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Tales of the unexpected: attentional awareness; goal-relevance and prior exposure to an unexpected change.

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Abstract

We report an experiment where we examine whether an unexpected stimulus change that occurs whilst performing an engaging task is more likely to be noticed if it is relevant or irrelevant to the goal of that task. The goal was to count the number of times moving targets (white letters) hit the side of the frame on a computer screen but to ignore similarly moving distractors (black letters). We found that a highly goal-relevant change (i.e., a black distractor changing into a white target) was more likely to be noticed than a less-relevant change (a white target turning into a black distractor). However, people with high working memory were more likely to notice the goal-relevant change but *less likely* to notice the goal-irrelevant change. High working memory capacity appears to be associated with the more efficient strategy, which is to notice the change when it is goal-relevant but to inhibit it when it is not relevant to prevent the possibility of interference with the goal of the primary task. We then investigated whether previous exposure to an unexpected change influenced the likelihood that a different change (an unexpected red cross in a standard dynamic inattentional blindness task) would be noticed. We observed prior experience of a change reduced the incidence of Inattentional Blindness. These findings are discussed in terms of dual-route model of Inattentional blindness, in which the failure to notice the unexpected stimulus can result from a lack of processing or from inhibition.

KEYWORDS: Inattentional Blindness, Change Blindness, Working Memory Capacity, Awareness, Dual-Route Model.

Tales of the unexpected: goal-relevance and prior exposure to an unexpected change and attentional awareness

Failures of attention are commonplace in everyday life. One such example of this is inattentional blindness (IB), which occurs when we fail to notice an unexpected stimulus when we are engaged in a resource-consuming task (Mack & Rock, 1998). This type of attention failure has been responsible for some tragedies, such as the incident of the flight crew who, when distracted by a flashing light, failed to notice their plane approaching the runway too early and fast, resulting in the plane crashing and killing over 100 people (Green, 2005). The standard laboratory-based dynamic inattentional blindness paradigm that is used to examine this phenomenon involves participants counting the number of times white moving letters (targets) bounce off the screen frame while ignoring similarly moving black letters (distractors) – this is the tracking task. After a few seconds, an unexpected red cross appears at the side of the screen, moves across the centre and disappears several seconds later at the other side. Participants report the number of target bounces and are then asked if they saw anything else. Those failing to report the red cross are deemed 'IB' whereas those reporting its presence are 'NIB' (not-IB).

Much research has shown that IB levels are affected by the physical display (Cartwright-Finch, & Lavie, 2007; Jensen, Yao, Street & Simons, 2011; Koivisto, & Revonsuo, 2008; Most, Scholl, Clifford, & Simons, 2005) but little research has been conducted on why some individuals in an identical situation are IB whereas others are not. We found no differences between those who were and were not inattentionally blind in processing style or ability to inhibit irrelevant stimuli (Hannon & Richards, 2010;

Richards, Hannon, & Derakshan, 2010), although some recent research has identified difference in saliency detection that are associated with IB status (Papera, Cooper, & Richards, 2014). Hannon and Richards (2010) found that although visual working memory did predict inattentional blindness when it was entered into the analysis on its own, when a more central executive measure of working memory capacity was entered into the analysis, only central executive resources predicted inattentional blindness and visual working memory was no longer a significant predictor. Likewise, in a study where we examined the personality trait, absorption (Tellergen Absorption Scale, TAS; Tellegen & Atkinson, 1974), it was found that this trait predicted inattentional blindness but fell out of the equation when working memory capacity scores were entered. People with high working memory capacity were more likely to notice the unexpected stimulus compared to those with low capacity (Richards, Gunnarsson Hellgren, & French, 2014). We call this the *limited-resources* hypothesis, where inattentional blindness is associated with reduced working memory capacity (WMC; Hannon & Richards, 2010; Richards, Gunnarsson Hellgren, & French, 2014; Richards, Hannon, & Derakshan, 2010; Richards, Hannon, & Vitkovitch, 2012; Seegmiller, Watson, & Strayer, 2011; Todd, Fougnie, & Marois, 2005; but see Bredemeier & Simons, 2012). Beanland and Pammer (2012) found a correlation between IB and the size of the attentional blink, suggesting there are individual differences in failures of conscious visual awareness across a variety of tasks.

One problem with the standard IB task is that the status of the red cross is ambiguous. It is not part of any task instructions and is therefore *irrelevant* to the primary task – which is to count the number of target bounces. However, because participants are not told anything about the red cross at the beginning of the experiment, they may assume that it has some relevance and therefore remember its occurrence. It is therefore unclear whether the most efficient and effective strategy is to process the unexpected stimulus in case it is relevant so that it is available to conscious awareness or whether, given its probable irrelevance, it is more efficient to inhibit it. Inattentional blindness has been shown to occur in people performing a task in which they have a high level of expertise. Drew, Võ and Wolfe (2013) asked a group of expert radiologists to examine a series of computer-tomographic axial lung slices for lung nodules, and found 83% of them failed to notice the unexpected gorilla that was embedded in the last case in the series. In this task, the presence of the gorilla is irrelevant to the goal of the task (i.e., to detect lung abnormalities) and arguably the most efficient strategy would be to inhibit it, and expert radiologists are more able to inhibit this unexpected and irrelevant stimulus.

A related failure of conscious awareness is change blindness (CB), which occurs when a change in a scene goes unnoticed (Rensink, O'Regan, & Clark, 1997). Change blindness can occur when the change is not expected such as in the example provided by Simons and Levin (1998) in which a participant's conversation with a stranger was interrupted by a large object coming between them obscuring each person's view of the other. During this interruption, a different person replaced the stranger and many participants failed to notice that they were speaking to a different individual after the interruption compared to before. Change blindness can occur even when participants are aware that there is a change occurring, such as in an oscillating change in a flicker task (e.g., Luck & Vogel, 1997; Hyun, Woodman, Vogel, Hollingworth, & Luck, 2009; Simons, 1996). Change blindness and inattentional blindness are similar in that they both involve visual awareness failures (Jensen, Yao, Street, & Simons, 2011) but they come from different theoretical and empirical backgrounds. McCarley, Vais, Pringle, Kramer, Irwin and Strayer (2004) found that having fewer available mental resources increased the incidence of change blindness. This is consistent with our research where inattentional blindness was associated with executive function but not visual memory (e.g., Hannon & Richards, 2010). The *one-scene* change blindness research is similar to inattentional blindness research, but the change that occurs in the former is directly relevant to the goal of the task (e.g., having a conversation with a stranger) whereas the change in inattentional blindness research is not *directly* relevant to the task (e.g., a red cross traversing the screen when counting moving letters).

Here we use a novel task, based on the *one-scene* change change blindness task where a single change occurs during a dynamic tracking task. In our task, the change occurs *within* the task such that the unexpected stimulus is either relevant or irrelevant to the primary task of target tracking. It could be argued that a relevant change should be noticed if it is directly related to the goal but inhibited if not relevant and might therefore cause interference. In the current experiment, we have two conditions: one where the change is goal-relevant and a distractor transforms into a target (distractor-to-target) and a second condition that is comparatively goal-irrelevant, where a target changes into a distractor (target-to-distractor). The *task-relevance* hypothesis predicts that the unexpected change is more likely to be reported if that change is goal-relevant rather than goal-irrelevant. Although both changes are important, it is more efficient to suppress the processing of the target-to-distractor event, as this change renders the stimulus irrelevant in the display whereas it is important to use resources on the distractor-to-target stimulus, as this change is important and relevant to the primary task of counting white targets.

The task-relevance hypothesis would therefore predict noticing levels to be higher for the relevant than for the irrelevant change condition. The relevant change condition results in an increase in task difficulty, as there are more targets to track compared to the irrelevant change condition (5 targets vs. 3 targets respectively). On the basis of our previous research, however, we have consistently observed increases in the incidence of inattentional blindness when task difficulty increases. We call this the *limited-resources hypothesis* because failure to notice the change occurs as a result of reduced capacity. Following on from this, people with lower working memory therefore would be less likely to notice the unexpected stimulus than those with higher working memory. The task-relevance hypothesis and the limited-resources hypothesis therefore make opposing predictions, with the former predicting higher incidence of awareness of the change when it is relevant whereas the latter predicts that awareness rates will be *lower* for the relevant condition because it is a more difficult task and requires more resources.

In a subsequent task, we examine whether prior exposure to a change in a tracking task influences performance on a standard inattentional blindness task. Gaspar, Neider, Simons, McCarley and Kramer (2013) observed improved change detection performance in participants who were trained on the task compared to those who were not, but this training effect did not generalize to a new change detection task. We previously demonstrated that primary-task practice (with no changes occurring) significantly reduces the incidence of IB on a subsequent IB task (Richards et al., 2010). Therefore, to rule out practice effects per se, our control condition required participants to perform (practice) the primary task before the standard-IB task.

In sum, we investigate whether goal-relevant changes are more noticeable than less relevant ones, and whether prior exposure to a change influence later noticing of the unexpected stimulus on a standard inattentional task.

Method

Participants

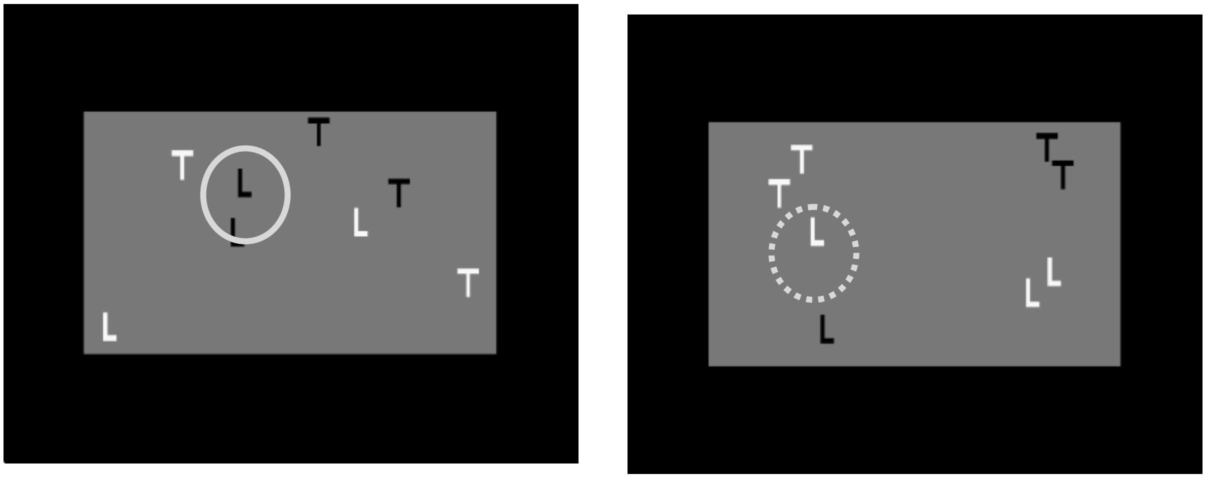
Ninety-four participants were recruited but those with accuracy scores on the tracking tasks at 70% and below were excluded from the main analyses (21 participants were excluded). It is important that participants perform the tracking task to a minimum standard, as participants need to be engaged in a resource-consuming task. There were therefore 63 participants (mean age of 32.32 (SD = 9.37); 38 males) in the final sample. The number of exclusions, age and sex ratio did not differ between the conditions.

Materials

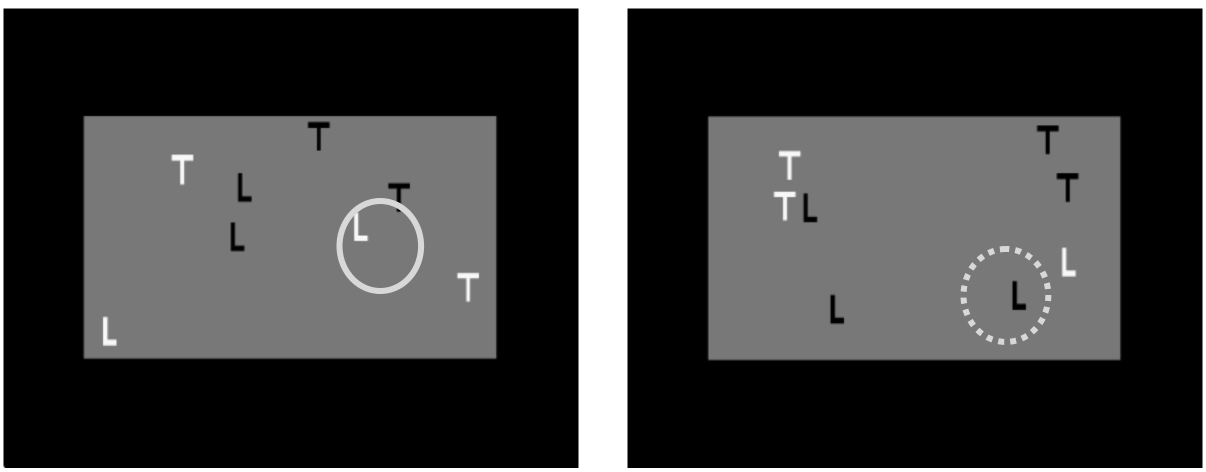
Automated Operation Span task (Unsworth, Heitz, Schrock, & Engle, 2005) to measure WMC. Participants completed a series of simple maths problems. A letter was presented after each problem and retained in memory until the end of the trial. At the end of each trial (varying between 3 maths problems/3 letters to 7 maths problems/7 letters) a letter matrix appeared and the participant clicked the letters in the exact order in which they appeared in the trial. Each maths problem had to be solved within a time limit (determined during the preceding practice). Scores range between 0 and 75.

The three videos (*Change* videos; see Figure 1) were created using MatLab, and were similar to that of Most, Scholl, Clifford and Simons (2005; see Simons, 2003). The primary task comprised four white (two Ls and two Ts) and four black letters (two Ls and two Ts) moving around the screen, hitting the borders of the display. Participants were required to silently count the number of white letters hitting the border of the picture frame but ignore the black letters. Each video lasted for 31 s. Each began with a 6 s still frame after which the letters moved around the screen linearly for 25 s. After 16 s (from the very beginning of the video), one letter in the two training conditions changed colour. In the Target-to-Distractor condition a white L (a target) hit the frame on two occasions and then changed into a black L (a distractor) whereas in the Distractor-to-Target condition a black L (a distractor) turned into a white L (a target). There was no change in the control condition. There were 20, 27 and 24 hits in the target-to-distractor, distractor-to-target, and control conditions, respectively. The target-to-distractor and the distractor-to-target videos both involved a change that occurred to one of the stimuli on the screen during the video. Before participants in these two conditions were presented with the final, standard inattentional blindness video, they had either noticed the change when questioned or they were made aware of the change by the experimenter. These two videos exposed participants to an unexpected change occurring in the tracking task. Participants in the control video were not exposed to any such changes and therefore their participation served as a control condition.

A.



B.



C.

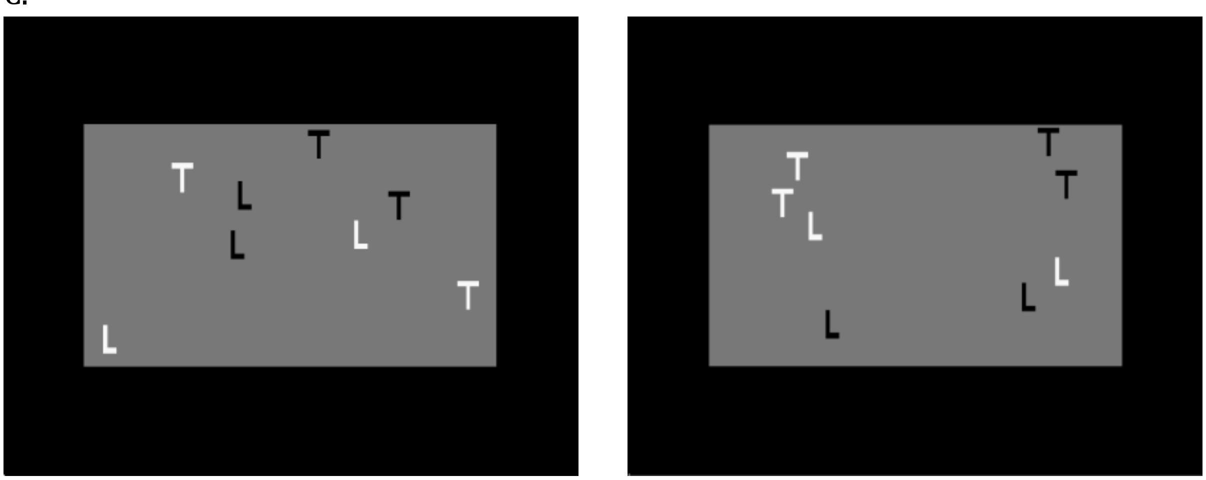


Figure 1. Sample video stills: A. Relevant change where a distractor (black L) changes into a target (white L). B. Irrelevant change where a target (white L) changes into a distractor (black L). C. Control (no change). Left panel = start configuration with letter that will change circled. Right panel = post-change configuration with change circled with broken line.

A video (*standard-IB*) of the same duration and format was created but with no changes to targets or distractors. After 12s an unexpected red cross appeared at the right-hand side of the frame, traversed the centre for 11secs exiting at the left-hand side of the frame (see Figure 2).

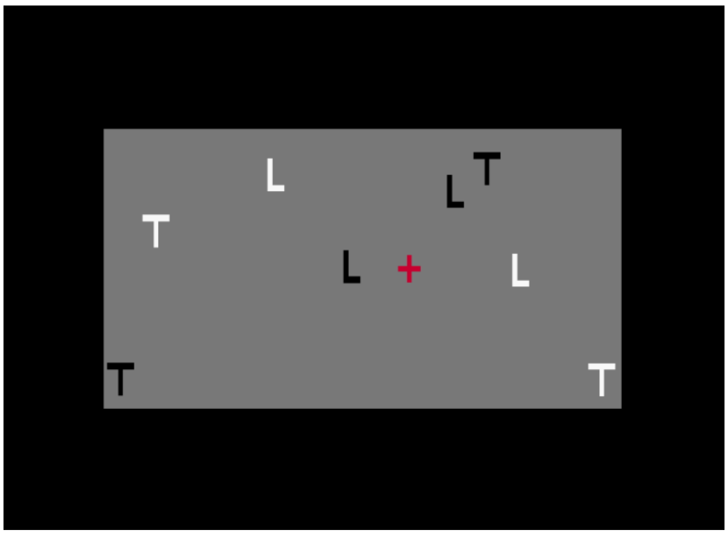


Figure 2. Standard dynamic inattentional blindness in which the unexpected stimulus (the red cross) appears at the right hand frame and then travels across the screen in a straight line, disappearing on the left hand frame 11 s later.

Recognition Task. A 16-object array (cross, triangle, circle and diamond, in red, green, yellow and blue) was presented to all IB participants.

Full Attention Trial. To check that participants saw the red cross when not engaged in any additional task, they simply viewed the video again.

Procedure

Participants completed the Automated Operation Span Task and were then randomly assigned to the relevant (distractor-to-target), irrelevant (target-to-distractor) or control condition. The task was to monitor how many times the white letters hit the frame but to ignore the black letters. At the end, participants reported the number of hits. In the prior exposure conditions where there was either a change to a target or a change to a distractor, participants were asked if anything unexpected had happened during the video. If participants noticed the colour change of one of the letters, they were recorded as being aware and the remaining participants as being unaware. The participants in the control condition were simply asked to report the number of target hits during the video (there were no changes here). All participants watched the video again but those in the two change-exposure conditions were made aware of the change to one of the letters during the video.

All participants then performed the standard dynamic inattentional blindness task by counting the number of times the white letters hit the frame while ignoring the black letters. At the end, they were asked how many hits they counted and then asked if they noticed anything unexpected. Participants were recorded as being 'non-inattentionally blind' if they noticed the red cross but 'inattentionally blind' if they had not. The recognition task was administered and inattentionally blind individuals were asked to try to identify/guess the identity of the unexpected stimulus (none were successful). Finally, the standard-inattentional blindness video was shown for a second time but without task requirements. All participants spontaneously reported the appearance of the red cross.

Results

Relevance of Change. Participants were more aware of the change when the change was irrelevant to the task (i.e., target-to-distractor) than when it was relevant (distractor-to-target; χ^2 = 4.58, N=42, *p*=.03, ϕ = .33; see Figure 3).

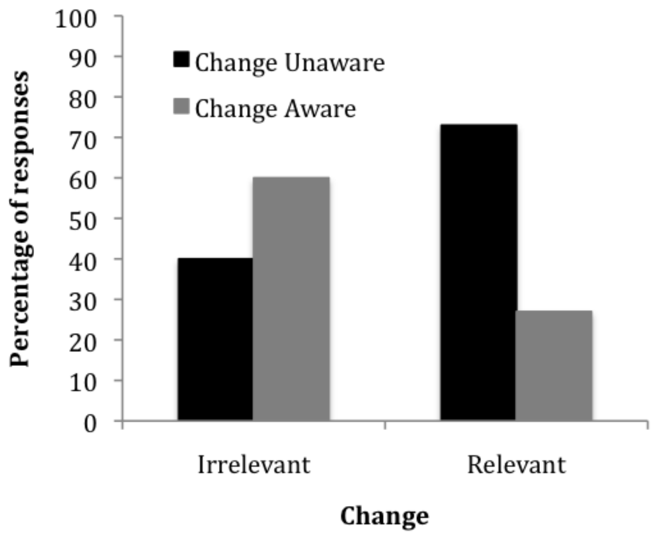


Figure 3. Percentage of participants who were aware of the change when it was irrelevant (when a target changed into a distractor) and relevant (when a distractor changed into a target) to the tracking task of counting the number of time targets (white letters) hit the frame of the display.

This supports the limited-resources hypothesis rather than the relevance hypothesis, as a relevant change required more tracking than an irrelevant one (5 targets rather then 3) and the incidence of awareness of the change was higher for the easier task. However, an examination of AOSPAN scores (which measured working memory capacity), with awareness status (aware, unaware) and task-relevance (relevant, irrelevant) as between-subjects factors revealed an interaction between task-relevance and awareness ($F(1,38) = 4.37$, $p = .043$, $\eta_p^2 = .10$; See Figure 4). Those participants who were aware of the change in the relevant condition had higher Automated Operation Span scores than those who were aware in the irrelevant condition ($t(16) = 2.34$, $p=.03$, mean difference = 13.8, CI_{95} = 1.3, 26.2). The opposite pattern was found for participants who were not change aware, but this was non-significant ($t(22) = -1.05$, $p = .3$, mean difference = -8.5, CI_{95} = -25.2, 8.2).

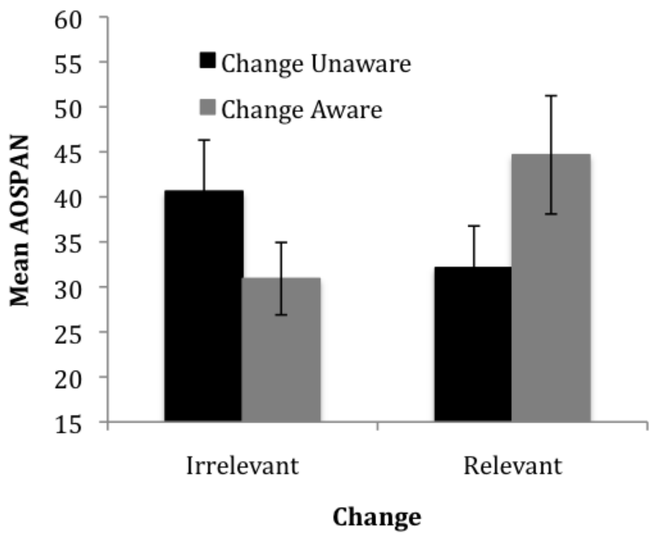


Figure 4. Mean AOSPAN scores for change unaware and change aware participants in the relevant and irrelevant conditions.

Across both tasks, there were no differences in performance of the tracking task (i.e., counting the number of target hits) suggesting that all participants performed the tracking task to a similar standard (*Fs<1).*

Awareness of the unexpected stimulus in the standard inattentional blindness task was increased in those participants who had had prior exposure to a change compared to those in the control condition ($\chi^2 = 6.08$, N=63, $p=.009$, $\phi = .33$).

Discussion

More people detected the change in the video when the task was easy (4 targets reduced to 3) and relatively goal-irrelevant than when it was difficult (4 targets increased to 5) and goal-relevant. This finding supports the idea that when the task is easier (and less resource-consuming) the change is more easily spotted than when it is difficult. On the surface this does not offer support for the idea that when a change is goal-relevant, it is more likely to be seen than if it is relatively goal-irrelevant. However, the working memory capacity data (as measured by the AOSPAN) reveal that for those participants with high working memory capacity, the nature of the change is important. Given the overall task, when the change is highly relevant to the goal then the most efficient strategy is to process it fully, and should be noticed. When this change is relatively goal-irrelevant, then a better strategy would be to inhibit it and, as a result, not notice it. The working memory capacity data support this idea, as higher working memory capacity was associated with using the better strategy in both instances. Participants with higher working memory capacity noticed the change when it was goal-relevant but failed to notice the change when it was goal-irrelevant. These findings support previous research that high working memory capacity is associated with greater flexibility in attentional allocation (Bleckley, Durso, Crutchfield, Engle, & Khanna, 2003). The evidence showing that working memory resources are required for effective inhibition of information (e.g., Daneman & Carpenter, 1980; Conway & Engle, 1994; Conway, Tuholski, Shisler, & Engle, 1999) supports the idea that participants do not report the change in the goal-irrelevant condition precisely because it *is* relatively goal-irrelevant and therefore inhibited (see also Drew, Võ & Wolfe, 2013). These data also support Vogel, McCollough and Machizawa (2005) in that the more efficient strategy was associated with higher working memory capacity than the less efficient strategy.

The data from this experiment support the dual-route model of inattentional blindness, which suggests that there are different ways in which inattentional blindness can occur. Whether IB occurs or not is largely determined by the physical environment, but individual differences must play a part given that in the exact same physical environment, some people will be IB whereas others will not. The dual route model predicts that low working memory capacity individuals will not process the unexpected stimulus because they have insufficient resources whereas the high working memory capacity individuals will fully process the unexpected stimulus (because they *do* have sufficient resources) but this will result in the unexpected stimulus being processed to full awareness (if the unexpected change is relevant to the goal of the task) or inhibited (if the unexpected change is not relevant to the goal of the task).

Being exposed to a change (relevant or irrelevant) resulted in participants being more likely to notice the unexpected stimulus (red cross) appearing in a standard inattentional blindness task in comparison with the control group (who were exposed to the same tracking task as those in the relevant/irrelevant conditions but without any change occurring during the task). This suggests that participants exposed to, and made aware of, an unexpected change subsequently altered their goals and invested more resources in the task making the red cross more likely to be detected. Participants previously exposed to a change appeared to be better able to use their resources flexibly by changing their attentional set (Folk, Remington, & Johnson, 1992). Prior exposure may also have led to a degree of automatisation, thus freeing up resources even for those with lower working memory capacity. It is likely that those individuals with lower working memory resources will fail to detect unexpected changes irrespective of whether they are relevant or irrelevant simply because working memory resources are fully consumed by the main task and there are not sufficient resources left to fully process the unexpected stimulus. This is because processing a stimulus to awareness requires cognitive resources but inhibiting a stimulus also requires resources. When cognitive resources are low, we propose that the unexpected stimulus irrespective of its relevancy to the task will not be fully processed, rather it will be filtered out at an early stage.

The failure of any inattentionally blind individual to correctly identify the red cross in the recognition task argues against the idea of inattentional amnesia. However, a caveat here is that the standard inattentional blindness task does not have an explicit learning component, and therefore a more implicit memory task may have elicited some memory representation in those participants who were not consciously aware of the red cross (Schacter, Chiu, & Ochsner, 1993).

In sum, whether someone is consciously aware of a change in a task depends on the nature of that task (whether the unexpected change is relevant or irrelevant to the goal of the primary task) and their working memory resources. A relevant change requires resources to detect it but an irrelevant change requires resources to inhibit it. These data support the dual-route model, which proposes that inattentional blindness can result from either the unexpected stimulus not being fully processed due to a lack of cognitive resources or from the unexpected stimulus being fully processed and then inhibited because it is not relevant to the goal of the task.

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