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ORIGINAL ARTICLE

The role of unattended distractors in sustained inattentional blindness

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Abstract When participants are attending to a subset of visual targets or events and ignoring irrelevant distractors (''selective looking''), they often fail to detect the appearance of an unexpected visual object or event even when the object is visible for several seconds (''sustained inattentional blindness''). An important factor influencing detection rates in selective looking is the attentional set of the participant: the more similar the features of the unexpected object are to the attended ones, the more probably it will be detected. We examined the possible contribution of active ignoring to this similarity effect by studying the role of the distractor objects in sustained inattentional blindness. First we showed the similarity effect for chromatic colors and then we manipulated the similarity of the unexpected object in relation to the distractor objects and did not find any effects. Moreover, we found that inattentional blindness was present even when the displays did not contain any irrelevant to-be-ignored objects. We conclude that attending to target items on the basis of attentional set, but not active ignoring of nontargets items, is sufficient for the occurrence of sustained inattentional blindness.

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Introduction

Visual attention and visual awareness seem to be closely linked. Observers with normal vision are surprisingly often functionally ''blind'' to the appearance of unexpected objects or large unexpected changes. In inattentional blindness, the observers performing an attention-demanding task often do not notice an additional object that appears without any expectation (Mack & Rock, 1998; Simons, 2000). In change blindness, even large changes between two versions of the scene remain undetected if the versions are separated by brief interruptions and attention is not directed to the location of the change (Simons & Levin, 1997).

In typical inattentional blindness experiments of Mack and Rock (1998), observers attended to a cross appearing for 200 ms in the center of the viewing area. The primary task was to judge whether the horizontal or vertical arm of the cross was longest. In the third or fourth trial, an unexpected stimulus (e.g., a square) appeared in a quadrant of the cross. When the observers were asked after the trial if they had seen anything that had not been present on previous trials, about 25% of the observers showed inattentional blindness, reporting that they did not see anything additional. Inattentional blindness decreased when the unexpected stimulus was positioned within the attention zone, suggesting that attention is needed for conscious detection. When the cross appeared parafoveally and the unexpected stimulus appeared at fixation, about 75% of observers did not detect it. Mack and Rock (1998) suggested that attention to fixation position could be actively inhibited when no objects were expected to appear there.

The studies on inattentional blindness using static displays like Mack and Rock suggest that an unexpected stimulus presented for 200–700 ms does not capture attention (Mack & Rock, 1998; Newby & Rock, 1998; Koivisto, Hyönä, &, Revonsuo, 2004). Even more dramatic and long lasting examples of inattentional blindness can be seen in selective looking studies inspired by the experiments of Neisser and his co-workers (cited in Neisser, 1979). They showed observers two partially transparent, overlaid videos. In one of them, a team wearing white shirts was passing a basketball, in the other one a team wearing black shirts was passing. Observers monitored the passes made by one of the teams. After half minute, unexpectedly, a woman with an open umbrella (also partially transparent) walked across the display, being visible for about 4 s. When asked after the trial, only 21% of the observers reported having noted the woman. In an additional experiment, no difference in noticing was observed whether the color of the woman's shirt was similar to the attended or the unattended team. Becklen and Cervone (1983) showed that stopping the video while the woman with umbrella was still present in the scene did not help observers to detect the woman.

In Simons and Chabris's (1999) selective looking study, participants monitored either a team in black shirts passing basketball or a team in white shirts passing basketball. The unexpected event was either the umbrella woman or a gorilla (woman wearing gorilla costume) walking across the screen for 5 s. For both events, strong inattentional blindness was found with the detection rates being lower for transparent than opaque versions of the videos. Interestingly, it was found that the observers who were monitoring the black team detected the appearance of the gorilla more often than those who monitored the white team, suggesting that the similarity of the color of the unexpected object to that of the attended objects plays a role in determining whether or not the unexpected event will capture attention. Most, Simons, Scholl, and Chabris (2000) and Most et al. (2001) combined the dynamic nature of the earlier selective looking studies (Becklen & Cervone, 1983; Neisser, 1979; Simons & Chabris, 1999) and more rigorous experimental control of the static displays (Mack & Rock, 1998). They presented moving shapes (T and L) and varied the luminance of the shapes and that of the unexpected object (+ mark moving across the display). They found that detection rates of the unexpected object increased when the similarity of the luminance between the unexpected object and attended shapes increased (Most et al., 2001). In a further study Most, Scholl, Clifford, and Simons (2005) replicated the effect of the similarity of luminance and extended the similarity effect to similarity between the shapes of unexpected object and attended objects. These results suggest that observers are able to establish an attentional set (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994) on the basis of a range of features that distinguish attended objects from unattended distractors, and that the probability of detecting the unexpected object may be strongly determined by its featural similarity to the attended set of features.

When the similarity of the unexpected stimulus to the attended stimuli is manipulated (e.g., the unexpected stimulus is white or black and the attended stimuli are white or black), its similarity in relation to the unattended distractor stimuli typically varies at the same time. When the unexpected object is similar in color to the attended objects (e.g., both are black), it is dissimilar in color to the distractor objects (white). When the unexpected object (e.g., black) is dissimilar to attended objects (white), then it is similar to the distractor objects (black). Therefore, the previous evidence for the role of similarity in inattentional blindness (Most et al., 2001, 2005; Simons & Chabris, 1999) can be interpreted in three different ways. First, it is possible that only the similarity of the unexpected stimulus to the attended stimuli is the critical factor in determining whether the unexpected stimulus is detected or not. Second, it is possible that the similarity of the unexpected stimulus to the distractor stimuli is the critical factor. Third, it is possible that both factors play a role. In order to distinguish between these alternatives, Most et al. (2001, Exp 2) conducted a selective looking experiment in which the attended objects were gray, halfway between black and white, and the distractor objects were either black or white; the unexpected object was either black or white, so that it was always dissimilar to attended objects but either similar or dissimilar to distractor objects. Fewer observers detected the unexpected object when it was similar to the distractor objects than when it was dissimilar to them. Most et al. (2001, Exp 2) concluded that selective ignoring of irrelevant stimuli may partially explain the similarity effect. They noted, however, two objections to this view. First, it is possible, for example, when the distractor items are white, that the observers establish a luminance threshold and attend to all items darker than the threshold. Therefore, a black unexpected stimulus would fall onto the darker side of the threshold and it would be detected, whereas a white item would not be detected as it falls onto the lighter side. A second interpretation is based on the fact that the unexpected item was more distinctive when it was dissimilar to the distractors because it had a unique luminance value (e.g., a black unexpected object when the attended objects were gray and the distractors were white). The distinctiveness of the unexpected object might have captured attention. In fact, when the unexpected stimulus was made more distinctive (a red cross when the attended items and distractors were black and white circles and squares instead of Ls and Ts), 72% of observers detected it (Most et al., 2001, Exp 3). This detection rate did not differ significantly from the 82% detection rate in the condition (Exp 2) where the unexpected object was dissimilar to the distractors (but had a unique luminance and was therefore distinctive).

Thus, it is clear that the more similar to the attended set (and at the same time the more dissimilar to unattended distractor set) the unexpected stimulus is, the more likely it will be detected. Whether this effect is driven solely by selective attending to the ''attended'' stimuli or whether it is contributed by selective ignoring of the distractor stimuli remains open. More generally, the contribution of distractor items to inattentional blindness in selective looking is unclear and needs further studies. Note that inattentional blindness experiments using static displays (Mack & Rock, 1998) typically do not include any irrelevant distractor stimuli in their displays. Therefore, the presence of distractors is not necessary for inattentional blindness to occur for brief stimulus durations. It remains to be tested whether longer lasting, sustained inattentional blindness can be observed in paradigms using dynamic events similar to those used in selective looking but without any need to distinguish between attended and ignored sets of stimuli.

In the present study, we examined the role of the distractor stimuli in sustained inattentional blindness for dynamic events during selective looking. Experiment 1 aimed to replicate the basic finding of similarity to confirm that our procedure produces similar results as previous studies. In Experiments 2 and 3, we studied whether or not active ignoring/inhibition of distractors plays a role in inattentional blindness by testing the effects of the similarity of the unexpected object to the distractor objects, while controlling for stimulus distinctiveness. Because we did not find any evidence for such active ignoring or inhibition, Experiments 4 and 5 examined whether it is at all necessary to include any irrelevant, unattended set of distractors in dynamic displays to produce sustained inattentional blindness.

Experiment 1

The purpose of this experiment was to replicate with the general procedure used in the present study the finding that the similarity of the unexpected stimulus to the attended stimuli (and at the same time dissimilarity to the unattended stimuli) increases the probability of detecting the unexpected stimulus (Most et al., 2001, 2005; Simons & Chabris, 1999). The stimuli were three green and three blue moving circles. The observers selectively attended to either blue or green circles. In the third trial, an unexpected stimulus (a blue or green cross) moved across the screen horizontally. For half of the participants, the color of the cross was the same as that of the attended stimuli and for half the color was different. After this inattention trial, the observers were asked whether or not they detected anything new or different that was not present in the previous trials. The inattention trial was followed by a full attention trial which was otherwise identical to the inattention trial but here the only task was to watch whether anything new or different occurred.

Method

Participants

Thirty-five participants (mean age 22.5 years, range 20–30; 12 males) with normal or corrected-to-normal vision took part. They participated as a part of a course in neuroscience at the Medical School of University of Turku. The participants were tested in subgroups of 8–10 persons. The similarity of the unexpected stimulus to the attended stimuli was manipulated between participants.

Apparatus and stimuli

The stimuli were presented by a ASK video projector with 60-Hz refresh rate and 1,024 × 768 resolution on a screen against a gray viewing area. The participants were seated about 2.5–3.5 m away from the screen, so that everyone saw the whole viewing area. From the 3-m distance, the size of the viewing area was 33° × 25°. The stimuli were three blue and three green circles (1.6° in diameter); the unexpected stimulus was a blue or green cross (1.6°). The colors of the stimuli are illustrated in Fig. 1. The luminance was 19 cd/m^2 for the gray background, 15 cd/m^2 for blue, and 19 cd/m^2 for green.

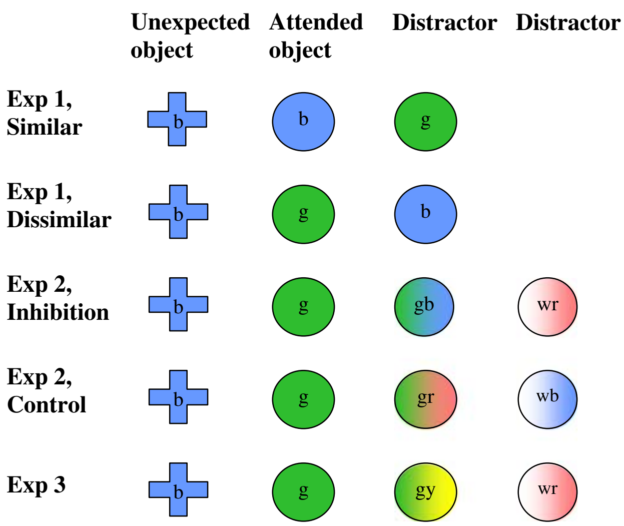

Fig. 1 Examples of the unexpected, attended, and distractor stimuli in different conditions of Experiments 1–3. In these examples the unexpected stimulus was always *blue*. The letters in the objects refer to their colors: blue (*b*), green (*g*), red (*r*), white (*w*), and yellow (*y*). For half of the participants, the unexpected stimulus was green and the green and blue colors in the attended objects and distractors were reversed accordingly

Procedure

In the beginning of each trial there were three blue and three green circles in the center of the screen. When a trial started, the stimuli started to move independently at variable rates toward the edges of the viewing area. The stimuli bounced to the edges and then bounced off to new directions. Each trial lasted for 10 s. The trials were divided into five 2 s segments so that the segments ended with a flicker of a 0.1 s black viewing area. The participants were asked to silently count the total number of bounces made either by the blue circles or by the green circles. They were told that they did not need to attend to the nontarget objects. The blue and green color of the circles was reversed depending on the attention condition so that the attended circles always were the same items with the same trajectories (this holds also to Experiments 2–3). After each trial, participants wrote down their answers on an answer sheet. The first and second trial did not include the unexpected stimulus. On the third, critical inattention trial, a blue cross (for nine participants attending to blue objects and for eight participants attending to green objects) or a green cross (for eight participants attending to green objects and for ten participants attending to blue objects) moved in along a straight line from left to right across the center of display (see Fig. 2). This unexpected stimulus appeared during a flicker after 4 s from the start of the trial and continued to be visible until the end of the trial, that is, for 6 s. Immediately after the question about the bounces in the critical trial, the participants were asked: "Did you detect anything new or different that had not been present on the prior trials; if you did, what did you detect"?

After writing down the answers, the experiment continued with the full attention trial which was otherwise identical to the inattention trial but here the only task was to watch whether anything new or different appeared as compared to the first and second trials. The full attention trial was followed by the question about detecting anything new or different as compared to the original two trials.

Results and discussion

Participants were considered as having detected the unexpected stimulus in the inattention trial when they answered "yes" to the question about noticing anything new or different and they could specify that a cross (or "+") appeared. Those of the observers who answered "yes" but explained that some irrelevant change occurred (e.g., "The number of bounces was different", "The movement speed was different") were scored as not having detected the unexpected stimulus. All the participants were able to detect the unexpected stimulus either in the inattention or in the full attention trial.

Here as well as in the other experiments, the results were analyzed with χ^2-square test, but when any of the cells had an expected value smaller than five, Fisher's exact test was used. The effect of similarity across all observers was statistically significant ($\chi^2 = 10.98$, $P < 0.01$). When the unexpected stimulus was similar

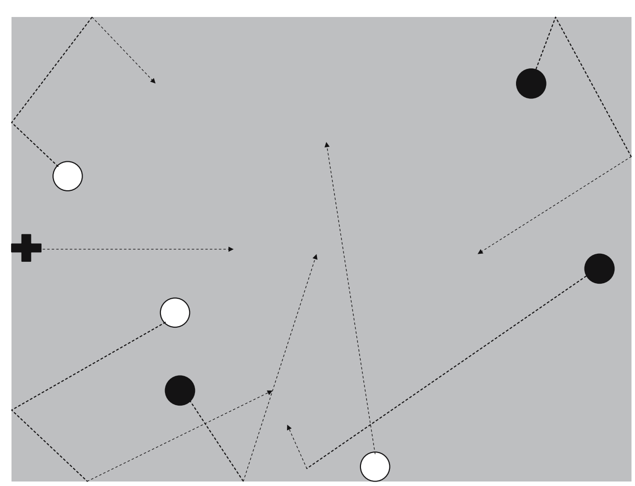

Fig. 2 An example of a critical trial showing the movement lines of the stimuli during a 2-s period

in color to the attended stimuli, 88.2% of the observers detected the unexpected stimulus (88% in the green cross and 89% in the blue cross conditions). When the unexpected stimulus was dissimilar in color to the attended stimuli, 33.3% detected it (40% in the green cross and 25% in the blue cross conditions).

Proportional error scores in the primary counting task were calculated for the first, second, and third trial. This was done by dividing the absolute value of the difference between counted bounces and actual bounces by the number of actual bounces. These scores for Experiments 1–5 are reported in Table 1. There was no difference in errors in any of the trials between those observers who detected the unexpected stimulus and those who did not ($P > 0.10$ in all experiments). These results suggest that detectors and nondetectors did not differ from each other in the attentional effort in the precritical trials (first and second trials) or in the critical, third trial.

The results replicate the effect of the similarity of the unexpected stimulus to the attended stimuli: detection rates were higher when the unexpected object was similar to the attended stimuli (and dissimilar to the unattended stimuli) than when the unexpected object was dissimilar to the attended stimuli (and similar to the unattended stimuli). While this effect has been observed in earlier studies by manipulating the luminance of achromatic stimuli (Most et al., 2001, 2005; Simons & Chabris, 1999), the present experiment extends this finding to equiluminant chromatic colors.

Experiment 2

Similarity/dissimilarity of the unexpected stimulus to the unattended distractor stimuli covaries with the dissimilarity/similarity to the attended stimuli. Therefore, it is possible that the similarity effect is contributed not only by the capture of attention by similar stimuli but also by active ignoring or inhibition of dissimilar stimuli. If the unexpected stimulus is similar to distractors and hence ignored stimuli, then it would not capture attention. In Experiment 2, we tested whether the observers inhibit attention to distractor stimuli or actively ignore them during selective looking. We manipulated the similarity of distractors to the unexpected stimulus, while the attended stimuli were always dissimilar to the unexpected stimulus.

Method

Participants

Sixty-eight observers (mean age 22.5 years, range 19–34; 21 males) with normal or corrected-to-normal vision participated as a part of a course in neuroscience at the Medical School of University of Turku. The participants were tested in subgroups of 7–10 persons. The similarity of the unexpected stimulus to the distractors was manipulated between participants.

Apparatus and stimuli

The apparatus was the same as in Experiment 1. In each condition, the attended stimuli had different color than the unexpected stimulus (see Fig. 1). The attended stimuli were either three blue or three green circles (1.6° in diameter) and the unexpected stimulus was a green or a blue cross (1.6°), respectively. The four-distractor stimuli were two-color circles with the left and right side or the upper and lower part containing a different color. In the ''inhibition'' condition ($n = 34$), two of the distractors were half of the color of the attended stimuli and half of the color of the unexpected stimuli; two of the distractors were half red and half white (the luminance for red and white were 14 and 43 cd/m^2, respectively). In the control condition ($n = 34$), two of the distractors were half of the color of

Table 1 Proportional error scores (standard deviations in parentheses) in the primary counting task in each experiment for those participants who detected the unexpected stimulus and for those who did not

	Exp 1	Exp 2	Exp 3	Exp 4	Exp 5
Detectors					
1. Trial	0.04 (0.09)	0.02 (0.04)	0.03 (0.07)	0.07 (0.15)	0.19 (0.34)
2. Trial	0.09 (0.08)	0.16 (0.14)	0.06 (0.05)	0.11 (0.16)	0.15 (0.24)
3. Trial	0.04 (0.05)	0.08 (0.08)	0.05 (0.08)	0.08 (0.16)	0.15 (0.22)
Nondetectors					
1. Trial	0.03 (0.05)	0.06 (0.12)	0.02 (0.07)	0.09 (0.18)	0.13 (0.27)
2. Trial	0.09 (0.08)	0.12 (0.12)	0.12 (0.11)	0.14 (0.18)	0.22 (0.24)
3. Trial	0.02 (0.03)	0.09 (0.17)	0.05 (0.06)	0.08 (0.18)	0.15 (0.27)

the attended stimuli and half red; two of the distractors were half white and half of the color of the unexpected stimuli. Thus, in both conditions the attended stimuli were different in color in relation to the unexpected stimulus and both conditions included exactly the same colors but in different combinations. In the inhibition condition, the color of the unexpected stimulus was paired with the attended color, so that the observers should ignore especially the two-color stimuli including the attended color, and at the same time the color of the unexpected stimulus, in order to avoid confounding these stimuli to the attended ones. In the control condition, the color of the unexpected stimulus was paired with the irrelevant color (red), so that there was less need to avoid the objects containing the color of the unexpected stimulus.

Procedure

In the beginning of each trial, there were three blue or three green circles in the center of the screen and four two-color stimuli. The participants were asked to silently count the total number of bounces made either by the entirely blue objects (34 participants) or by the entirely green objects (34 participants). They were told that they did not need to attend to the two-colored nontarget objects. They were warned that particularly attending to the nontargets containing the color of the attended objects might interfere with task performance. All the other aspects of the procedure were similar to those in Experiment 1.

Results and discussion

Three participants failed to detect the cross both in the inattention and full attention trial. They were eliminated from further analyses. The detection rate did not differ between inhibition and control condition ($\chi^2 = 0.67$, $P < 0.42$). In the inhibition condition, 14.7% of the observers detected the unexpected stimulus; in the control condition, 22.6% of the observers detected it.

The results do not support the hypothesis that the observers would inhibit or actively ignore the color that was paired with the attended color in distractor objects. We assumed that, if inhibition or ignoring occurs, it would be important to avoid these objects because the presence of the attended color in them would make them confoundable with attended objects. However, it remains possible that all the additional colors in the distractors were inhibited, including the color of the unexpected object, irrespective of with which color each color was paired. In Experiment 3, we tested this hypothesis by removing the color of the unexpected stimulus from the distractors and by replacing it with a new color so that the color of the unexpected stimulus did not appear in any of the other stimuli. If only those colors are inhibited that appear in the distractor stimuli, then the detection rate should substantially increase as compared to that in Experiment 2.

Experiment 3

Method

Participants

Thirty-two participants (mean age 22.0 years, range 19–37; 16 males) with normal or corrected-to-normal vision took part. They participated as a part of a course in neuroscience at the Medical School of University of Turku. The participants were tested in subgroups of 7–10 persons.

Apparatus, stimuli, and procedure

The apparatus was the same as in Experiments 1 and 2. The stimuli were the same as in Experiment 2 with the exception that the four two-color distractors did not contain the color of the unexpected stimulus. Instead, in the distractors the color corresponding to the unexpected stimulus was replaced with yellow (luminance = 45 cd/m^2) (see Fig. 1). The procedure was identical to that in Experiment 2.

Results and discussion

One of the participants failed to detect the cross both in the inattention and full attention trial and was eliminated from further analyses. Ten of the 31 observers (32.3%) detected the unexpected stimulus. This detection rate did not differ from that in Experiment 2 (18.5%, $n = 65$) ($\chi^2 = 2.26$, $P < 0.14$) or from the rate in the condition where the unexpected stimulus was similar in color to the unattended stimuli in Experiment 1 (33.3%, $n = 18$) ($\chi^2 = 0.01$, $P < 0.95$). Thus, strong sustained inattentional blindness (68%) was present even when the unexpected stimulus did not contain any of the colors included in the attended stimuli or distractors. This finding suggests that for sustained inattentional blindness to appear, there is no need to inhibit or actively ignore the specific color of the unexpected stimulus.

One should note that in Experiment 3 the color of the unexpected stimulus was distinctive as it did not hold any of the colors of attended stimuli or distractors. In the study of Most et al. (2001, Exp 3), 72% of observers detected the distinctive unexpected stimulus. This is noticeably higher value than the 32% in the present experiment. The difference in the salience of the unexpected stimuli is likely to explain the different results between the studies. In Most et al. (2001), the unexpected stimulus was a red cross appearing among black and white stimuli. In the present experiment, the unexpected stimulus (e.g., a blue cross) appeared among a larger variety of chromatic and achromatic stimuli (e.g., wholly green circles, half green and half yellow circles, half red and half white circles). Therefore, the salience of the color of the unexpected stimulus in relation to those of the other stimuli was lower in the present study.

Experiment 4

Previous experiments suggested that one does not need to actively ignore specific features of the distractor stimuli for sustained inattentional blindness to appear in selective looking. It remains possible that after establishing an attentional set that distinguishes attended objects from unattended distractors, the observers nonspecifically ignore all the other stimuli but the attended ones. In that case, one would expect that the presence of only one distractor should make a clear difference in detection rates as compared to condition which does not contain any distractors to ignore. In order to test this prediction, we manipulated the number of distractors: the stimulus displays contained either no distractors, one distractor, or five distractors.

Method

Participants

Seventy-six participants (mean age 23.4 years, range 19–45; 29 males) with normal or corrected-to-normal vision took part. They participated as a part of a neuroscience course at the Medical School of University of Turku. The participants were tested in subgroups of 6–11 persons. The number of distractors was manipulated between participants. Each participant was assigned either to the none ($n = 24$), one ($n = 26$), or five ($n = 26$) distractor stimulus condition.

Apparatus and stimuli

The apparatus was the same as in previous experiments. The attended stimuli were three black circles (1.6° in diameter); the distractors were white circles (1.6°). A white cross (1.6°) served as the critical, unexpected stimulus. The luminance for the gray background was 52 cd/m^2, for black 25 cd/m^2, and for white 93 cd/m^2.

Procedure

In the beginning of each trial there were three black circles in the center of the screen, and depending on the condition, either no white circles (0-distractor), one white circle (1-distractor), or five white circles (5-distractors). The participants were asked to count the number of bounces made by the black objects. In the 1- and 5-distractor conditions they were told that they did not need to attend to the white nontarget object(s). Otherwise the procedure was the same as in previous experiments.

Results and discussion

Two participants failed to detect the cross both in the inattention and full attention trial and they were excluded from further analyses. The detection rate differed between the conditions ($\chi^2 = 6.31$, $P < 0.05$): 78.3% of the observers in the 0-distractor condition detected the unexpected stimulus, 46.2% in the 1-distractor condition, and 48.0% in the 5-distractor condition. The detection rate was significantly higher in the 0-distractor condition than in the 1-distractor condition ($\chi^2 = 5.30$, $P < 0.05$) and in the 5-distractors condition ($\chi^2 = 4.68$, $P < 0.05$), whereas the detection rate did not differ between 1- and 5-distractor stimulus conditions ($\chi^2 = 0.02$, $P < 0.90$).

The degree of inattentional blindness was affected by the number of distractors. Compared to a situation where distractors were not present at all, the presence of only one distractor increased the proportion of inattentional blindness. However, adding a larger number of distractors to the display did not have any further effect on detection performance. Thus, it seems that simply the need to establish an attentional set for distinguishing between attended objects and distractors enhances inattentional blindness. However, differentiating between attended events and distractor events is not necessary for inattentional blindness to occur. Even when the display contained no distractors, 22% of the observers did not notice the unexpected stimulus. This is a surprisingly high proportion, given that the unexpected object was distinctive in shape, color, and movement. This result, if it can be replicated, would suggest that selective looking is not necessary for sustained inattentional blindness of dynamic events. All that would be necessary for inattentional blindness is attending to the target stimuli, without any need for additional active ignoring of other stimuli. Therefore, in Experiment 5 we ran a condition in which there was no distractors in order to replicate the occurrence of inattentional blindness in nonselective looking, but this time the unexpected stimulus was unique only in shape and color but not in motion trajectory. Unlike in previous experiments, the cross moved like the attended stimuli, making bouncing off the edges of the display window.

Experiment 5

Method

Participants

Sixteen observers (mean age 23.3 years, range 19–38; five males) with normal or corrected-to-normal vision participated as a part of a neuroscience course at the Medical School of University of Turku. The participants were tested in subgroups of eight persons.

Apparatus, stimuli, and procedure

The apparatus, stimuli, and procedure were otherwise the same as in the 0-distractor condition of Experiment 4, but now the unexpected stimulus did not move in a straight line from left to right across the display. Now its trajectory and speed were similar to the attended objects.

Results and discussion

One of the observers was excluded from the analyses because of a failure to detect the unexpected stimulus both in the inattention and full-attention trial. Nine of the 15 observers (60%) detected the unexpected stimulus. This rate is significantly ($P < 0.01$) lower than the 100% detection rate which would be expected on the basis of the hypothesis that distractors are necessary for sustained inattentional blindness.

Thus, when there were no distractors and the unexpected stimulus moved like the other stimuli, 40% of the participants showed inattentional blindness. This result shows clearly that the presence of distractors (and selective looking) is not necessary for sustained inattentional blindness to occur.

General discussion

Sustained inattentional blindness is greatly affected by the similarity of the unexpected event to the attended objects, suggesting that observers are able to establish an attentional set (Folk et al., 1992) on the basis of a whole range of features that distinguish attended objects from irrelevant distractors. This effect was replicated also in the present study by manipulating the attended colors. It is possible to selectively attend to a given color, provided that the number of elements that need to be attended to is limited (Turatto & Bridgeman, 2005). Experiment 1 showed that similarity of unexpected event's color to attended objects increased the probability of detecting the unexpected event, extending the range of the effect from achromatic luminance differences (Most et al., 2001, 2005; Simons & Chabris, 1999) to chromatic colors. However, here as well as in the earlier studies, this similarity effect has been confounded by the dissimilarity to distractors which typically covaries with the similarity to attended objects. Therefore, selective ignoring of the distractors on the basis of a ''negative'' attentional set might partly explain why the detection rate is low when the unexpected object is similar to the distractors. When the unexpected object's similarity of color to distractors was manipulated (Experiment 2), we did not find any effect of similarity, suggesting that the observers do not actively ignore the distractors on the basis of color. Moreover, when the color of the unexpected object was distinctive (it was not represented among the colors of unattended objects), strong inattentional blindness was observed (Experiment 3), comparable with the results in the condition where the distractors had the same color as the unexpected object (Experiment 1). This suggests that active ignoring of all the irrelevant colors that are present in the display does not contribute to inattentional blindness in selective looking.

It seems on the basis of the present results that instead of ignoring the distractors on the basis of any specific set of features (such as particular color), they are left unattended in rather nonspecific and passive manner. The clear demonstrations of inattentional blindness in the absence of any to-be-ignored stimuli (22 and 40% in Experiments 4 and 5, respectively) show that allocating attention to the target objects is sufficient to induce inattentional blindness. In the absence of distractors the attentional set was probably rather vaguely specified (e.g., ‘‘attend to these three objects’’ in the case of three black moving target items). In addition, there may be individual differences in the way the observers define their attentional sets in the absence of distractors. For example, some of them might be ‘‘attending to moving objects’’. Such observers would be likely to detect the unexpected but moving stimulus (like most of the observers did in Experiments 4 and 5), as the unexpected stimulus matches the attentional set. Some of the participants may be attending to the ‘‘black objects’’ and thus would not detect the white unexpected stimulus.

On the other hand, in Experiment 4 the detection rate decreased from the 78% of the 0-distractor condition to about 48% when the display contained one or five distractors. The presence of one or more irrelevant objects in the display makes a need to define the attentional set in a more specific manner in order to make a distinction between attended objects and distractors (e.g., ‘‘attend to the three *black* objects’’). This restricts the scope of attended features to some specific set of features and therefore the probability of detecting the unexpected stimulus decreases if its features do not match to those of the attended ones. Thus, once the attentional set has been constructed for attended objects, the other irrelevant objects which do not correspond to the attentional set are left unattended. It does not play a role whether there is one or several irrelevant objects in the display—the requirement to make a distinction between attended objects and irrelevant distractors has a significant effect on detection.

The finding that sustained inattentional blindness for dynamic events can be observed in the absence of any irrelevant objects resembles the phenomenon of inattentional blindness observed in brief static displays. In both cases, the stimulus displays contain attended items but there are no irrelevant items to selectively ignore. Thus, when viewing either static or dynamic displays the observer may not need to establish an attentional set for ignoring the irrelevant stimuli, and inspite of that, inattentional blindness is manifested. However, the durations of the unexpected stimuli have been rather short in static displays (200–700 ms) (Mack & Rock, 1998; Koivisto et al., 2004) as compared with the durations of several seconds in the paradigms using dynamic events. It remains to be tested whether or not inattentional blindness occurs for several seconds also in static displays. Provided that the primary task engages attention for a sufficient long duration and assuming that selective ignoring is not essential for inattentional blindness, there are no reasons why inattentional blindness would not occur in static displays for stimuli that are presented for several seconds.

What happens to the representation of the unexpected object in our minds when it is not consciously detected? According to one interpretation, it is not represented in visual awareness at all, because awareness is assumed to require attention (Mack & Rock, 1998). However, concluding from the phenomenon of inattentional blindness that one consciously perceives only the attended objects takes at face value the subjective reports given after the critical trial. The implicit assumption here is that if the unexpected object enters awareness at all, then the observer can report it after the trial. This assumption clearly goes against the evidence concerning the relationship between attention and memory (Wolfe, 1999). The fact that the unexpected stimulus is presented for a long duration (e.g., 6 s in the present study) is not relevant here. If the unexpected stimulus was not attended to, it cannot be reported afterwards because reporting requires explicit memory and explicit memory requires attention, irrespective of how long the stimulus was presented. Also recognition of the object as a particular object calls for attention (for evidence from change blindness, see Turatto & Bridgeman, 2005). Thus, it remains possible that the observers are visually aware of *something* additional occurring in the display, but, because the stimulus is not attended to, it is not recognized as any particular object (e.g., as a cross or a gorilla). In this case, inattentional blindness could be considered as *inattentional agnosia* (Most et al., 2005; Simons, 2000): something unrecognized appears in the subjective visual field of the observer (i.e., in the phenomenal consciousness, see Block, 2005; Lamme, 2004; Revonsuo, 2006).

It is possible to develop further this inattentional agnosia hypothesis by making an additional assumption that, because the unexpected stimulus is not recognized as any particular object, it might be confounded with other irrelevant stimuli present in phenomenal consciousness. On the basis of this account one could predict that inattentional blindness would increase as a function of the number of distractors, because the larger the number of irrelevant objects is, the greater the probability of confounding the unexpected stimulus to them might be. This prediction does not receive full support from the present study because the displays containing only one distractor were associated with similar amount of inattentional blindness as the displays including five distractors. In addition, if the observers confound the unexpected stimulus to distractors, then (assumed that color is recognized without attention) one would expect that the similarity of its color to that of the distractors would have an effect on the degree of inattentional blindness but that was not observed. Also the finding of inattentional blindness with displays without any distractors appears to be inconsistent with the confounding explanation because there were no objects with which to confound the unexpected object. However, one should note that attentional resources may be dynamically allocated within the attended set of objects. In the present kind of tasks, the observers may try to predict the movements of the target objects and allocate more attention to those target objects that are most likely to be the next ones to make bounces to the edge and less attention to those target objects that most recently have made bounces. This leaves open the possibility that the unexpected stimulus is consciously perceived as something but confounded with the least attended target stimuli.

In sum, the more similar to the attended set the unexpected stimulus is, the more likely it will capture attention in selective looking tasks, reflecting the influence of the attentional set on detection. The present study suggests that this effect can be driven solely by attending to the target stimuli, without the contribution of active ignoring of the distractors. However, the presence of nontarget stimuli in selective looking tasks gives rise to a need to define the attentional set more clearly for distinguishing attended stimuli and distractors from each other, leading to increased failure to detect objects whose features are not included in the attended set.

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