SIMILARITY AND FEATURE DIMENSIONS IN INATTENTIONAL BLINDNESS

BY

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THESIS

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ABSTRACT

Obvious but unexpected events often go unnoticed when people are selectively attending to one set of objects and ignoring another. People are more likely to notice something unexpected if it is more similar to the group of objects to which they are attending, and less similar to the group of objects that they are ignoring. Previous studies of this phenomenon often vary similarity along a single continuum, such as black to white, with the attended and ignored objects occupying either extreme. This results in similarity and dissimilarity that have a zero-sum relationship; as an object becomes more similar to one set of objects and moves closer to one end of the continuum, it necessarily becomes less similar from the other set of objects and moves farther from the other end of the continuum. This obscures the separate contributions of similarity to a set of objects and dissimilarity from a set of objects to the noticing of unexpected events. To disentangle these similarity roles, we designed a series of inattentional blindness tasks in which we held similarity to the attended set along a critical feature constant while varying it with respect only to the ignored set, or vice versa. Across five experiments, we varied similarity both along task-relevant dimensions and task-irrelevant dimensions. We consistently observed strong inhibitory effects for stimuli similar to the ignored set; however, this effect depended on whether similarity varied on a task-relevant or task-irrelevant dimension. We did not consistently observe enhancement of objects similar to the attended set. This suggests that suppression alone may explain many of the observed similarity effects, and reveals that these similarity effects do not extend cleanly to task-irrelevant dimensions.

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CHAPTER 1: INTRODUCTION

Focused attention on a task can induce a phenomenon known as *inattentional blindness,* in which we are oblivious to unexpected events, even salient or strange ones (Neisser & Becklen, 1975; Mack & Rock, 1998; Simons & Chabris, 1999). Some unexpected objects are more likely to reach awareness than others, however, especially those that differ from the ignored stimuli and match the attended ones (e.g. Most, Scholl, Clifford, & Simons, 2005). Typically, the objects to be attended and ignored differ along a critical feature dimension, such as shape, color, or luminance. Often these objects occupy two extremes of a feature continuum—for example, one group of objects may be white while the other is black. When the appearance of the unexpected object changes along the critical feature dimension, such as shifting from black to gray to white, noticing rates change in turn. 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).

Studies have previously 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. When luminance is the critical feature, for example, a typical continuum is black-to-white. Gray, then, ought to be equally similar to black and white, as it lies halfway between black and white. When subjects attend gray and ignore black, a black unexpected object matches the ignored set; a white unexpected object differs from the ignored objects, but should be just as different from gray as black is. With this set of display objects and unexpected objects, subjects often notice white but rarely detect black; the reverse pattern occurs when subjects instead ignore white while attending gray (Most et al., 2001).

This pattern replicates when gray unexpected objects are added; subjects only rarely detect an unexpected object that matches the ignored set, but tend to notice objects that match the set to which they are attending, gray in this case, as well as objects that differ substantially from the ignored objects—black when ignoring white, and vice versa (Goldstein & Beck, 2016). The same basic relationship also holds in the color dimension. When red-orange and yellow-orange are used as display objects, subjects are least likely to notice an unexpected object that matches the ignored set, and generally more likely to notice a match to the attended set or to an extreme end of the red-yellow continuum (Goldstein & Beck, 2016).

The effect of similarity has also been explored in a circular color space, rather than an end-stopped linear continuum (Drew & Stothart, 2016). As in previous studies, subjects rarely detected unexpected objects in the same color as ignored objects in the display, and they were most likely to notice an object in the attended color. All other colors were noticed more often than the ignored ones. The further from an ignored color an object was, the more likely it was to be noticed (Drew & Stothart, 2016).

These previous results consistently support a role of similarity to the ignored objects. In every case, an unexpected object that matched the ignored set was the least likely to be noticed. The evidence for a role of similarity to the attended objects is less clear, however. 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. This leaves a question of whether similarity to the attended set of objects actually plays a role in noticing at all, or if it is driven entirely by dissimilarity from the ignored set of objects.

To address this question, we developed two variants of a sustained inattentional blindness task. In one variant, 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. In the other, the unexpected object varies along a task-irrelevant feature that affects its similarity to only one set of objects in the display, because only one set of objects has the task-irrelevant feature while the other does not. That approach allows us to disentangle the effects of similarity to the attended objects and the ignored objects.

CHAPTER 2: GENERAL METHODS

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

Subjects

All subjects were recruited via Amazon's Mechanical Turk service and paid $.10 for completing the study. Only workers based in the United States and with an overall HIT approval rate of at least 95% (that is, 95% of all HITs returned ended up being approved) could access the study. Using TurkGate (Gideon & Goldin, 2013), we validated the Worker IDs of interested subjects against a database containing the IDs of workers who had previously participated in either our studies or in studies conducted by our colleagues. People whose Worker IDs were already in these databases were informed that they could not participate in this study.

Materials and Procedure

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—the precise objects varied depending on the experiment—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. At the start of the experiment, each participant was randomly assigned to count bounces from one set,

and they tracked the same set of objects on all trials. 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.

Each trial lasted 17 seconds. The objects moved individually with randomly varying velocities, occluded one another when they crossed paths, and always passed behind the fixation square if it intersected with it. 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, moved horizontally across the display (passing behind the other objects and the fixation square), and exited 6750 ms 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, the options for which varied by experiment.

In Experiments 1 and 2 subjects completed a "full attention" trial after the critical trial. The display in this trial was identical to that of the critical trial, but participants were instructed 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. We discovered that this full-attention trial excluded a large number of subjects without changing the pattern of results, and dropped it from Experiments 3, 4, and 5 (see also Peer, Vosgerau, & Acquisti, 2013).

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.

Noticing

In all experiments, 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.

Exclusion Criteria

Prior to analysis, we applied the same preregistered exclusion criteria in all experiments. We eliminated 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 (Experiments 1 and 2); 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.

CHAPTER 3: EXPERIMENT 1

This chapter describes a previously published experiment.[1]

In previous experiments exploring the effects of similarity on noticing, the attended and ignored items differed from each other along a single, critical feature dimension, such as color. Unexpected objects similarly differed from the display objects in this dimension, confounding similarity-to and dissimilarity-from. Here, subjects attended either to white squares or to black-and-white checkerboards. The unexpected object could be either a black or white circle. Because the checkerboards are equal parts white and black, they should be equally similar to both the black and white circle. The white squares, on the other hand, should vary in similarity, being more similar to the white unexpected object than the black one.

This set of stimuli allows us to examine similarity to just one set of objects at a time. When subjects attend to the white squares and ignore the checkerboards, both unexpected objects will be equally similar to the ignored set of objects. However, they will vary in similarity to the attended set, allowing us to isolate the role of similarity to attended objects while holding similarity to the ignored objects constant. The reverse is true when subjects attend to checkerboards and ignore white squares. In this case, we isolate the role of similarity to the ignored objects while holding similarity to the attended objects constant. We expect clearly discriminable data patterns depending on whether similarity to the attended set, the ignored set, or both drive noticing (Figure 1).

Methods

[1] Wood, K. & Simons, D. J. The role of similarity in inattentional blindness: Selective enhancement, selective suppression, or both? *Visual Cognition.* DOI:10.1080/13506285.2017.1365791

We recruited 644 subjects via Amazon's Mechanical Turk service per the details outlined in the General Methods. 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 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.

There were two possible unexpected objects: a white circle (14 pixel radius) or a black circle (see Figure 2, panel A).

Results and Discussion

Using the exclusion criteria described in the General Methods, we excluded data from 138 subjects (29% of the sample). There were 451 subjects in the final analysis. A breakdown of condition assignment can be found in Table 1.

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.

If similarity to the attended objects contributes to noticing, people ought to be more likely to notice the white circle than the black one when attending white squares (a positive difference between white and black). The ignored checkerboards, equally similar to both unexpected objects, should not contribute to any difference in noticing between white and black. Consistent with a role for the similarity to the attended items, the difference between noticing rates was

positive when attending to white squares (70.5% noticing white versus 48.7% noticing black 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, but white is more similar to the ignored white squares than black. If this similarity to the ignored set affects noticing of unexpected objects, the difference in noticing rates between white and black when attending checkerboards should be negative. Consistent with a role for similarity to the ignored items, the difference in noticing rates between white and black was -46.7% (20.2% noticed white and 66.9% noticed black; 95% bootstrapped CI: [-47.4, -45.4]). The positive difference when attending to white squares and the negative difference when attending to checkerboards suggests that similarity to the attended set modulates noticing rates independently from divergence from the ignored set.

While these results suggest independent and simultaneous enhancement of attended items and suppression of ignored items, several possible confounds remain. We may have inadvertently exchanged a black-white continuum for a "percent black" continuum, rather than eliminating it entirely—white would be at one end, at 0% black, the checkerboards in the middle, at 50% black, and the black unexpected object at the other end, at 100% black. This may have caused asymmetry in how similar the two unexpected objects were to the checkerboards.

There are also imbalances in the stimuli themselves. The squares are solid white, but the checkerboard contains both white and black. "Presence of black" is therefore a possible way to segment the display objects, and the unexpected objects could be classified as "black present" and "black absent," which would change their similarity relationships to the checkerboards. The black unexpected object is also the only solid-black shape in the display, making it more

distinctive than the unexpected white object. We ran Experiment 2 to attempt to control for these potential confounds by altering our stimuli.

CHAPTER 4: EXPERIMENT 2

While the results of Experiment 1 suggest independent enhancement of attended items and inhibition 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 100% black. Additionally, the stimuli are somewhat unbalanced. One set of objects contains only white, but one contains both white and black. Thus the attended and ignored objects differ from each other in color space, in the same way that the unexpected objects differ from the display objects.

To control for this, in Experiment 2 we varied the similarity of the unexpected object along a dimension that is irrelevant to that which separates the two sets of display objects. We retained the checkerboards, but replaced the white squares with gray rectangles. The unexpected objects were either vertically-oriented gray rectangles, identical to the display rectangles, or horizontally-oriented gray rectangles. This orientation difference should have no bearing on how similar the unexpected object is to the square checkerboards, but should affect the similarity to the rectangles. The unexpected objects thus varied on a dimension that was only relevant to one set of objects, and one completely unrelated to that which separated the display objects.

Methods

We recruited 818 subjects according to the restrictions in the General Methods. The eight objects onscreen consisted of four gray rectangles (#808080) measuring 22 x 44 pixels and four black-and-white checkerboards**,** identical to those used in Experiment 1. The unexpected object

could be either a vertically-oriented rectangle or a horizontally-oriented rectangle. Subjects completed the task as they did in Experiment 1 (see Figure 2, panel B).

Results and Discussion

Prior to analysis, we excluded subjects who failed to meet the pre-registered exclusion criteria. We used the same set of exclusions as in Experiment 1, and excluded 484 subjects (59% of our sample), leaving 334 subjects in the final analysis; see Table 1 for condition assignment. 200 subjects were assigned to attend to the rectangles, with 108 assigned to the horizontal unexpected rectangle and 92 assigned to the vertical unexpected rectangle. 134 were assigned to the checkerboards, 78 to the horizontal unexpected rectangle and 56 to the vertical. As in Experiment 1, to have noticed the object subjects had to both report noticing something new on the critical trial and to correctly identify its shape, color, or both.

We compared the difference between noticing of the vertical unexpected rectangle and the horizontal rectangle in the attend-rectangles and attend-checkerboards conditions. When people attend to the rectangles, the unexpected objects vary in similarity; the vertical rectangle is more similar (in fact, a perfect match) to the attended set, but the horizontal rectangles are less similar. However, both unexpected objects are equally similar to the ignored checkerboards, as the change in orientation is irrelevant, and so similarity to the ignored set is held constant. Conversely, when subjects attend to checkerboards, both unexpected objects are equally similar to the attended set, but differ in their similarity to the ignored rectangles.

If there are independent effects of enhancement and inhibition, then there ought to be different effects if similarity when subjects attend versus ignore rectangles. Based on similarity alone, we might expect vertical rectangles to be noticed more often than horizontal when

subjects attend to the rectangles, as they are more similar to the attended set; this effect might be expected to reverse when subjects ignore the rectangles, as the less-similar horizontal rectangles might escape inhibition.

While we do observe different effects of similarity between the attend-rectangles and attend-checkerboards conditions, we do not find the expected effects of similarity (see Figure 3, panel B). When subjects attend rectangles, subjects notice the more similar, vertical unexpected objects *less* often than the less-similar horizontal ones (75% noticing for vertical versus 88.9% for horizontal for a difference of -13.9%, 95% bootstrapped CI: [-17.2, -10.8]). However, there was no difference between the noticing of the vertical and horizontal rectangles when subjects attended checkerboards and ignored rectangles (5.4% for vertical and 3.9% for horizontal for a difference of 1.5%, 95% bootstrapped CI: [0%, 3.8%]).

While the effect of orientation in one condition but not the other suggests two independent filters, we observe unexpected effects of similarity (there is no record in the literature of a dissimilar object being noticed more than the attended set itself).

These results may also reflect a strong novelty effect. Perhaps, when subjects ignore rectangles, they very effectively suppress any rectangle, regardless of orientation (thus generating the results we observed in which both unexpected rectangles were noticed at similar low rates). However, when attending to rectangles, perhaps selection is more narrow. The horizontal rectangles may receive a boost due to their similarity, plus an additional boost due to novelty. There may also be a role of confusability between the unexpected object and the display objects. Subjects may be grouping the unexpected object with the other display objects and not recognizing it as an “extra” object, deflating apparent noticing rates. Any differing effects of

similarity between conditions may be masked by this confusability. If this were the case, we might also expect to observe that the vertical rectangle is noticed less often when it is ignored, as well; both the novelty account and the confusability account would predict more noticing of the horizontal rectangle in both conditions. However, there may be a floor effect in the ignore-rectangles condition that obscures differences which might emerge were noticing rates higher.

This pattern of results may also be in part due to the chosen display objects. The rectangles differ from the checkerboards in color, shape, and size, leading to unbalanced object sets. In order to control for our stimuli and attempt to pull noticing off of floor, we ran Experiment 3.

CHAPTER 5: EXPERIMENT 3

In Experiment 3, we exchanged the black and white checkerboards for medium-gray circles. The two sets of display stimuli were thus the same color and more similar in size than in Experiment 2, while still differing in shape. We retained the same vertical and horizontal unexpected objects; their orientation is irrelevant to their similarity to the circles, but does affect their similarity to the display rectangles. Similarity still varied with respect to only one set of objects, and along the orientation dimension, which is irrelevant to the shape dimension separating the rectangles from the circles.

Methods

601 subjects participated in the study according to the restrictions outlined in the General Methods.

The display objects consisted of four gray (#808080) rectangles measuring 32 x 64 pixels and four gray (#808080) circles with a radius of 21 pixels. The procedure proceeded as it did in Experiment 2, except this time subjects did not complete a full-attention trial. The same vertically- and horizontally-oriented rectangles were used as in Experiment 2. After they responded to the appearance of the unexpected object, they proceeded directly to the demographic and debriefing questions (see Figure 2, panel C).

Results and Discussion

We excluded 165 subjects (28% of the sample) according to pre-registered criteria prior to analysis. Of the remaining 436 subjects, 222 were instructed to attend to the rectangles, with 113 presented with the vertical unexpected rectangle and 109 presented with the horizontal

unexpected rectangle, and 214 attended circles, with 115 in the vertical unexpected rectangle condition, and 99 in the horizontal condition.

We replicated the results of Experiment 2 (Figure 3, panel C). Subjects noticed the vertical rectangle less often than the horizontal when attending to rectangles and ignoring circles (55.8% noticing for vertical versus 75.2% noticing for horizontal, a difference of -19.4%, 95% CI: [-20.4, -18.0]). Overall rates of noticing were lower than those in Experiment 2, but again, the more similar unexpected object is noticed less frequently than the less-similar object.

When subjects ignored rectangles, rates of noticing remained near floor, with the vertical rectangles noticed less often than the horizontal ones (1.7% for vertical and 8.1% for horizontal for a difference of -6.4%, 95% CI: [-8.9, -3.0]). This difference is consistent with the similarity account; in this case, the unexpected object that better matched the ignored set of items was noticed less frequently.

Despite reducing the number of differences between the two sets of display objects, the unpredicted finding that more similarity begets less noticing in the attend-rectangles condition persisted. Indeed, rather than pulling noticing off of floor when subjects ignored rectangles, noticing rates fell when subjects attended to rectangles relative to Experiment 2. Since the only change was to the display objects between experiments, this result would seem to be driven entirely by the relationship between the display objects themselves, independent of their similarity to the unexpected objects. This suggests that perhaps the less discriminable the display objects are from one another, the more severe inattentional blindness becomes.

Despite raising this intriguing possibility, Experiment 3 failed to rule out the possible confounds of Experiment 2. The peculiar pattern in the data may be due to novelty effects or

confusability of the unexpected objects with display objects. We attempted to account for these potential confounds with a fourth experiment.

CHAPTER 6: EXPERIMENT 4

In Experiment 4, we replicated Experiment 3 with a critical change. The unexpected object was a different color than the other objects in the display, making it unique and less likely to be confused for a display item. This control, coupled with the stimuli from Experiment 3, should clearly reveal the effects of similarity in each of the two conditions. The unexpected object is unique, and varies in similarity along a dimension irrelevant to that which separates the display objects. This should reduce confusability and the imbalance in novelty, as well as pull noticing away from floor when subjects ignore the vertical rectangles (see Figure 2, panel D).

Methods

We recruited 612 subjects according to the restrictions outlined in the General Methods. The display objects were identical to those in Experiment 3. The unexpected objects were a vertical and horizontal rectangle, but this time were dark gray (#404040). This color was selected according to pilot data, which indicated that it best avoided both ceiling and floor effects in noticing. Subjects completed the experiment according to the procedure in the General Methods, but without a full attention trial (as in Experiment 3).

Results and Discussion

Prior to analysis, we excluded 174 subjects (28% of the sample) according to our pre-registered criteria. 225 subjects attended to rectangles (114 received the vertical unexpected rectangle, 111 the horizontal one), and 213 attended to circles (100 in the vertical condition, 113 in the horizontal).

After making the unexpected object unique in the display, the difference in noticing rates between the vertical and horizontal unexpected rectangles when subjects attended rectangles

disappeared (77.2% noticed the horizontal rectangles and 78.4% noticed the vertical rectangles for a difference of -1.2%, 95% CI: [-2.0, -0.3]; see Figure 3, panel D). Noticing rates when subjects ignored rectangles rose dramatically, although remained lower than when subjects attended rectangles, and the unexpected objects were noticed just as often (62% noticed the horizontal rectangles and 61.9% noticed the vertical rectangles for a difference of 0.1%, 95% CI: [-0.9%, 1.3%]).

The results from Experiments 2-4 provide a degree of evidence for the independent roles of similarity to attended and ignored objects. In Experiment 2, the effect of the unexpected object's identity changed depending on whether people were attending rectangles (an effect, albeit an unexpected one, of object similarity) or ignoring them (no effect of similarity). In Experiment 3, the horizontal rectangle was noticed more often in both conditions. In Experiment 4, when the unexpected object was unique in color, both types were noticed at the same rates within an attention condition.

It seems that not only does the choice of display objects heavily influence overall rates of noticing (noticing rates dropped from Experiment 2, with the checkerboards, to Experiment 3, with the circles), but also that varying unexpected objects along a non-critical feature dimension is not necessarily a pure, straightforward way to examine the role of similarity. In these experiments, we did not replicate one of the most straightforward similarity-based findings; that you are more likely to notice an object the more similar it is to the set of attended objects. This may only hold for unexpected objects that vary in similarity along the same feature dimension that separates the display objects from one another. In these experiments, subjects may have formed an attention set first for "pattern" and "no pattern," (Experiment 2), then for "rectangles"

and “circles”; the similarity of the horizontal unexpected object thus may not have been as graded as we predicted, but put the object into an entirely different category.

While these results raise unexplored questions about how feature dimensions and task-relevance interact to influence noticing rates, they provide mixed answers to the question asked in Experiment 1: when similarity to one set of display objects is held constant, what are the roles of similarity to the other set?

To address this, we ran Experiment 5.

CHAPTER 7: EXPERIMENT 5

This chapter describes a previously published experiment.[2]

In Experiment 5, we employed stimuli more similar to those originally used in Experiment 1. We again used checkerboards for one set of objects, but replaced the white squares with medium-gray squares. This ensured that average luminance was equated between the two sets of objects, eliminating one imbalance from Experiment 1.

We varied the unexpected objects with respect to the checkerboards instead of the solid squares by using patterned objects. One version of the unexpected object was a black-and-white checkerboard of a lower spatial frequency than the display checkerboards. The other was a black-and-white tessellation of triangles, using the same number of pieces as the unexpected checkerboards. The unexpected objects were therefore the same on virtually every dimension—number of component pieces, average luminance, spatial frequency, surface area of each cell, and so on. The only difference is in the internal arrangement of the black and white pieces.

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. However, these objects all differ with respect to the critical feature—pattern—that separates the two sets of display objects. We also avoid introducing any new colors into the display with the unexpected objects, removing the potential problem introduced by the uniformly black unexpected object in Experiment 1. The two unexpected objects are both different from all other items in the display, eliminating the

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[2] Wood, K. & Simons, D. J. The role of similarity in inattentional blindness: Selective enhancement, selective suppression, or both? *Visual Cognition.* DOI:10.1080/13506285.2017.1365791

confounds of Experiments 2-4. Experiment 5 separates the role of similarity to the attended and ignored items, while eliminating the potential confounds of the previous experiments.

Methods

We recruited 602 subjects on Mechanical Turk. The attended and ignored objects were four medium-gray (#808080) squares measuring 60 x 60 pixels and four black-and-white checkerboards of the same size (structured as a 5 x 5 grid of 12 x 12 pixel cells). Two of the checkerboards had white in the upper-left and two had black.

The two unexpected objects (60 x 60 pixels) were a either black-and-white checkerboard or a tessellation of black and white triangles. The checkerboard (a 4 x 4 grid of 15 x 15 pixel cells) was randomly assigned to have its pattern begin with black or white in the upper left. The tessellation (formed from 16 triangles with a base of 30 pixels and height of 15 pixels) was arranged such that no contiguous triangles shared a color, and was randomly assigned to one of two possible patterns. The cells of the checkerboard and the tessellation had the same surface area, so each pattern had an equal amount of black and white.

Subjects did not complete a full-attention trial after the critical trial. We collected the same demographic information as in the General Methods, 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 according to the General Methods (except for the full-attention trial criterion) and removed 139 subjects (23% of our sample) from analysis,

leaving 463 subjects. 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.

If similarity to the ignored set matters, then similarly to Experiment 1, participants who ignored checkerboards should notice the unexpected checkerboard less often than the unexpected tessellation (the difference in noticing between checkerboard and tessellation should be negative). 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]).

If similarity to the attended items matters, then participants who attended to the checkerboards and ignored gray squares should notice the unexpected checkerboard more often than they notice the tessellation. Participants in both unexpected object conditions had much higher rates of noticing than the participants who attended gray squares. Unlike Experiment 1, however, both unexpected 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]). This difference in the effects of similarity suggests that similarity to the ignored objects contributes to noticing independently of similarity to the attended objects.

CHAPTER 8: GENERAL DISCUSSION

Across five experiments, we explored the influence of similarity on task-relevant and task-irrelevant feature dimensions on rates of noticing unexpected objects.

In Experiment 1, we attempted to isolate the effect on noticing of similarity to the attended items and ignored items by employing white squares and black-and-white checkerboards as the display objects, and a black or white circle as the unexpected object. The white circle is more similar to the white squares than the black circle is, but both ought to be equally similar to the half-black, half-white checkerboards. When people attended white squares, they noticed the similar white circles more often than the black ones, while holding similarity to the ignored set constant. This suggests that similarity to the attended set enhances noticing of similar objects independently of any effect of the ignored set of objects. Conversely, when people ignored the white squares, they were less likely to notice the white circles versus the black ones, suggesting an effect of similarity to the ignored set that suppresses similar objects independent of the attended set.

While Experiment 1 suggested two independent roles of similarity, one to the ignored set and one to the attended set of objects, potential confounds remain in the experimental design. In particular, the unexpected black circle was the only solid object to appear in the display, and thus more unique than the unexpected white circle. Additionally, the use of white squares and black and white checkerboards may have induced a continuum such as "proportion black," introducing an asymmetry in how similar the black and white circles were to the checkerboards.

Experiments 2-4 attempted to skirt these issues by varying the unexpected object along a feature dimension that was irrelevant to the one that separated the objects in the display. In

Experiment 2, the display objects differed in pattern and shape, while the unexpected objects varied in orientation; in Experiment 3-4 the display objects differed in shape. By making one set of these objects vertically-oriented rectangles, we hoped to vary the similarity of the unexpected object only to the rectangles, while holding constant its similarity to the checkerboards (Experiment 3) and circles (Experiments 3-4).

Interestingly, not only did we fail to replicate Experiment 1, we observed a striking departure from previous inattentional blindness findings: when attending to the vertical rectangles, the less-similar horizontal rectangles were noticed 15% more often than the vertical ones. Even highly salient unique objects tend to be noticed at the same rate as a match to the attended object (Most et al., 2001), not more often. We observed the same pattern in Experiment 2 and 3, but eliminated the effect of orientation entirely in Experiment 4, when the unexpected objects were also a unique color.

These experiments provided uneven evidence for the possibility of two independent roles of similarity; sometimes the effect of orientation varied by attention condition, and in other cases it did not. Several factors may have contributed to these unusual results. It may be that orientation as a feature lacks salience, yielding a uniqueness effect but no similarity effect. When we made the object a different color in Experiment 4, the effect of orientation vanished, suggesting at the very least that the effects of color are stronger than those of orientation. Alternatively, the classic similarity effects in inattentional blindness (e.g. Most et al., 2001) may depend on the similarity between the objects varying along the critical feature dimension. Orientation was entirely task-irrelevant and unrelated to luminance or pattern—the critical

feature in Experiment 2—and may also have little to no relation to the critical shape feature used to divide the display objects in Experiments 3 and 4.

Interestingly, we also observed that overall rates of noticing changed considerably depending on the objects used in the display. When the objects were easily separable, as in Experiment 2, noticing rates for all unexpected objects were higher than in Experiment 3, when the display objects were more similar. This suggests that it is not only the similarity of the unexpected objects, but also of the display objects that influences noticing rates.

In Experiment 5, we returned to using stimuli that all varied along the same critical dimension. This time, however, the unexpected objects varied in their pattern, changing their similarity to the checkerboards in the display but leaving their similarity to the solid gray squares unaffected. This controlled for many of the confounds in Experiment 1 while still confining the variance to the critical feature dimension (color/pattern). In Experiment 5, we found a similarity effect when people ignored checkerboards; they were less likely to detect the more similar unexpected checkerboard than the unexpected tessellation. However, when people attended checkerboards, they noticed both unexpected objects at the same rate, suggesting a role of similarity to the ignored set but no such role to the attended set.

Why the difference between the results of Experiment 1 and Experiment 5? It may have been that the enhancement we observed in Experiment 1 arose from the confounds present in the design. For example, it may not have been that the white circle was enhanced relative to black when attending white squares, but that the black circle was suppressed due to it sharing a feature (presence of black) with the ignored checkerboards. Alternatively, attentional selection may be

less selective than suppression. The two unexpected objects in Experiment 5 may have been sufficiently similar to receive the same boost to noticing.

Finally, it may be that the similarity effects are driven entirely by the ignored set. When objects are more similar to the ignored set, they are noticed less often. The more objects differ from the ignored set, the more often they are noticed. There may be no similarity effect at all for the attended set, when all factors are properly controlled.

Constraints on Generality

The role of similarity in sustained inattentional blindness has been demonstrated with a variety of different stimuli and critical features (Simons and Chabris, 1999; Most et al., 2001; Most et al., 2005). However, as we have discovered, the usual similarity effects seem to depend on all objects varying along the feature that separates the display objects from each other. We expect that the effects we observed in Experiments 1 and 5 to be replicable, provided that the unexpected objects vary with respect to just one set and vary along whatever feature dimension separates the display objects. These effects may not hold under inattentional blindness paradigms that do not use dynamic stimuli (e.g., Mach & Rock, 1998; Cartwright-Finch & Lavie, 2007).

We expect these results to hold in both online and laboratory-based samples, for anyone who meets our inclusion criteria and is evaluated with the same exclusion criteria. Overall levels of noticing will likely vary depending on the precise nature of the stimuli used, as we observed appreciable variance even within our own paradigm.

Conclusion

This set of experiments explored the effects of similarity to attended and ignored objects on rates of inattentional blindness. In some experiments, we isolated these two types of similarity

by using unexpected objects that varied in similarity to only one set of objects—attended or ignored—at a time; in others, we did this by varying the unexpected object along an irrelevant feature dimension. In so doing, we provide two possible avenues for removing a persistent confound in the design of inattentional blindness experiments that prevents 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 when the unexpected object varies within the same feature dimension that separates the display 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. Additionally, there remain questions about the precise role of task-irrelevant features on noticing and the nature of the relationship between the two sets of display objects and the unexpected objects.

FIGURES AND TABLE

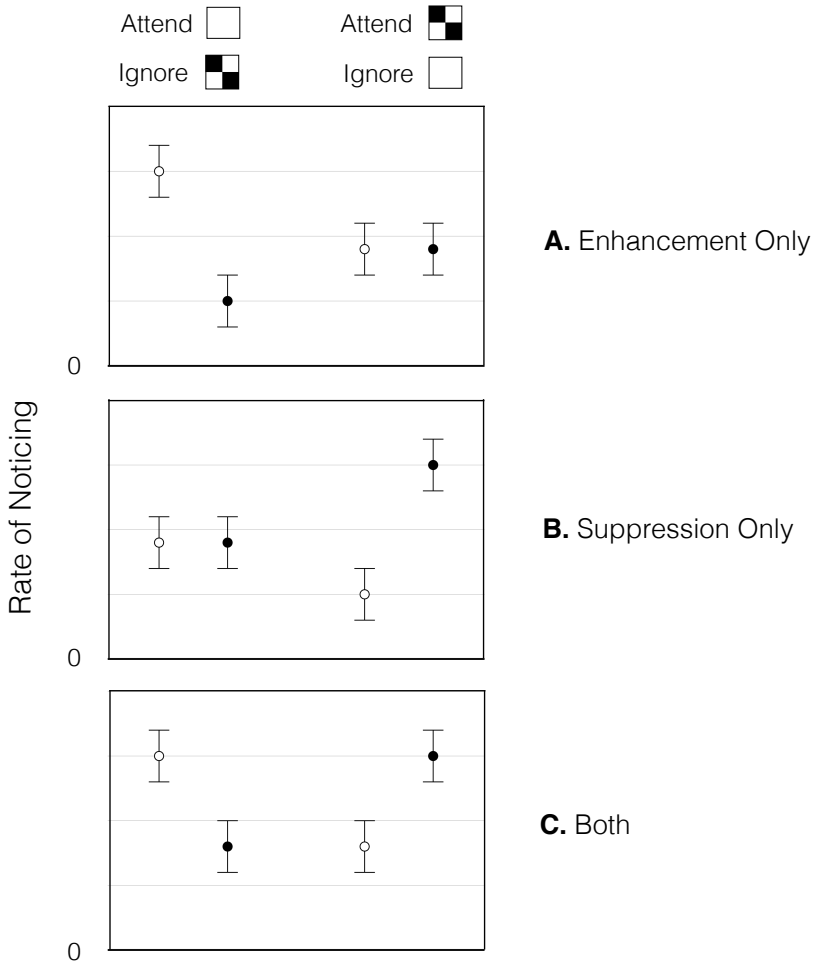

Figure 1. Predicted patterns of noticing rates for three hypotheses for the stimuli used in Experiment 1. The attended and ignored objects are indicated at the top of the graphs, while the dots indicate the color of the unexpected object. **Panel A.** If only similarity to the attended set matters, then the white unexpected object should be noticed more often than black one when subjects attend white, but 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).

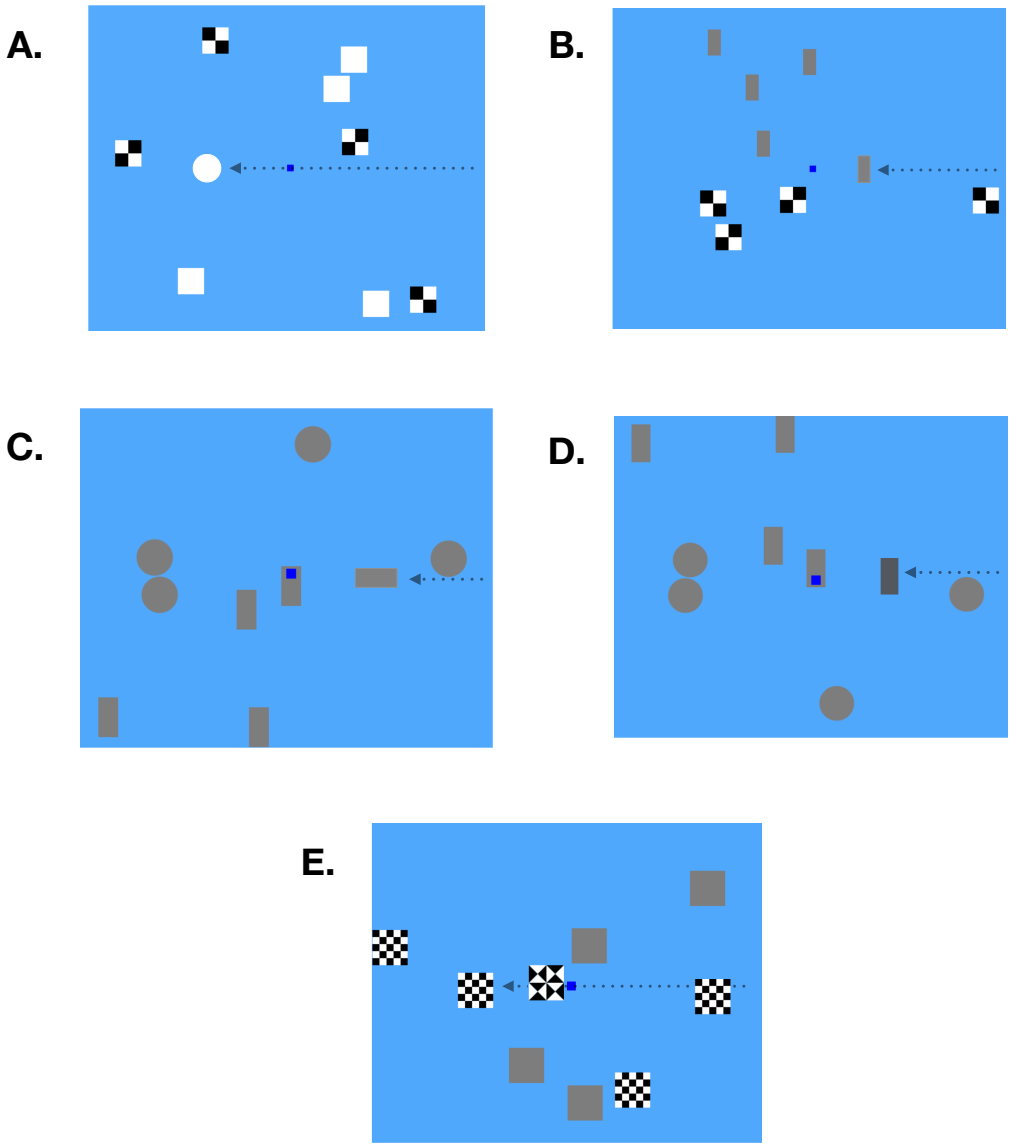

Figure 2. Display objects and a sample unexpected object used in each experiment. **A.** The stimuli used in Experiment 1. The display objects were white squares and black and white checkerboards, while the unexpected object could be a white or black circle. **B.** The stimuli used in Experiment 2. The display objects were gray, vertically-oriented rectangles and black and white checkerboards, while the unexpected object could be a vertical or horizontal rectangle. **C.** The stimuli used in Experiment 3. The display objects were gray, vertically-oriented rectangles and gray circles, while the unexpected object could be a vertical or horizontal rectangle. **D.** The stimuli used in Experiment 4. The display objects were gray, vertically-oriented rectangles and gray circles, while the unexpected object could be a dark gray vertical or horizontal rectangle. **E.** The stimuli used in Experiment 5. The display objects were gray squares and black and white checkerboards, while the unexpected object could be a checkerboard or a tessellation.

Experiment 1		
	Unexpected white square	Unexpected black square
Attend white squares	112	111
Attend checkerboards	104	124
Experiment 2		
	Unexpected vertical rectangle	Unexpected horizontal rectangle
Attend rectangles	92	108
Attend checkerboards	56	78
Experiment 3		
	Unexpected vertical rectangle	Unexpected horizontal rectangle
Attend rectangles	113	109
Attend circles	115	99
Experiment 4		
	Unexpected vertical rectangle	Unexpected horizontal rectangle
Attend rectangles	114	111
Attend circles	100	113
Experiment 5		
	Unexpected checkerboard	Unexpected tesselation
Attend gray squares	116	112
Attend checkerboard	111	124

Table 1. The number of subjects assigned to each attended object and unexpected object condition. These numbers indicate only the subjects in the final analysis, after exclusions were processed.

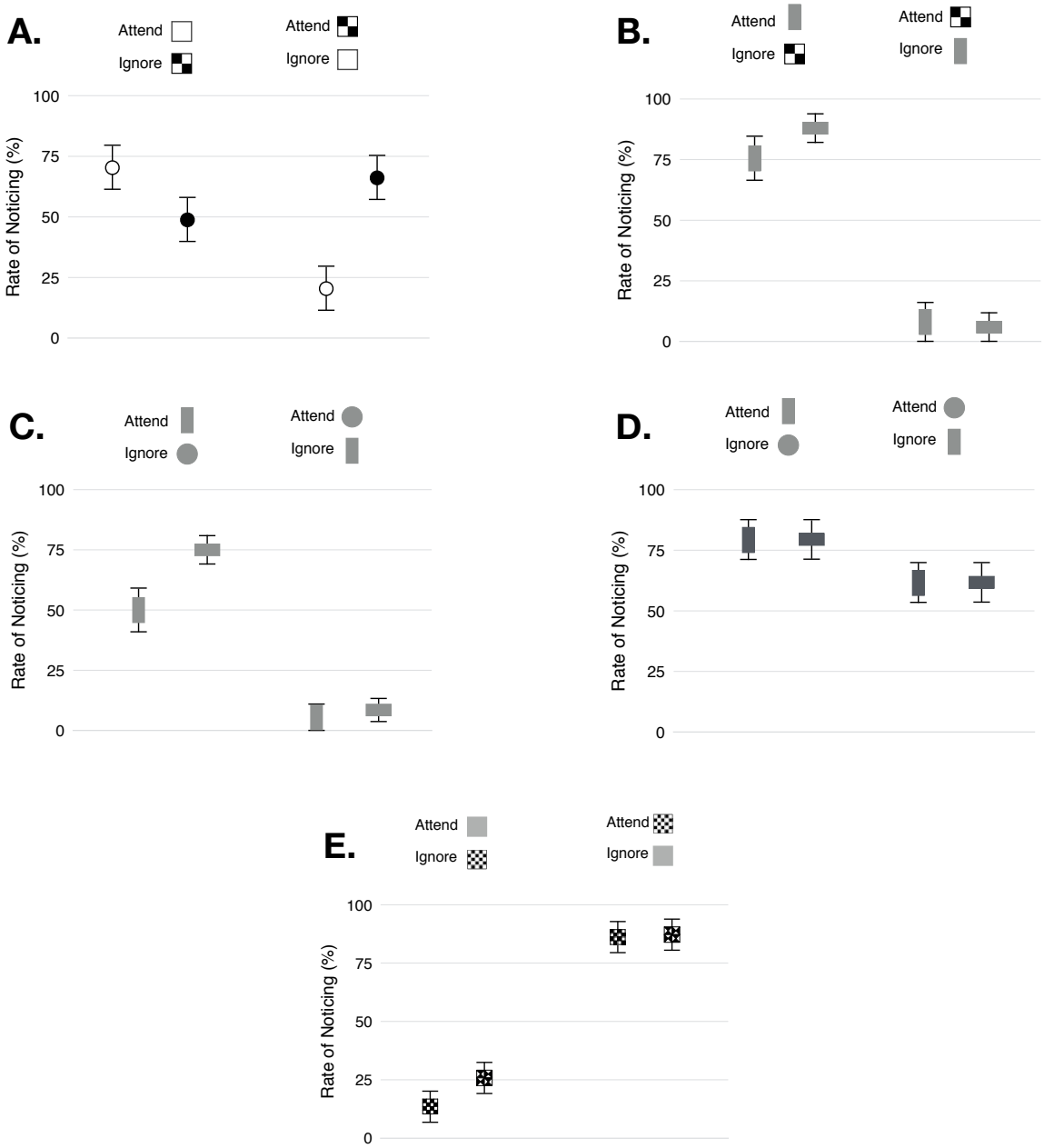

Figure 3. Results from each experiment. **A.** Results of Experiment 1. When subjects attended white squares and ignored checkerboards, they noticed white unexpected objects more often than black ones, irrespective of similarity to the ignored set; when subjects attended checkerboards and ignored white squares, they noticed black unexpected objects more often than white, irrespective of similarity to the attended set. **B.** Results of Experiment 2. When subjects attended rectangles and ignored checkerboards, they noticed the less-similar horizontal rectangles more often than the vertical rectangles. When subjects attended checkerboards and ignored the rectangles, both types of rectangles went unnoticed. **C.** Results of Experiment 3. When subjects attended rectangles and ignored gray circles, they again noticed the less-similar horizontal rectangles much more often than the vertical rectangles. When subjects attended gray circles and ignored the rectangles, both types of rectangles went unnoticed. **D.** Results of Experiment 4. When subjects attended rectangles and ignored gray circles, they noticed both unexpected, dark gray rectangles at the same rate, and more frequently than when they ignored the rectangles and attended to circles. **E.** Results of Experiment 5. When subjects attended gray squares and ignored checkerboards, they were less likely to notice an unexpected checkerboard than an unexpected tessellation. However, when subjects attended checkerboards and ignored gray squares, they were equally likely to notice the checkerboard and the tessellation.

REFERENCES

Cartwright-Finch, U., & Lavie, N. (2007). The role of perceptual load in inattentional blindness. *Cognition, 102*(3), 321–340. http://doi.org/10.1016/j.cognition.2006.01.002

Drew, T., & Stohart, C. (2016). Clarifying the role of target similarity, task relevance and feature-based suppression during sustained inattentional blindness. Journal of Vision, 16(15), 1–9. http://doi.org/10.1167/16.15.13.doi

Goldin, G., Darlow, A. (2013). TurkGate (Version 0.4.0) [Software]. Available from http://gideongoldin.github.com/TurkGate/

Goldstein, R. R., & Beck, M. R. (2016). Inattentional blindness: A combination of a relational set and a feature suppression set? *Attention, Perception, & Psychophysics*, *78,* 1245–1254. http://doi.org/10.3758/s13414-016-1091-x

Most, S. B., Scholl, B. J., Clifford, E. R., & Simons, D. J. (2005). What you see is what you set: Sustained inattentional blindness and the capture of awareness. *Psychological Review, 112*(1), 217–242. http://doi.org/10.1037/0033-295X.112.1.217

Most, S. B., Simons, D. J., Scholl, B. J., Jimenez, R., Clifford, E., & Chabris, C. F. (2001). How not to be seen: the contribution of similarity and selective ignoring to sustained inattentional blindness. *Psychological Science, 12*(1), 9–17. http://doi.org/10.1111/1467-9280.00303

Neisser, U., & Becklen, R. (1975). Selective looking: Attending to visually specified events. Cognitive Psychology, 7(4), 480–494. http://doi.org/10.1016/0010-0285(75)90019-5

Peer, E., Vosgerau, J., & Acquisti, A. (2013). Reputation as a sufficient condition for data quality on Amazon Mechanical Turk. *Behavior Research Methods, 46*(4), 1023–1031. http://doi.org/10.3758/s13428-013-0434-y

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Simmons, J. P., Nelson, L. D., & Simonsohn, U. (2011). False-positive psychology: Undisclosed flexibility in data collection and analysis allows presenting anything as significant. *Psychological Science, 22*(11), 1359-1366. http://doi.org/10.1177/0956797611417632

Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception*, 28(9), 1059–1074. http://doi.org/10.1068/p2952

Stothart, C., Boot, W. R., & Simons, D. J. (2015). Using Mechanical Turk to assess the effects of age and spatial proximity on inattentional blindness. *Collabra, 1*(1), 1-7. doi:10.1525/collabra.26

Wickham, H. (2009). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag, New York.