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Change perception and change interference within and across feature dimensions

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ABSTRACT

The ability to perceive a change in a visual object is reduced when that change is presented in competition with other changes which are task-irrelevant. We performed two experiments which investigate the basis of this *change interference* effect. We tested whether change interference occurs as a consequence of some form of attentional capture, or whether the interference occurs at a stage prior to attentional selection of the task-relevant change. A modified probe-detection task was used to explore this issue. Observers were required to report the presence/absence of a specified change-type (colour, shape) in the probe, in a context in which - on certain trials - irrelevant changes occur in non-probe items. There were two key variables in these experiments: the attentional state of the observer, and the dimensional congruence of changes in the probe and non-probe items. Change interference was strongest when the irrelevant changes were the same as those on the report dimension. However the interference pattern persisted even when observers did not know the report dimension at the time the changes occurred. These results seem to rule out attention as a factor. Our results fit best with an interpretation in which change interference produces feature-specific sensory noise which degrades the signal quality of the target change.

1. Introduction

Observers are surprisingly poor at noticing changes in their visual environment, a phenomenon dubbed *change blindness* (Simons & Levin, 1997). Change blindness is often demonstrated using the flicker paradigm (Rensink, O'Regan, & Clark, 1997). In the paradigm two versions of a scene - an original and altered version - are presented in cycling alternation interleaved by a blank mask. The general finding is that changes between the two scene versions are often perceived only after several iterations. The interleaved blank mask plays a critical role in the flicker paradigm, suppressing the visual transients in the retinal image which accompany a change and otherwise immediately reveal its presence.

1.1. Change perception and change interference

In the majority of change perception studies the target change is unique in the display on trials in which a change occurs (e.g. Cole, Kentridge, & Heywood, 2004; Gaspar, Neider, Simons, Mccarley, & Kramer, 2013; Hollingworth, Schrock, & Henderson, 2001; Hughes, Caplovitz, Loucks, & Fendrich, 2012; Luck & Vogel, 1997; Rensink et al., 1997; Wolfe, Reinecke, & Brawn, 2006; Wright, Green, & Baker, 2000). Other studies have investigated change perception using displays in which, in addition to the target change, one, or several *task-irrelevant* changes are also presented in competition with it (Gao, Gao, Li, Sun, & Shen, 2011; Hyun, Woodman, Vogel, Hollingworth, & Luck, 2009; Jiang, Chun, & Olson, 2004; Jiang, Olson, & Chun, 2000; O'Regan, Rensink, & Clark, 1999; Rensink, 2000; Sänger & Wascher, 2011; Schneider, Beste, & Wascher, 2012; Shen, Tang, Wu, Shui, & Gao, 2013; Wascher, Schneider, Hoffmann, Beste, & Sänger, 2012). These studies of *competitive change detection* are of particular interest because they explore the limits of the visual system in identifying goal-relevant changes (Wascher & Beste, 2010). Unlike the standard change detection task the observer has to do more than just detect if a change has occurred, they also need to evaluate if the change is one which is relevant to the task goals. The general finding from the literature is that observers can reliably selectively report about the presence or absence of specified kinds of task-relevant changes; however performance is often found to be substantially reduced when compared against a baseline condition in which only task-relevant changes are present. The reduced change detection performance, which results from task-irrelevant changes, can be described as a *change interference* effect. The effect is

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something worthy of study in itself. By understanding when and why change interference occurs, we can further our understanding of the cognitive architecture underlying change detection.

Given the importance of attention in change detection (Rensink et al., 1997; Wolfe et al., 2006), it seems plausible that attention may also play a role in mediating change interference effects (Rensink, 2000). It could be that change interference occurs in a manner akin to the *contingent capture effects* found in cued visual search tasks and associated with goal-directed manipulations of feature-selective attention (Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Lien, Ruthruff, Goodin, & Remington, 2008). It is established that feature-selective attention is also a relevant factor in change detection: task-relevant changes tend to be noticed more when the observer is focused on the dimension on which it occurs (Niklaus, Nobre, & Van Ede, 2017; Pilling & Barrett, 2016; van Lamsweerde & Beck, 2011). Feature-selective attention can be manipulated in a task-defined way in the change detection paradigm. For instance, in some change detection studies conditions are given in which observers must only respond when certain types of specified change occur and ignore others (Hyun et al., 2009; Rensink, 2000). If an observer is instructed to only report about, for instance, colour changes, then it is likely that the task goals will mean that attention becomes weighted towards the colour dimension, and away from other feature dimensions (Krummenacher & Mueller, 2012; Maunsell & Treue, 2006; Pilling & Gellatly, 2013).

We wished to explore whether attention, manipulated in this feature-selective manner, has analogous effects on change interference to those in the contingent capture paradigm. Our a priori expectation was that change interference would be most evident when the competing irrelevant changes were consistent with the feature-specific attentional state of the observer.

One relevant study which has a bearing on this question is reported by Jiang et al. (2000). In this study the observer had to report about colour changes in a modified change defection task. In their task observers saw an array of coloured squares presented once before and after a brief blank interval. In the second display, the test display, one of the coloured squares was surrounded by a hollow square box which indicated the probe item. Observers had to report whether or not the probe item had changed in colour across the blank interval. This was done in two conditions. In one, all the non-probe items retained the same colours across the blank interval; in another, the non-probes each had a new randomly-determined colour across the interval. Accuracy was found to be substantially lower in the latter condition. This reduction in accuracy was found despite the fact that the non-probe items were entirely task-irrelevant.

One interpretation of this effect is that it is a consequence of attentional capture of the relevant colour change in the probe by the more numerous, but task-irrelevant, colour changes in the non-probe items; because the relevant and irrelevant changes occurred on the same dimension it may have been impossible for the attentional system to filter them out. Unfortunately it is hard to determine if attention played any role in mediating change interference in Jiang et al.'s study: no comparative condition was given in which task-irrelevant changes occurred on a task-irrelevant dimension.[1] Several other studies, however, have given tasks in which irrelevant changes were presented on a feature dimension that itself was task-irrelevant. However the tasks and paradigms used are varied and in all cases very different to that in Jiang et al. Despite this - and consistent with the account we have proposed - some experiments have found no, or only marginal, change interference to occur from such irrelevant-dimension changes. For instance, Rensink (2000) gave a change search task in which observers had to search for, and locate, as specified type of feature change (either a luminance polarity change or an orientation change, depending on the assigned condition) in a display consisting of a number of black or white vertical or horizontal oriented bars. On some trials there were changes on the task-irrelevant dimension which competed with the searched for task-relevant change. For instance if the searched-for change was luminance polarity then all the items in the display, including the target also changed in orientation each time the luminance change occurred. The irrelevant changes, had little-to-no measurable effect on performance. Rensink concluded from this that the irrelevant dimension changes were attentionally ‘filtered out’, meaning that they did not influence behaviour. However, other studies using different methods, have found interference effects arising from task-irrelevant dimension changes which are rather larger than what Rensink found (e.g. Hyun et al., 2009; Schneider et al., 2012).

1.2. The present experiments

It seems possible that attention might play a role in mediating change interference effects of the kind described above. However no experiment to date has directly tested this. The experiments in this paper do this by looking at the effect of irrelevant changes on two different types of target change. In these experiments the irrelevant changes occur either on the same dimension as the task-relevant change, or the other task-irrelevant dimension. The experiments use a modified version of Jiang et al.'s probe-change detection paradigm (Jiang et al., 2000) that we described earlier. In this modified version of the paradigm, observers have to report about the presence or absence of a specified type of change in the probe. In all experiments there are two types of report condition, *report colour* and *report shape*. In the first experiment these conditions are done across two separate groups of observers. In each group observers reported whether or not the specified type of change had occurred in the probe item on each trial. This had to be done in a context in which the other (non-probe) items in the display also changed in either in colour or shape on some trials.

Our principal interest was the effect of these irrelevant non-probe changes on reporting the specified probe change. We wanted to establish if these irrelevant changes would produce interference, and, if they did, whether attention was in some way responsible for it. Based on our task we assumed four possible accounts of how change interference might occur. We now outline these four accounts of change interference in turn.

The first of these, we call the *feature-selective attention* account. This account is that we have already outlined. According to this account, change interference occurs when attention is drawn away from a task-relevant change by task-irrelevant changes of the same feature type. The consequence of this loss of attention is reduced sensitivity to the task-relevant change event. This account is, in essence, a re-description of the *contingent capture hypothesis* (CCH) originally proposed by Folk et al. (1992). However the CCH is largely based on evidence from cued search (Folk et al., 1992; Folk et al., 1994; Lien et al., 2008). It is an open question whether the hypothesis will apply to the different context of competitive change detection.

The second account, we call the *stimulus-directed attention* account. This account, like the first, also deems that change interference is a consequence of attentional capture. However it departs from the first account by proposing that the putative capture by irrelevant changes is determined by the intrinsic salience of the irrelevant change events themselves, not the attentional demands of the observer (Theeuwes, 1992; Yantis, 1998). Thus, on this account attention is important, but in it change interference occurs to the same extent independently of the top-down governed attentional state of the observer, or of the nature of the task-relevant change itself.

The first two accounts we have mentioned both assume that change interference is a consequence of some form of attentional capture. However it is possible to conceive that attention is not a factor in mediating change interference. The last two accounts propose that change interference occurs at a processing stage which occurs prior to

[1] The focus of Jaing et al.'s paper was on understanding the organisation of representations in VSTM, not on understanding change interference.