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The effects of eye movements, spatial attention, and stimulus features on inattentional blindness

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Abstract

Observers often fail to detect the appearance of an unexpected visual object ("inattentional blindness"). Experiment 1 studied the effects of fixation position and spatial attention on inattentional blindness. Eye movements were measured. We found strong inattentional blindness to the unexpected stimulus even when it was fixated and appeared in one of the expected positions. The results suggest that spatial attention is not sufficient for attentional capture and awareness. Experiment 2 showed that the stimulus was easier to consciously detect when it was colored but the relation of the color to the color of the attended objects had no effect on detection. The unexpected stimulus was easiest to detect, when it represented the same category as the attended objects.
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1. Introduction

Most of the studies on attentional capture have focused on implicit attentional capture, that is, on how well observers can ignore something they expect but know to be irrelevant (Simons, 2000). These studies have examined how a salient, irrelevant stimulus affects performance on another task, regardless of whether the observers become aware of the stimulus or not. Explicit attentional capture, on the other hand, occurs when a salient, unexpected stimulus draws attention and leads to subjective visual *awareness* of it. The critical question here is whether or not the observers will consciously notice something that they do not expect. For example, it is important that you notice a child appearing in front of your car as you are fiddling with the radio (explicit attentional capture), but it does not matter if you are slower in turning the knob (implicit attentional capture) (Most, Scholl, Clifford, & Simons, in press). Recent studies suggest that observers with normal visual ability are often functionally "blind" to the appearance of unexpected objects or large unexpected changes, not only for artificial displays under laboratory conditions (Mack & Rock, 1998; Simons & Chabris, 1999) but also in real-world situations (Simons, Chabris, Schnur, & Levin, 2002; Simons & Levin, 1998). Although observers intuitively believe that they will easily become aware of the appearance of such unexpected objects or changes, empirical studies on the beliefs of observers have shown that their intuitive conceptions about their probability of detection are strongly overestimated (Levin, Drivdahl, Momen, & Beck, 2002; Levin, Momen, Drivdahl, & Simons, 2000).

Do we subjectively see an object that we are not attending to? Mack and Rock (1998) have recently

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developed an *inattentional blindness* paradigm to study this issue. In the typical version of their task, observers attended to a cross appearing for 200 ms in the center of the viewing area. Their primary task was to judge which of its arms was longest. In the third or fourth trial, an unexpected stimulus (e.g., a square) appeared in a quadrant of the cross. Immediately after the trial, the observers were asked if they had seen anything that had not been present on previous trials. The results revealed that about 25% of the observers showed inattentional blindness, that is, they did not detect the unexpected stimulus. Even more surprising was the finding that when the cross appeared parafoveally and the unexpected stimulus appeared at fixation, about 75% of observers missed it. In principle, this finding could be explained by assuming that the unexpected stimulus at fixation is not seen as a new object but as a change to the fixation cross and therefore it is not considered anything additional to be reported. Mack and Rock (1998) were able to rule out this explanation in their follow-up experiments. They suggested that attention to objects at fixation could be actively inhibited when no objects were expected to appear to fixation.

They also manipulated the zone of attention in different ways. Inattentional blindness decreased when the unexpected stimulus was positioned within the attention zone, suggesting that attention is needed for conscious perception. However, it is surprising that still about 25% of observers failed to detect the unexpected stimulus even when it fell within the zone of attention. Why did they not detect the stimulus within the attended area? It seems that spatial attention to the relevant area is not sufficient for conscious perception of an unexpected stimulus. The same point is illustrated also in selective-looking experiments, in which observers monitor one of two simultaneous events, for example a video of a team in black shirts passing basketball superimposed on a video of a team in white shirts passing basketball. When the observers monitor one of the teams, they often fail to notice that a gorilla or a woman with an open umbrella walks across the display (Becklen & Cervone, 1983; Simons & Chabris, 1999). It is possible that the undetected gorilla and the woman appeared at the attended spatial area, although the distribution of spatial attention was not systematically manipulated in these studies. The distance of the unexpected stimulus from the focus of attention was systematically manipulated in a selective-looking study by Most, Simons, Scholl, and Chabris (2000). The results supported a role for object distance from the focus of attention. In spite of that, less than half of the observers detected the unexpected object when it appeared on the horizontal line that was monitored, suggesting that spatial attention cannot fully account for detection of unexpected objects.

In the present study, we examined further the effects of fixation position, on the one hand, and spatial attention, on the other hand, on inattentional blindness. The finding of stronger inattentional blindness at fixation than at periphery needs further replications because it has been shown only in the laboratory of Mack and Rock (1998) and only with variants of their cross judgement task. In addition, it might be important to control for fixation position with an eye tracker. On the other hand, an exactly opposite prediction may be put forth on the basis of change blindness studies where observers are explicitly asked to look for sudden changes in a visual environment. In the study of Hollingworth, Schrock, and Henderson (2001) it was found that a change is more readily detected if it appears close to the current fixation than further away from the location of current fixation (see also Dornhoefer, Unema, & Velichkovsky, 2002). Such an effect may not necessarily generalize to inattentional blindness, however, because the location of attended targets may be dissociated from the location of fixated targets (e.g., Newby & Rock, 1998; Posner, Snyder, & Davidson, 1980), even though in many visual tasks there exists a close link between eye movements and attention shifts.

Unlike the previous studies on explicit attentional capture and inattentional blindness, we measured the eye movements by an eye tracker to ensure that the participants followed the instructions and kept their fixation at the center where the unexpected stimulus appeared. In addition, eye movement measurements allowed us to identify different eye movement patterns and to study whether they would reveal anything important about explicit attentional capture.

2. Experiment 1

In Experiment 1, we studied the effects of eye movements and spatial attention on inattentional blindness. Although it is clear that when a stimulus is *expected*, attending to the spatial position in which it is going to appear enhances its detection (Posner et al., 1980), it is not clear to what extent an *unexpected*, *irrelevant* stimulus can be detected when attention is distributed to the spatial location in which it appears. The finding of the relatively large amount of inattentional blindness (about 25%) for unexpected, irrelevant stimuli within the attended zone in the series of experiments by Mack and Rock (1998) suggests that attending to the spatial location of the unexpected stimulus is not sufficient for conscious detection of it.

In the present experiment, the observers named red and blue digits that appeared sequentially on the screen. In the third trial, an unexpected stimulus (black circle) appeared at the center of the viewing area for 700 ms. After the third trial, the observers were asked whether or not they detected anything new that was not present in the previous trials. Then the experiment continued in

the same way with three trials but now the observers could expect something new to appear—therefore, these trials were divided attention trials (Mack & Rock, 1998). Finally, three full attention trials were presented. Here the only task was to detect whether or not anything new appeared. We expected that the detection performance in the divided and full attention trials would improve, which would confirm that the unexpected stimulus is perceptible with attention.

Because only one critical inattention trial was possible for each observer, all the variables had to be manipulated between the participants. We used two different tasks in the experiment: the observers either kept fixating on the center (*fixation* condition) or they followed the digits with their eyes (*eye movement* condition). To our knowledge, this is the first time eye movements have been recorded in the inattentional blindness paradigm to verify that the observers really were looking at the unexpected stimulus. A second issue that was studied was the role of spatial attention in inattentional blindness. For half of the participants within the fixation and eye movement groups, the digits never appeared at the center of the viewing area and, therefore, there was no reason to monitor the fixation position (*center-unattended* condition). For the other half of the observers, one of the two digits could appear also at the center in the non-critical trials—this manipulation was assumed to distribute their attention also to the center of the area (*center-attended* condition).

3. Method

3.1. Participants

Sixty-four participants (mean age: 23.3 years) with normal or corrected-to-normal vision took part for partial course requirement in introductory psychology at the University of Turku. Each participant was assigned either to the eye movement or fixation condition. Within the eye movement and fixation conditions, half of the participants were assigned to the center-unattended condition and the other half to the center-attended condition.

3.2. Apparatus and stimuli

Eye movements were collected by the EYELINK eyetracker manufactured by SR Research Ltd. (Canada). The eyetracker is an infra-red video-based tracking system combined with hyperacuity image processing. There are two cameras mounted on a headband (one for each eye) including two infrared LEDs for illuminating each eye. The headband weighs 450 g in total. The cameras sample pupil location and pupil size at the rate of 250 Hz. Registration is monocular and is performed for the selected eye by placing the camera and the two-infra-red light sources 4–6 cm away from the eye. The spatial accuracy is better than 0.5°. Head position with respect to the computer screen is tracked with the help of a head-tracking camera mounted on the center of the headband at the level of the forehead. Four LEDs are attached to the corners of the computer screen, which are viewed by the head-tracking camera, once the subject sits directly facing the screen. Possible head motion is detected as movements of the four LEDs and is compensated for on-line from the eye position records.

The stimuli were presented on a CRT within a round, white area (10.1° in diameter, 88.6 cd/m^2) (see Fig. 1). The stimuli were red and blue digits (1–4, or 5) (0.5°), and a black circle (0.5°) served as the critical, unexpected stimulus. The luminance for the red color was 22.7 cd/m^2, for blue 13.2 cd/m^2, and for black 4.3 cd/m^2, respectively.

3.3. Procedure

The experiment began with one practice trial followed by three inattention trials. Each trial began with a presentation of the fixation cross at the center of the area for 1500 ms. It was followed by a red digit in one of the quadrants or at the center for 350 ms, and then by a blue digit in an other quadrant or in the center for 350 ms, followed by a mask for 500 ms. The blue digit never appeared in the quadrant opposite to the red one (e.g., the red one in the upper left quadrant, and the blue one in the lower right quadrant) but always in

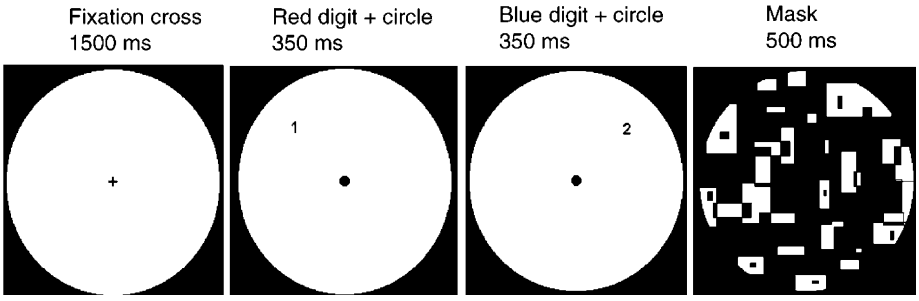

Fig. 1. An example of a critical trial. The circle was black while the first digit was actually red and the second one was blue.

the nearest position to the left/right or up/down from it. This pattern was favored over complete randomization to avoid eye movements via the center to the opposite quadrant (in the eye movement conditions), and thus to avoid possible accompanying fixations to the center when no digit was presented there. The digits that appeared in the quadrants were positioned 3.2° away from the center. The third trial was the critical inattention trial in which the unexpected stimulus (the black circle) appeared at the center of the screen at the same time that the first digit appeared and remained visible until the mask was presented, that is, for 700 ms. During the critical trials, the digits never appeared at the center.

The participants in the *eye movement* condition ($N = 32$) were asked to move their eyes first to the red digit and then to the blue digit in the same order that they appeared, and at the same time they were asked to name the digits. The participants in the *fixation* condition ($N = 32$) were asked to fixate throughout the trials on the fixation cross and to name aloud the digits. In addition, the area on which the digits could be expected to appear was manipulated. For half of the observers in each condition, the digits in the primary task never appeared at the center of the viewing area (*center-unattended* condition). For the other half, one of the digits in the primary task appeared in center of the screen in the practice/show up trial and in the first non-critical trial in the inattention, divided-attention, and full-attention conditions. Thus, these observers could expect digits to appear also in the center (*center-attended* condition). Prior to the practice/show-up trial the participants were told that this trial will demonstrate how the digits will be presented on the screen. In the center-attended condition, one of the two digits appeared in the center, whereas in the center-unattended condition both digits appeared in the quadrants.

Immediately after the critical trial, the participants were asked, "Did you detect anything new that had not been present on the prior trials; if you did, what did you detect (identification task)"? After answering, five alternative shapes (diamond, star, triangle, circle, square), printed in black on a white paper, were presented and the participants were asked to select the new shape or to make a guess in the case that they did not perceive it (forced choice task). Then they were asked to specify or guess the location in which the shape had appeared. Observers were regarded as having detected the stimulus if they answered "yes" when asked if they detected anything new that had not been present on the prior trials and if they also were able to perform correctly either in the identification, forced choice, or location task.

After answering the questions, the experiment continued with three divided-attention trials which were otherwise identical to the inattention trials but now the participants could expect something new to appear on the screen. The divided-attention trials were followed by three full-attention trials. Here the only task was to detect whether anything new appeared on the screen. The third trial within each sequence was always the critical one, which was followed by the detection, identification, forced-choice and location tasks about the shape of the new object.

4. Results

In the analyses of the eye movements, participants were considered to be fixating at the center of the viewing area if their fixations did not deviate more than 0.8° from the center. Fixations in the quadrant where a stimulus appeared, with the distance more than 0.8° from the center, were classified as eye movements toward the stimulus.

In the eye movement condition, various patterns of eye movements were observed during the critical inattention trial. Two observers made an eye movement to one of the two digits only and two participants remained fixating on the center and did not move their eyes to either of the digits. These four participants were removed from the analyses reported below because they were not following the instructions. The most typical pattern was that the eyes moved from the fixation cross to the red digit and then to the blue digit (19 observers). It was also quite common that after moving the eyes from the fixation cross to the red digit, an additional fixation was made on the unexpected stimulus in the center of the screen, and then the eyes were moved to the blue digit (nine observers). This pattern was more common in the center-attended condition (seven observers) than in the center-unattended condition (two observers). When the number of such eye movement patterns was counted across the second and third inattention trial and the second and third divided-attention trial (which were physically identical in the two attention area conditions), the total number of such patterns was 28 in the center-attended condition and 10 in the center-unattended condition. These results suggest that the manipulation of the attention area was effective. However, of the nine observers who moved their eyes to the unexpected stimulus in the critical trial between the saccades to the first and second digits, only three (33%) detected that something new appeared. Thus, these observers did not consciously perceive the unexpected stimulus. It is also clear that this eye movement pattern should not be considered as evidence for implicit perception either. A similar pattern (first digit-fixation cross-second digit) was equally common also in the preceding non-critical trial in which the unexpected stimulus was not present (three observers in the center-unattended condition and seven observers in the center-attended condition), suggesting that the pattern was not related to the

appearance of the unexpected stimulus. It was a more general pattern related to the distribution of attention.

In the fixation condition, most of the observers kept their fixation on the center during the critical inattention trial (25 observers). Seven observers made an eye movement either to one or both of the digits, and they were removed from the further analyses as they did not follow the instructions.

Fig. 2 presents the results as a function of the eye movement vs. fixation condition. As can be seen, only 17% of the observers detected that an unexpected stimulus appeared. However, the overall performance level is higher in the divided-attention trials than in the inattention trials. In full-attention trials, the performance approached ceiling.

The results were analyzed with Chi-square test, but when any of the cells had an expected value smaller than five, Fisher's Exact test was used. Comparisons of the eye movement condition ($N = 28$) and the fixation condition ($N = 25$) (see Fig. 2) in inattention trials did not show any differences in detection (14% vs. 20%) (Fisher's Exact Test: $p < 0.72$). There were no differences between the conditions (p-values > 0.76) in the divided-attention and full-attention trials.

Next we analyzed the data by contrasting the two attention area conditions (see Fig. 3). In the inattention trials, there seems to be a non-significant tendency for the observers in the center-unattended condition ($N = 25$) to perform better than those in the center-attended condition ($N = 28$) (28% vs. 7%) (Fisher's Exact Test: $P < 0.08$). Of those participants in the center-attended condition, who were allowed to move their eyes, seven made eye fixations to the unexpected stimulus between fixations to the digits, but only one of them detected the stimulus.

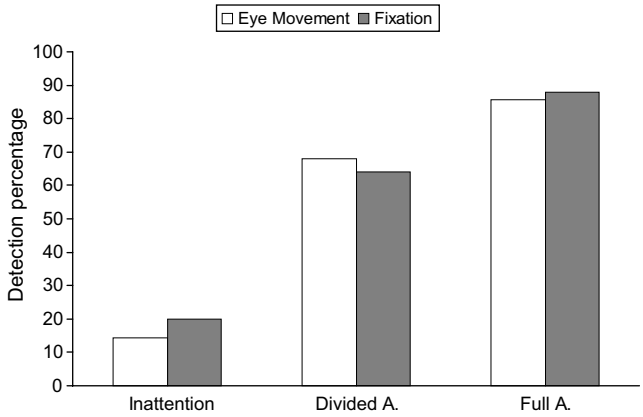

Fig. 2. Percentage of observers in the eye movement and fixation conditions for detecting the unexpected stimulus under inattention, divided attention, and full attention. The results are pooled across the center-unattended and center-attended conditions.

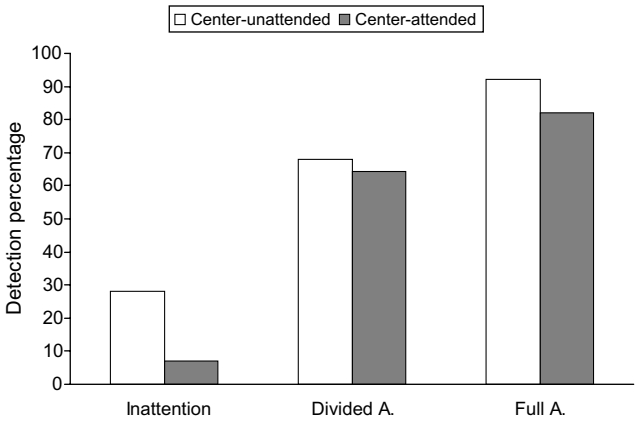

Fig. 3. Percentage of observers in the center-unattended and center-attended conditions for detecting the unexpected stimulus under inattention, divided attention, and full attention. The results are pooled across the eye movement and fixation conditions.

In the divided-attention and full-attention conditions, detection performance did not differ between the attention area conditions (P-values > 0.28).

Mack and Rock (1998) suggested that the strong inattentional blindness that was observed when the unexpected stimulus was presented to the fixation position in their experiment was due to participants actively inhibiting attention to fixation. We tested this hypothesis by comparing the results in the inattention trials between the attention area conditions for the observers included in the fixation condition ($N = 12 + 13$). The hypothesis predicts stronger inattentional blindness for the observers in the center-unattended condition because they did not expect any stimuli to appear at the fixation point and hence they would inhibit attention to fixation position. The results did not support this prediction as the participants in the center-unattended condition (33%) did not show any evidence for decreased detection of the unexpected stimulus at the fixation as compared with the participants in the center-attended condition (8%) (Fisher's Exact Test: $p < 0.17$).

5. Discussion

Fixation position did not have any effects on inattentional blindness. The unexpected stimulus was equally poorly detected irrespective of whether the observers kept on fixating on the center of the field in which the circle appeared or whether they followed the digits with their eyes. In general, this finding supports the view that attention can move in the visual field independently of fixation (Newby & Rock, 1998; Posner et al., 1980). Our result contrasts with the finding of Mack and Rock (1998) who reported that the stimuli displayed at fixation were less likely to be detected than those presented in the periphery. Their hypothesis that attention to the

fixation position is inhibited did not gain empirical support because the participants in the center-unattended condition, who did not expect any stimuli at the fixation position and, therefore, should have inhibited attention to fixation, were not less likely to detect the unexpected stimulus than the participants in the center-attended condition who should not have inhibited attention to fixation. It should be noted, however, that we presented the unexpected stimulus always at center (i.e., at the place of the fixation cross), so that the fixation-periphery manipulation is not directly comparable to that of Mack and Rock (1998).

Neither were we able to get support for the prediction made on the basis of a change blindness study of Hollingworth et al. (2001) about the role of fixation position in detection performance. Hollingworth et al. (2001) demonstrated more accurate (and faster) detection performance if the stimulus appeared close to the fixation than further away from the fixation—a phenomenon we did not observe. However, it should be noted that there are important differences in the task employed by Hollingworth et al. (2001) and by us. In Hollingworth et al. (2001) the to-be-detected change was one among the attended stimuli (the participants were to attend to relatively large visual scenes), so it is understandable that allowing the eyes to move along with the attention improved performance. In the present study, however, the to-be-detected target was not expected, and even cueing the eyes to move to the location where the unexpected stimulus later arrived (i.e., in the center-attended condition) did not seem to help detect the unexpected stimulus.

Although fixation position and attention can be experimentally dissociated, in normal viewing conditions they are closely related. The eyes tend to move to the stimuli or features which have drawn attention to themselves. In the present eye movement condition, eye movement analyses showed that the observers in the center-attended condition made more fixations to the center of the viewing area than those in the center-unattended condition, suggesting that they were attending to the center of the viewing area. Thus, the manipulation of the attention area was effective. However, the observers monitoring the fixation position were not able to detect the unexpected stimulus any better than the observers who were not monitoring it. This result contrasts with the findings that the closer to the center of the attention the unexpected stimulus appears, the better it will be detected (Mack & Rock, 1998; Most et al., 2000; Newby & Rock, 1998). However, we did not manipulate the distance between the center of attention and the stimulus but the size of the attended area. The attention area was distributed across the entire viewing area in the center-attended condition. In this case, the larger attention area did not enhance the detection of the unexpected stimulus. There was a greater number of possible combinations of the locations in which the red and blue digits in the primary task could appear in the center-attended condition (16) than in the center-unattended condition (8). Thus, although none of the observers in the two conditions had any difficulties in naming the digits, it is likely that more attentional resources were needed for the primary task in the center-attended condition, leaving less resources for detecting anything new. We conducted post-hoc analyses of the pupil sizes to test this possibility. Pupil size has been shown to reflect variation in processing load. For example, Hyönä, Tommola, and Alaja (1995) demonstrated that a cognitively more demanding task was associated with larger pupil size than a less demanding task (for a review, see Beatty, 1982).

Pupil sizes (area in pixels) were measured in the second inattention trial both during the fixation cross and the actual task in the center-attended and center-unattended conditions of the eye movement condition. The second trial was selected because it did not contain the unexpected stimulus. It was possible to measure separately the pupil sizes during the fixation and the naming task performance for those observers who moved their eyes away from the fixation cross during the task ($n = 14 + 16$). Pupil area rather than pupil diameter was used as the dependent variable, as pupil area may be considered a more sensitive measure (the pupil's shape is elliptical, so changes in pupil size may be more noticeable in area than in diameter). A Time (fixation vs. task) × Condition (center-unattended vs. center-attended) ANOVA revealed a main effect for Time ($F(1,28) = 5.01$, $p < 0.05$), showing that the pupil was larger during the task performance (2781 pixels) than during fixation (2316 pixels). This result suggests that pupil size was sensitive to the increase of attentional load during the task. Also the main effect for condition was significant ($F(1,28) = 4.54$, $p < 0.05$), indicating that the pupils were larger in the center-attended condition (2781 pixels) than in the center-unattended condition (1931 pixels). This suggests that the center-attended condition was associated with a higher processing load than the center-unattended condition. The Time × Condition interaction approached statistical significance ($F(1,28) = 3.82$, $p = 0.06$), suggesting that the difference in pupil size tended to be larger during the fixation cross (2776 and 1855 pixels, for center-attended and center-unattended conditions, respectively) than during the actual task (2786 and 2006 pixels). Thus, the pupil in the center-attended group was larger, suggesting that they were experiencing stronger cognitive load than the center-unattended group. Moreover, the pupil sizes differed between the conditions already during the fixation cross when the observers were expecting the stimuli ($t(28) = 2.39$, $p < 0.05$). This pattern is understandable as it is likely that the observers were preparing for the task and distributing their attention to the appropriate

locations while gazing at the fixation cross. In the center-attended condition, the more demanding primary task may have withdrawn attentional resources away from the "secondary task" (that is, the resources available for detecting the unexpected stimulus), which may partly explain why the detection performance was not better when also the center area was monitored. In Section 9, we will discuss further this issue of detecting stimuli at fixation.

Before leaving the pupil size analyses, a word of caution might be in place. The difference in pupil size between the center-attended and center-unattended conditions is based on a between-subject comparison. As pupil size in general differs across individuals, it is in principle possible that more participants with bigger pupils were by chance selected to the center-attended condition. A within-subject comparison, which would not entail this potential confound, was not possible to do in the present circumstances.

6. Experiment 2

Experiment 1 suggested that fixating the eyes on and distributing attention to the area on which the unexpected stimulus appears are not sufficient for its detection. It appears that something more than that is required. Perhaps the stimulus must be of certain kind for it to capture attention. According to the contingent-capture hypothesis (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994) attentional capture is not purely a function of the presence of a stimulus property (e.g., color or onset) but depends on the existence of a prior attentional "set" for the eliciting property. The observer's attentional set consists of the properties that the participant attends to and prepares to respond to selectively. When the attentional set of an observer is for a particular feature, only that feature will capture attention. It should be noted that the contingent-capture hypothesis has been developed primarily in the implicit attentional capture studies, in which an expected but irrelevant stimulus affects performance, having no direct predictions for explicit attentional capture and awareness. It does not make any predictions concerning unexpected stimuli. However, selective-looking experiments suggest that some of the predictions of contingent capture generalize to explicit attentional capture: the similarity of the color of the unexpected stimulus to that of the expected stimulus may play a role in attentional capture when viewing dynamic events (Most et al., 2001; Simons & Chabris, 1999). However, it is not clear whether or not the results from the selective-looking tasks can be generalized to static and less complex inattention conditions. In selective-looking, the display contains several items and the observers attend to one type of items and selectively ignore other types of items. Most et al. (2001) provided preliminary evidence indicating that selective ignoring of items on the basis of color may contribute to detection of the unexpected stimulus in the selective-looking paradigm. In contrast, there is nothing to selectively ignore in the stimulus displays of a typical inattentional blindness paradigm as they contain only one or two expected items but no to-be-ignored items. Therefore, the observer may not have any need to establish an attentional set for the purpose of distinguishing attended from ignored items in tasks with more simple displays like those used in the present study. This view predicts that an unexpected stimulus with an expected color would not be detected more frequently than an unexpected stimulus with an unexpected color. However, if the salience of the color plays a role here, then a stimulus with a salient but unexpected color should be detected more often than a stimulus with a less salient color. In Experiment 2a we tested the effect of the color of the unexpected stimulus on detection under inattention. As in the primary task of Experiment 1, the observers were expecting red and blue digits which they had to name; the unexpected stimulus was presented either in the same color as the attended stimuli (red or blue) or in an unexpected but salient color (green).

In addition to stimulus salience and color, the meaning of the stimulus may contribute to the detection of unexpected stimuli. Mack and Rock (1998) found that some stimuli (observer's name, happy face icon) were more easily detected under inattention than other stimuli (someone else's name, neutral face icon). They attributed this effect to the signal value (i.e., meaningfulness) of the stimuli. One should note that the happy face and observer's name are emotionally loaded stimuli. In Experiment 2b, we tested the effect of the stimulus meaning by including an emotionally neutral stimulus condition in which the unexpected stimulus was a digit appearing in black. Thus, the stimulus was from the same category as the attended red and blue digits in the primary task but it had a different color. If the category of the stimulus determines whether inattentional blindness occurs or not, then the degree of inattentional blindness should be smaller for the black digit than for the black circle. We also included a pseudo-digit condition to control that salience or similarity of the unexpected stimulus to the digits would not be responsible for the expected effect of category.

7. Method

7.1. Participants, stimuli, and procedure

Forty participants (mean age: 22.1 years) took part in Experiment 2a and 40 (mean age: 21.8 years) in Experiment 2b. They had normal or corrected-to-normal

vision took and participated for partial course requirement in introductory psychology at the University of Turku. The apparatus and stimuli were the same as in Experiment 1 with the exception that in Experiment 2a for half of the observers the critical stimulus in the third, sixth, and ninth trial was a red or a blue circle and for the other half it was a green circle. The luminance for the green color was 16.2 cd/m^2. In Experiment 2b, the critical stimulus was either a black digit (6) or a black pseudo-digit which was constructed by cutting the digit 6 vertically into two parts and then changing the positions of the left half and the right half. The procedure was the same as that for the fixation and center-attended condition in the previous experiment. The participants were instructed to keep fixating on the fixation cross, and one of the digits appeared in the center of the screen in the practice trial and in the first non-critical trial in the inattention, divided-attention, and full-attention conditions. After each critical trial, the detection, identification, forced-choice, and location specification tasks were presented as in Experiment 1 with the exception that in the forced-choice task of Experiment 2b the circle was replaced by the digit "6" or the pseudo-digit.

8. Results

Five of the participants in Experiment 2a and five in Experiment 2b were eliminated from the analyses due to eye movements deviating more than 0.8° from the center during the critical inattention trial.

Fig. 4 shows the results from Experiment 2a. The comparison of the red/blue circle condition ($N = 18$), green circle condition ($N = 17$) and the corresponding black circle condition of Experiment 1 ($N = 13$) with the same instructions showed a statistically significant difference in the critical inattention trial ($\chi^2 = 9.66$, $p < 0.01$). Pair-wise tests revealed that the detection of the black circle (8%) was poorer than that of the red/blue circle (61%) ($\chi^2 = 9.08$, $p < 0.01$) and that of the green circle (53%) (Fisher's Exact Test: $p < 0.02$), whereas there was no difference between the red/blue and green circle conditions. There were no significant differences between the conditions in divided- and full-attention trials. The results suggest that the color of the unexpected stimulus has an effect on attentional capture under inattention. However, the similarity of the color of the unexpected stimulus to the color of the expected stimulus does not seem to play a role in the current task.

Fig. 5 shows the results from Experiment 2b. The comparison of the detection performance in the critical inattention trial between the digit ($N = 18$), pseudo-digit ($N = 17$), and black circle (Experiment 1; $N = 13$) conditions showed a significant difference ($\chi^2 = 30.19$, $p < 0.001$). The performance was better in the digit condition (100%) than in the pseudo-digit condition (29%) ($\chi^2 = 19.34$, $p < 0.001$) or black circle condition (8%) ($\chi^2 = 27.11$, $p < 0.001$). The pseudo-digit condition did not differ from the black circle condition ($p > 0.14$). In the divided-attention trial, the detection rate was lower in the black circle condition (69%) than in the other conditions (100%) ($\chi^2 = 11.75$, $p < 0.01$). There were no significant differences between the conditions in the full-attention trial ($p > 0.25$).

It is also interesting that the detection of the black digit in Experiment 2b was better than the detection of the red/blue circle in Experiment 2a (61%) in the inattention trial (Fisher's Exact Test: $p < 0.01$), showing that a stimulus from the same category as the expected stimuli was easier to detect than a stimulus with the same color but a different form as the expected stimuli.

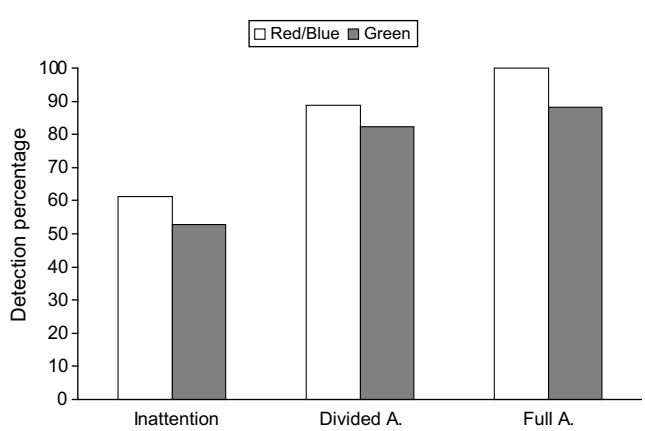

Fig. 4. Percentage of observers in the color conditions for detecting the unexpected stimulus under inattention, divided attention, and full attention.

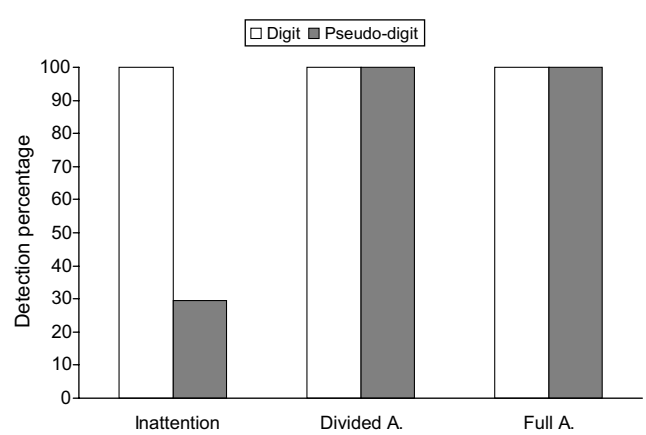

Fig. 5. Percentage of observers in the category conditions for detecting the unexpected stimulus under inattention, divided attention, and full attention.

9. General discussion

The present study showed strong inattentional blindness for a relatively long lasting (700 ms), irrelevant, unexpected stimulus. Most of the observers did not detect such a stimulus even when it fell into one out of five attended locations or when their eyes were fixated on it, or both. However, inattentional blindness to colored stimuli was reduced, irrespective of whether or not the color of the stimulus corresponded to that of the attended stimulus. When the unexpected stimulus was from the same category as the expected stimuli, all the observers detected it. The enhancement of the detection performance in the divided attention and full attention trials confirmed that the unexpected stimulus was observable with attention.

Experiment 1 demonstrated that an unexpected stimulus (the black circle) that did not share any salient features with the expected stimuli (red and blue digits) was not detected by most of the observers. Importantly, inattentional blindness was also present when the observers attended to the spatial position in which the stimulus appeared. Similarly, in selective-looking experiments observers tend to fail to notice unexpected objects which pass through the attended area (Most et al., 2000; Most et al., 2001; Simons & Chabris, 1999). Thus, spatial attention to the relevant location is not sufficient for attentional capture. In addition, the present study showed that fixating the eyes on the position of the unexpected stimulus does not increase the probability of detection. The same point was indirectly illustrated in a recent study (Strayer, Drews, & Johnston, 2003) which used an eye-tracker and showed that people talking on a cell phone during a driving simulation could not remember the contents of road signs even though they had fixated them. In contrast, the current study showed that immediately after the presentation of an unexpected stimulus people do not report having noticed it at all, even though it is fixated.

The hypothesis proposed by Mack and Rock (1998), that unexpected stimuli in the fixation position are difficult to detect because attention to fixation position is inhibited, did not gain support in the present study. In Experiment 1 those observers who attended to the center were no more likely to detect the unexpected stimulus than those who did not attend to it—there was in fact a trend toward the opposite direction. In the center-attended condition attention was distributed across the whole viewing area, whereas in the center-unattended condition attention was only distributed to the peripheral areas around the center. Thus, attentional load was higher in our center-attended condition than in the center-unattended condition, which was supported also by the analysis of the pupil size. The greater attentional demand may have withdrawn attentional resources away from the resources available for detecting the unexpected stimulus. A similar explanation may be put forth to account for why in the experiments of Mack and Rock (1998) inattentional blindness was greater when the unexpected stimulus appeared at the fixation and the expected stimulus at the periphery, as compared to the condition in which the unexpected stimulus appeared at the periphery and the expected stimulus at the fixation. In the former condition the observers did not know in advance where in the periphery the expected stimulus was going to appear. Therefore, attention was more widely distributed across the viewing area when the unexpected stimulus appeared at fixation than when it appeared at periphery, which may have interfered with the detection of the unexpected stimulus by withdrawing attentional resources left for detection. Thus, variation in attentional demands seems to explain the different findings that at first glance may look contradictory between our study and that of Mack and Rock.

The detection of the unexpected stimulus improved in Experiment 2 when the unexpected stimulus belonged to the semantic category of the expected stimuli. An unexpected stimulus from the expected category but with an unexpected color (black digit) captured attention under inattention condition and led to awareness of the stimulus. This finding is in line with the results of Mack and Rock (1998) who showed that there were some stimuli that did capture attention and were detected under inattention conditions. These were the observer's name and a happy face icon (see also Mack, Pappas, Silverman, & Gay, 2002), but not for example stimulus onset, motion, or color singleton which capture attention under divided attention. Highly familiar words, someone else's name, neutral face icon, or colored spot yielded strong inattentional blindness. After ruling out that stimulus familiarity was responsible for the capture of attention, Mack and Rock (1998) concluded that the critical factor was the signal value (meaningfulness) of the stimulus. Our finding for the category condition extends this view by suggesting that a neutral stimulus without any prior signal value will become a meaningful one for the observer and capture attention if it is related to the task at hand.

The color of the unexpected stimulus had an effect on detection. When a red/blue or green circle was presented instead of the black one, inattentional blindness was reduced, although not to the extent that occurred when the circle was replaced with a black digit, which completely eliminated inattentional blindness. The finding that the green circle was detected better than the black circle suggest that stimulus salience has an effect on detection. Mack and Rock (1998) also manipulated the color of the unexpected stimulus in several experiments. In general, a colored stimulus (i.e., red or blue) did not increase detection rates as compared to a black stimulus in their experiments. Similarly, a selective-looking study failed to show any enhanced detection for a colored, distinctive unexpected stimulus when the color of the

stimulus was different from the colors used in the primary task (Most et al., 2001). However, in a subsequent study (Most et al., in press) an unexpected stimulus with salient color was detected with a higher probability than a stimulus without salient color, suggesting together with the current study that some of the bottom-up properties of the stimulus, such as color, contribute to the likelihood of detecting an unexpected stimulus under inattention. Mack and Rock (1998) may have failed to demonstrate the effect of color because they typically used only black stimuli in the primary task and thus the color was a completely irrelevant dimension.

In the present study, the primary task was to name the first digit (the red one) and then the second digit (the blue one) in the order they appeared. In this task, the relationship of the color of the unexpected stimulus to the color of the attended digits did not have any effects on the probability of detection: a green stimulus was equally often detected as a red/blue stimulus. However, previous studies under selective looking conditions have shown that the degree of detection varies as a function of the visual similarity of the unexpected stimulus to the color of the attended stimulus (Most et al., in press; Most et al., 2001; Simons & Chabris, 1999). In these studies, the observers discriminated the to-be-attended objects from the to-be-ignored objects on the basis of the color, so that the color was a highly relevant feature and was likely to be included in the attentional set. In the present study, there were no to-be-ignored stimuli and the two attended objects occurred one at a time. Therefore, it was less important to include the colors in the attentional set to perform well in the primary task, whereas it was necessary to do so in the selective looking experiments. Thus, this crucial difference between the studies underlines the point that the task demands determine the features which are included in the attentional set and which will capture attention. This point obtained further support from a change blindness study of Wallis and Bülthoff (2000) who directly manipulated the task demands and observed that objects may not be afforded detailed processing if they are irrelevant to the task at hand. Moreover, the ability to notice changes in objects may depend on momentary task demands, so that the object feature needs to be task relevant at exactly the right moment (Triesch, Ballard, Hayhoe, & Sullivan, 2003).

In sum, the present study extends the previous work on inattentional blindness (Mack & Rock, 1998) and selective looking (Most et al., 2001; Simons & Chabris, 1999) by showing that looking at and monitoring the relevant spatial location is not sufficient for awareness under inattention and by underlining the critical role of the relevance of the semantic features of the unexpected stimulus to the observer's task under inattention. Consistent with the late selection accounts of selective attention (e.g., Deutsch & Deutsch, 1963), the finding that meaningful stimuli are detected under inattention implies that attention is captured after the stimulus has undergone semantic analysis, whereas stimuli that are not meaningful to the task at hand are less likely to capture attention and to lead to awareness. However, the meaningfulness of the stimuli is not the only critical factor. The degree of inattentional blindness also varies as a function of the visual similarity of the unexpected stimulus to the color of the attended stimulus, provided that the task calls for color discrimination (Most et al., in press; Most et al., 2001; Simons & Chabris, 1999). This effect was not, however, replicated in the present study probably because it was not necessary to discriminate the attended stimuli on the basis of their color. In addition, at least some bottom-up properties of the unexpected stimulus, such as salience (e.g., color in Experiment 2a and in Most et al., in press; stimulus size in Mack & Rock, 1998), contribute to the probability of explicit attentional capture.

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