkerboards, and the other was a black-and-white tessellation of triangles made of the same number of white

and black regions as the checkerboards. The unexpected checkerboard is more similar in pattern to the attended/ignored checkerboard than the tessellation, but the difference in pattern between the two unexpected objects does not change the similarity to the gray squares. Additionally, neither unexpected object introduces a new color to the display. Thus, Experiment 2 again separates the role of similarity to the attended and ignored items, while eliminating the potential confounds of Experiment 1.

Methods

Prior to data collection, we preregistered our methods, procedures, target sample size, exclusion rules, stimuli, experimental code, and analysis scripts (<https://osf.io/gndh3/>).

Subjects. We recruited 602 subjects on Mechanical Turk. We aimed for usable data from 100 subjects per condition after exclusions (total $n=400$). Subjects were automatically recruited in batches of up to 40 until at least 600 had completed the study, at which point recruitment stopped. To qualify for the study, subjects had to be based in the USA and have a HIT approval rating of 95% or higher, as in Experiment 1. Subjects received \$0.10 upon completing the study. Signed consent was waived as in Experiment 1.

Materials and procedure. A demonstration of the task without actual data collection may be found at http://simonslab.com/mot/checker_demo.html. Except as noted, the materials and procedures were identical to those of Experiment 1. The attended/ignored objects were either medium-gray (#808080) squares measuring 60 x 60 pixels or black-and-white checkerboards measuring 60 x 60 pixels (a 5 x 5 grid of 12 x 12 pixel cells). Two of the checkerboards had black in the upper-left and two had white.

The two possible unexpected objects (60 x 60 pixels) were a black-and-white checkerboard or a tessellation of black and white triangles. The checkerboard (a 4x4 grid of 15x15 pixel cells) was randomly assigned to have its pattern begin with black or white in the upper left. The tessellation (16 triangles with base = 30 pixels and height = 15 pixels) was arranged such that

no contiguous triangles had the same color, and was randomly assigned to one of two possible patterns (see Figure 3, panel B). The area of each triangle matched the area of each cell in the checkerboard.

As in Experiment 1, subjects completed two non-critical trials prior to the third critical trial, but they did not complete a full-attention trial. Based on other inattention blindness studies conducted between the time we completed Experiment 1 and Experiment 2, we discovered that the full-attention trial led to a large number of exclusions without changing the pattern of results. Consequently, we have stopped including full-attention trials for MTurk studies of inattention blindness (see also Peer, Vosgerau, & Acquisti, 2013). We collected the same demographic information as in Experiment 1, with the only difference being in the response options for the appearance of the unexpected object (shape: square, cross, circle, L-shape, none of these; color: solid black, solid white, solid gray, black and white pattern, gray and white pattern, gray and black pattern, none of these).

Results and Discussion

Prior to analysis, we excluded subjects who failed to meet the preregistered exclusion criteria. We used the same set of exclusions as in Experiment 1 except for the full-attention trial criteria, and excluded 139 subjects (23% of our sample), leaving 463 subjects in the final analysis. 224 subjects were assigned to attend to the gray squares, with 116 assigned to the unexpected checkerboard and 112 assigned to the unexpected tessellation. 235 were assigned to attend checkerboards, with 111 to the unexpected checkerboard and 124 to the tessellation. As in Experiment 1, approximately equal numbers of subjects were allocated to conditions, implying no differential dropout across conditions. As in Experiment 1, to be counted as having noticed the unexpected object subjects had to report noticing something new on the critical trial and correctly identify its shape, color, or both; changing this criterion does not substantially affect the pattern of results (see Figure 4, Panel D). Of 254 correct responses, 210 subjects correctly

identified both the shape and color of the unexpected object, 12 identified only the color, and 32 identified only the shape.

If similarity to the ignored set matters, then participants who ignored checkerboards should notice the unexpected checkerboard less than the unexpected tessellation; the difference in noticing between checkerboard and tessellation should be negative. As in Experiment 1, the pattern was consistent with a role of similarity to the ignored items (the checkerboards were noticed 12.9% of the time, the tessellations 24.1% for a difference of -11.2%, 95% CI: [-13.2, -9.2]).

Conversely, if similarity to the attended items matters, then participants who attended to the checkerboards and ignored gray squares should notice the unexpected checkerboard more than the tessellation. Participants in both groups noticed the unexpected objects at much higher rates when attending to checkerboards. Unlike Experiment 1, both objects were noticed at the same rate (checkerboards noticed 90.1% of the time, tessellations 90.3% of the time for a difference of -0.2%, 95% CI: [-0.9, 0.3]).

Unlike Experiment 1, in which the pattern of results was consistent with both similarity to the attended items and similarity to the ignored items contributing to noticing, the results of Experiment 2 are consistent with a role for similarity to the ignored objects, but not for similarity to the attended objects (Figure 2, Panel B).

General Discussion

Across two experiments, we find evidence for suppression of selectively ignored items independent of enhancement for attended items. In Experiment 1, when subjects attended white squares and ignored checkerboards, they were more likely to notice white circles than black ones. In contrast, when ignoring white and attending to checkerboards, they were more likely to notice black than white. These results suggest independent enhancement of objects similar to the attended set and suppression of objects similar to the ignored set. Experiment 2 addressed

possible confounds in Experiment 1 and observed only an effect of suppression of ignored items. When subjects attended to gray squares and ignored checkerboards, they were less likely to notice an unexpected checkerboard than the less-similar tessellation. However, when attending to the checkerboards, they noticed the checkerboard and tessellation at equally high rates.

Why did Experiment 2 only find an effect of similarity to the ignored items? In Experiment 1, the observed effect of similarity to the attended items (i.e., the difference in noticing white and black unexpected shapes when attending to white squares) might actually have been due to suppression of the ignored features; black was present in both the unexpected object and the ignored checkerboards. Alternatively, similarity to the attended items might enhance noticing, but in a way that is less selective than suppression. If so, we might not have seen the effect in Experiment 2 because the unexpected objects were sufficiently similar to each other that both were enhanced equally.

Alternatively, noticing of unexpected objects might be driven entirely by suppression of the ignored objects, with similarity to the attended items playing no role in noticing. That is, unexpected objects that match the attended items might be no more likely to be noticed than objects differing from the attended items, provided that they are equally similar to the ignored items. The results of Experiment 2, in which the tessellation was noticed more often than the checkerboards when subjects ignored checkerboards, is consistent with only similarity to the ignored set affecting noticing rates. The more similar an object is to the ignored set, the less it is noticed. However, the same was not true of the attended objects; when people attended checkerboards and ignored gray squares, the unexpected checkerboard and unexpected tessellation were noticed at the same rate. Because both unexpected objects were equally different from the ignored set, they may have escaped suppression to the same extent. This counterintu-

itive finding suggests that sustained inattention blindness might be driven by selective suppression rather than selective enhancement.

These results add nuance to the consistent finding in the inattention blindness literature that the more similar something is to selectively ignored objects, the more often it is missed. However, this pattern of noticing does not necessarily apply to other attention tasks, such as visual search or deliberate detection tasks. For instance, salient items that “pop out” in a visual search task often go unnoticed in an inattention blindness task (Most et al., 2001; Most et al., 2005). Further, behavioral and neural responses to simple object features, such as color, often do not predict noticing in inattention blindness (Drew & Stothart, 2016).

Both of our experiments showed that suppression of selectively ignored objects and objects similar to them affects noticing independent of any effects of similarity to the attended set. Experiment 2 shows that this suppression process discriminates between subtle differences in the pattern of an unexpected object, rather than suppressing a broad category of “patterned objects.” Enhancement, if it contributes to inattention blindness, appears to be less selective. It is unclear whether the same similarity mechanisms would apply to attention tasks in which participants expect objects to appear.

Constraints on Generality

Given that other studies using a variety of stimuli demonstrate a role for similarity in sustained inattention blindness (Simons and Chabris, 1999; Most et al., 2001; Most et al., 2005), we expect that our results would generalize to other types of stimuli and to other similarity relationships, provided that the task varies similarity with respect to just one set of objects. The effects of similarity on inattention blindness have been studied mostly using dynamic, continuous attention tasks, so this pattern may not hold for other types of inattention blindness tasks (e.g., Mack & Rock, 1998). Studies of the role of similarity in inattention blindness have used both laboratory and online methods with a wide range of participants. Consequently, we expect

our online results to generalize to anyone meeting inclusion criteria similar to ours and capable of performing the primary task accurately, even if overall levels of noticing vary somewhat (as long as they are not at ceiling or floor). We do not know whether our strict, preregistered exclusion criteria are essential to observe the same pattern of results, but we recommend using strict exclusion criteria to ensure that the critical objects are unexpected and that subjects are engaged in the primary task.

Conclusion

This study dissociated the effects of similarity to attended and ignored objects on rates of inattention blindness by using unexpected objects that varied in similarity to only one set of objects—attended or ignored—at a time. In so doing, we eliminated a persistent confound in the design of inattention blindness experiments that prevented an inference about the separate roles of similarity to attended and ignored items. Our experiments revealed an effect of similarity to the ignored objects on noticing that is independent of the effects of similarity to the attended objects. Future research should examine whether similarity to the attended items enhances noticing in a less specific manner than suppression, or whether it plays no role in noticing of unexpected objects.

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Supplementary Material

Figure S1. Noticing rates for Experiment 1 (Panel A) and Experiment 2 (Panel B) using stricter noticing criteria. Overall noticing rates change slightly, but the overall pattern of results is preserved.