# 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.

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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.

*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. Gaspar, Neider, & Simons et al., 2013; Luck & Vogel, 1997; Hollingsworth, Shrock & Henderson, 2001; Cole, Kentridge & Heywood, 2004; Hughes, Caplovitz, Loucks & Fendrich, 2012; Rensink et al., 1997; Wright, Green & Baker, 2000; Wolfe et al., 2006). 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 et al., 2011; Hyun, et al., 2009; Jiang, Chun & Olsen, 2004; Jiang, Olson & Chun, 2000; O'Regan, Rensink & Clark, 1998; Rensink, 2000; Shen, Tang, & Wu et al., 2013; Sänger & Wascher, 2011; Schneide, Beste & Wascher, 2012; Wascher, Schneider & Hoffmann et al., 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 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, et al. 1992; Folk, Remington & Wright, 1994; Lien et al. 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 (van Lamsweerde & Beck, 2011; Pilling & Barrett, 2016; Niklaus, Nobre & van Ede, 2017). 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 & Müller, 2012; Maunsel & 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 and colleagues (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.

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

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).

*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, Remmington and Johnston (1992). However the CCH is largely based on evidence from cued search (Folk, et al. 1992; Folk, Remington & Wright, 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 (Yantis, 1998; Theeuwes, 1992). 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 any attentional operations in the test display.

Research has shown that when a test display is presented in a change detection task, the objects in the display are automatically compared with the VSTM representation of items from the memory display in a parallel manner (Hyun et al, 2009). Hyun and colleagues argue that this comparison process is a rapid one and occurs prior to any serial attention towards items in the test display. The transient signals generated by this automatic comparison process between VSTM and current input may be sufficient in themselves for the observer to be aware that a change has occurred; however these transients may, additionally, serve to guide overt or covert attention towards the probable change location allowing a second serial and active comparison process to take place.

It is possible that change interference may be something which originates in this automatic comparison process between VSTM and current vision, in which these transient change signals are generated. If the probe change(s) are unique in the display then this probe transient change signal will be more prominent than when it occurs in a context in which the non-probes also change. Specifically, the simultaneously occurring non-probe changes will generate *sensory noise* (Stevens, 1975; Wickelgren, 1968) which would dilute the change signals emanating from the probe item itself. The consequence of this interference would be a reduction in SNR for probe changes. The last two models view that change interference to be a consequence of such sensory noise generated during this putative comparison process leading to a loss in the quality of the probe change signal. The two models differ in terms of the way in which the transient change signals between VSTM and current input are viewed to be processed, whether this occurs in a single co-active channel, or in separate channels segregated by feature-type.

In the *single-channel noise* account all changes, whether colour or shape, are reflexively compared in a single co-active channel (Tansend & Nozawa, 1995). In this channel any feature mismatch between VSTM and current input will generate a transient signal within this single perceptual channel. Thus, in this account, all types of irrelevant feature changes will add sensory noise to the probe change, irrespective of the relative dimension of the probe- and non-probe change. In the *separate-channel noise* account different types of feature change are viewed to be processed in independent, or largely independent, perceptual channels (Livingstone & Hubel, 1987; Magnussen, 2000). It means that transients associated with colour changes, for instance, would be generated in a separate perceptual channel from transient signals associated with from shape changes in the comparison process. Thus, irrelevant feature changes will tend to only reduce the SNR for probe changes of the same perceptual type, because only in this circumstance are these changes processed in the same channel. The consequence is that change interference is most evident when irrelevant changes occur on the same feature dimension as the reported probe change.

## Experiment 1

In Experiment 1 a probe-change detection task was given in which observers have to report about the presence of a specified type of feature change in a probe item. Observers had to either report if the probe item changed in colour or shape. The displays all consisted of five items around a central fixation; a radial cue indicated the probe. On some of the trials the non-probe items remained the same in both colour and shape. On other trials either the colour or the shape of the four non-probe items all changed[2].

It was expected that the requirement to report exclusively about colour or shape changes in the probe would determine the observer's adopted attentional set. According to the feature-selective attention account these feature-based attentional settings are instrumental in determining whether the changes in the non-probes capture attention. Consequently, these settings influence the extent to which change interference occurs from the non-probes. Therefore the feature-

[2] All four non-probes changed on interference trials to maximise any putative change interference effect in the display. Hyun et al. (2009) has already showed, in one experiment, that change interference tends to be greater when multiple irrelevant changes are presented compared to a single irrelevant change.

selective attention account predicts an interaction will occur between the dimension of the report condition and those of the irrelevant changes in the non-probes.

The stimulus-directed attention account views that attention is important, but not the task-governed attentional set of the observer. Therefore non-probes are predicted to capture attention to the same degree irrespective of the observer's attentional set. A main effect of the type of irrelevant changes in the non-probes might be found, e.g. irrelevant colour changes in the non-probes might generally produce more interference than irrelevant shape changes. However, no interaction should be found between the type of irrelevant change in the non-probe and report condition. The extent of capture, and therefore the level of change interference, should be the same across the two report conditions.

The single-channel noise account, like the stimulus-directed attention account, also predicts that there will be no interaction between the type of irrelevant change in the probe and the report condition. However it does so for different reasons. In this account the change interference occurs, not because of capture by attention, but because the probe change signal is degraded. It is viewed that irrelevant changes in the non-probes have the effect of increasing noise levels in a single co-active channel associated with the transients produced by the comparison of representations in VSTM and current vision; the increase in noise reduces the signal quality associated with the probe change(s). This account, like the stimulus-directed attention account, concedes that a main effect of non-probe interference–type could occur, if one type of irrelevant change tends to produce stronger transient signals. However there should be no interaction between the type of irrelevant change and report condition.

The separate-channel noise account makes the same prediction as the feature-selective attention account, described earlier. However, again, this is for different reasons. In separate-channel noise account the change interference is something which occurs prior to attentional selection. As in the single-channel noise account, irrelevant changes are viewed to interfere with detection of changes in the probe because they increase the level of sensory noise within a perceptual channel. The consequence is that they reduce the signal-quality in the probe change. This account departs from the single-channel account in viewing that sensory noise tends to be isolated within a particular feature channel. Consequently, performance in reporting about the probe will show most interference when the irrelevant non-probe changes are of the same feature type as the to-be-reported probe change. This should be expressed on our task as an interaction between interference-type and report condition.

Thus, whether we observe an interaction between manipulation of the type of irrelevant changes in the non-probes and manipulation of report type will be critical in distinguishing between some of these accounts. Experiment 1 tested this.

## Method

*Participants*

There were 24 participants (20 Female). All had normal or corrected-to-normal vision. None reported colour vision problems.

*Stimuli*

Stimuli were presented on a Sony Trinitron 15” CRT. The monitor was set to a resolution of 1024×768 with a 100Hz refresh rate. The monitor was viewed in a darkened room with backlighting and sound deadened room. It was viewed from an approximate distance of 1000 mm. The monitor was controlled by Pentium 4 PC fitted with a NVDIA GeForce 4 graphics card. Stimulus displays were generated online using bespoke software written in the *Blitzmax* programming language (Blitzmax, V. 1.5, Blitz Research Ltd. Auckland, New Zealand). This written software was also responsible for control of all timings, trial randomisation and response recording. The viewed stimulus displays consisted of two arrays, a memory and test array, presented in sequential order and separated by a blank interval. Each contained five coloured shapes arranged evenly spaced from one another in a notional circle around a fixation point. The fixation point consisted of a white cross. The distance between the adjacent items was always constant, however the specific positions of the items on the notional circle varied randomly from trial to trial.

The individual items in the array were each one of 12 possible shape-types (oval, equilateral triangle, rectangle, plus sign, crescent, heart shape, pentagon, kite, star, semicircle, sun, hourglass). The sizes of all stimuli are expressed in terms of approximate subtended visual angle at the viewed distance. The different stimuli varied between approximately 1.4° to 1.8° of subtended visual angle in height and 1.4° to 1.7° of subtended visual angle in width at the given viewing distance.

Each of the line drawn shapes was presented in one of twelve colours. These colours are listed with a descriptive name and their measured c/m$^2$ and CIE (1932) *xy* chromaticity coordinates. These were *black* (0.3, .30, .32), *red* (21.3, .62, .34), *pink* (25.3, .39, .21), *orange* (25.6, .55, .40), *brown* (14.7, .45, .47), *deep-green* (92.0, .29, .58), *pale-green* (79.5, .30, .46), *aqua* (18.6, .22, .36), *deep-blue* (7.1, .15, .07), *sky-blue* (46.35, .21, .26), and *violet* (23.9, .26, .16).

The coloured shapes were always presented on a neutral *grey* (31.5, .30, .35) background. The shape-type and colour of each of the five items in the memory array were randomly determined on each trial with the constraint that no shape or colour was present twice within the same array. The test array always followed the memory array. In this the probe item was indicated by a radial cue (1.4° in length) which was *white* (94.8, .30, .34). The probe item was randomly selected from one of the five display items on each trial. The probe item itself either did not change, changed in colour, changed in shape or changed in both colour and shape from what it was in the memory array. Trials in which both colour and shape changes occurred were included so that if one type of change was noticed to occur this conveyed no useful information about whether or not a change had occurred on the other feature dimension.

The character of non-probe items across the memory and test arrays depended on the irrelevant change condition. In the *no irrelevant change* condition, the non-target probe items remained the same as they were in the memory array. In the *irrelevant colour change* condition, all the non-probe items in the test display changed colour from what they were in the memory array; this was done with the constraint that each item colour in the memory array was unique. In the *irrelevant shape change* condition, all non-probe items changed in shape in the test array from what they were in the memory array, with the constraint that each item was a unique shape.

*Procedure*

Each trial began with the presentation of a fixation cross, the onset of which was accompanied by a brief alerting tone. This fixation cross was initially presented for 250 ms but remained onscreen throughout the trial until the participant made a response. After the fixation cross frame the memory array was then presented 400 ms. This was followed by a 600 ms blank inter-stimulus interval (ISI). After the ISI the test array was presented for 400 ms. In the test array the probe was indicated by a radial cue. Following the test array a fixation cross frame was presented until response. A schematic depiction of the trial sequence is shown in Figure 1.

Participants were able to respond from when the test array offset. They had to respond according to whether they thought the designated type of change had occurred in the probe. Responses were made via a handheld game pad, the left trigger was assigned as 'no relevant change' and the right trigger as 'relevant change'. There were two *report conditions*. Half of the participants were allocated to the *report colour* condition, the other half to the *report shape* condition. Allocation to groups was done by a random process with the constraint that equal numbers of participants were in each group. Participants under report colour change instruction had to a report change *only if the colour of the probe item* changed between memory and test. Participants in the report shape change group had to report a change *only if the shape of the probe item* had changed between memory and test. In both cases observers were asked to emphasise accuracy and not speed of responding. Auditory feedback immediately followed the participant's response according to whether it was correct or incorrect under the given task instruction. The experiment was the same across the report conditions; the only difference was in terms of the feedback given. There were a total of 450 trials. Equal numbers of trials were given under the three irrelevant change conditions. On half the trials there was a change of some form in the probe and on the other half there was no change in the probe. On trials in which there was a change this was equally often a colour change, shape change or a change in both shape and colour. Observers were given 30 practice trials before starting the experiment.

***Insert figure 1 about here***

## Results

Responses were subject to a signal detection analysis (MacMillan & Creelman, 2004). In this analysis correct responses to trials in which a task-relevant change occurred were treated as hits. Incorrect responses to trials in which no task-relevant change occurred were treated as false alarms. The proportion of hits and false alarms for the two report conditions are given in Table 1. These are given separately for each type of *report condition* (*report colour*, *report shape*), and each of the three non-probe *irrelevant change conditions* (*none*, *colour*, *shape*). *Accuracy* ($d'$), and *response bias* ($C$) were both calculated from the hit and false alarm data. In the analysis, the issue of interest for both metrics was the effect of the two conditions in which there were irrelevant changes in the non-probes (*colour*, *shape*), compared against the respective baseline condition in which the non-probes didn't change (*none*).

***Insert Table 1 about here***

*Accuracy*

The $d'$ scores are shown separately for the two report groups (report colour, report shape) for the three respective irrelevant change conditions (none, colour, shape) in Figure 2a. From these a measure of interference was calculated separately for the two report groups by subtracting the $d'$ score of the colour and shape condition each from the no interference (none) baseline. The resulting interference scores ($d'_{\Delta}$) are shown in Fig. 2b. The analysis focused on these interference scores.

A two-way mixed ANOVA was performed on the interference scores. In this analysis *report condition* (report colour, report shape) was an independent factor and *irrelevant change* in the non-probes (colour, shape) was a repeated measures factor. *Report condition* had no significant effect, $F(1,22)=0.58$, $MS_{error}=0.142$, $p=.812$, but *irrelevant change* did, $F(1,22)=5.16$, $MS_{error}=0.049$, $p=.033$, $\eta_p^2=.19$. The *report condition* × *irrelevant change* interaction was also significant, $F(1,22)=5.90$, $MS_{error}=0.049$, $p=0.24$, $\eta_p^2=.211$. This interaction reflects the fact that the effect of the irrelevant changes in the non-probes tended to be strongest when the changes were congruent with the report condition.

*Bias*

In the response bias metric $C$, negative values indicate liberal responding (a bias towards reporting a change under uncertainty), positive values indicate conservative responding (a bias towards reporting that there was no change under uncertainty). A value of 0 indicates an unbiased observer. Bias scores were calculated separately for each of the three irrelevant change conditions.

These are displayed in Fig. 2c. The effect of non-probe interference on bias was calculated in broadly the same way as that described for accuracy. It was done by subtracting the scores in the non-probe irrelevant change conditions from those in the no irrelevant change (none) baseline. The resulting subtracted value was then negated. The negation was done so that the values were easier to interpret: for the negated difference scores positive values indicated a shift towards conservative responding and negative values a shift towards liberal responding, the same as in the raw score metric. These criterion shift values (¬CΔ) were calculated separately for the report colour and report shape groups. They are shown in Fig. 2d.

These criterion shift values are all negative. In our metric they reflect a shift towards liberal responding in the irrelevant change conditions, compared against the respective baseline no irrelevant change (none) conditions. Furthermore it can be noted that this liberal tendency was most marked when the irrelevant changes were those congruent with the report condition. A mixed 2×2 ANOVA (report condition, irrelevant change), the same as that earlier described for the $d'_{\Delta}$ scores was performed on the $\neg C_{\Delta}$ values. The analysis showed that neither main effect was significant: *report condition*, F(1,22)<0.01, $MS_{error}$<0.01, p=.996; *irrelevant change*, $F(1,22)=2.02$, $MS_{error}=0.58$, $p=.17$. However there was a significant *report condition* × *irrelevant change* interaction: $F(1,22)=18.39$, $MS_{error}=1.06$, $p<.001$, $\eta_p^2=.455$. The interaction confirms that the shift in bias tended to be greatest when the non-probe irrelevant changes in occurred on the report dimension.

***Insert Figure 2 here****

## Discussion

The presence of the non-probe irrelevant changes had a clear effect on our probe change detection task. Crucially the extent to which these irrelevant changes influenced performance depended on the relative dimension with respect to the probe change. This can be seen in the interaction between task condition and irrelevant change, an interaction found in both the accuracy and bias data. On both measures the most interference was found when irrelevant non-probe changes occupied the same feature dimension as the task-relevant change. Under these conditions sensitivity to the test-relevant change was reduced and a greater proportion of false alarms -as reflected in the shift towards a liberal criterion- were made. When these irrelevant non-probe changes occupied the non-report dimension then the effects on accuracy and bias measures were generally less marked.

Two points can be made here. The first is that irrelevant changes had some effect on performance, even when they occur on an entirely task-irrelevant dimension. The finding is consistent with several other findings in the literature (Hyun et al., 2009; Shen et al., 2013; Wascher et al. 2012). The second point is that the dimension of task-relevant changes influenced the extent of the interference found, as evidence by the interactions between report condition and non-probe irrelevant change. It should be noted that this is not just explained as a consequence of observers simply being more likely to report a change when an irrelevant change occurred on the non-probes. The fact that we obtained a significant interaction on the d-prime sensitivity measure, in addition to the bias measure, demonstrates that the change interference actually made the task-relevant changes harder to perceive.

The data from Experiment 1 is inconsistent with two of the earlier proposed accounts, the stimulus-driven attention and the single-channel noise account. The change interference observed varies according to the type of feature the observer has to report.  However Experiment 1 does not tell us why this is. It could be because of the attentional state of the observer, as the feature-selective attention account proposes. Alternatively, it could be the consequences of a lower-level process, associated with a loss of SNR in perceptual channel associated with the target feature, as the separate-channel noise account proposes. Experiment 2 was performed to try to distinguish between these two remaining accounts.

## Experiment 2

In Experiment 2, feature-selective attention was manipulated in two ways. It was manipulated by requiring an observer to report about a colour change, or a shape change, on a particular trial. It was also manipulated by varying, within the trial, when the observer was told what the report dimension was. To achieve this, the report dimension was made to vary randomly from trial to trial, rather than being the same across all trials as it was in Experiment 1. An auditory verbal *task cue* informed the observer about the report dimension on a particular trial (report colour, report shape). The temporal position of the task cue was varied; this was done across two across two sub-experiments: Experiment 2a and Experiment 2b. In Experiment 2a the task cue was given before the trial stimulus sequence; in Experiment 2b the cue was presented at the end of the sequence. Thus in Experiment 2a observers knew the task-relevant feature dimension before the change occurred, in Experiment 2b they did not.

If voluntary attention is a relevant factor in mediating change interference, as the feature-selective attention account states, then Experiment 2a and 2b should produce fundamentally different interference patterns. In Experiment 2a the task conditions are effectively the same as in Experiment 1: observers knew the relevant change dimension prior to the beginning of the trial, and can therefore selectively focus their attention on the goal-relevant dimension before the change occurred. Thus, Experiment 2a should replicate the same basic interference pattern of Experiment 1. Specifically, non-probe irrelevant changes should affect performance most when these are congruent with the report dimension on the trial.

Experiment 2b was the critical experiment. Here the observer was unable to prioritise the feature dimension prior to changes being presented. Consequently if the expected interaction in Exp. 2a occurs because of feature-selective attention then then the interaction should be abolished in Exp 2b. If the attentional manipulation across the two sub-experiments fails to have any effect on change interference, then it would be evidence against the feature-specific attention account, and evidence in support of the separate channel noise account.

## Method

### Participants

There were 30 participants (24 female) in Experiment 2. Half the participants were allocated to Experiment 2a and the other half to Experiment 2b. A random process was used to achieve this allocation. Participants were selected with the same inclusion criteria described for Experiment 1 with the additional constraint that none had taken part in the first experiment.

### Stimuli and procedure

The auditory task cue was a recording of a synthetically-generated female human voice articulating either the word ‘colour’ or ‘shape’. The sound files (.wav) associated with these cues were software-generated[3]. The cue was presented through the loudspeakers located at either side of the computer monitor. The cues instructed the participant which change dimension they had to report regarding the probe item. On *report colour* trials observers were required to report if the probe changed in colour. On such trials observers were instructed to report ‘yes’ only if the probe changed in colour ( they had to respond ‘no’ if the probe changed only in shape or didn’t change at

[3] . These stimuli were generated offline from http://www.fromtexttospeech.com. The ‘British female’ voice option ‘Rachel’ selected with the generate speech rate set to ‘medium’ speed).

all). *On report shape* trials observers were required to report if the probe had changed in shape. On such trials they had to report 'yes' only if the probe change in shape (they had to respond 'no' if the probe changed in colour or didn't change at all). They had to respond 'no' on trials in which the probe only changed in colour or did not change at all. The same number of report colour and report shape trials was given in the experiment. These were given in a random order. Report colour and report shape trials occurred in one of three non-probe irrelevant change: none, colour, shape. On no interference trials (none) the non-probe items remained the same across memory and test, on colour trials the non-probes changed in colour, on shape trials the non-probes changed in shape across memory and test.

In Exp. 2a the report cue was presented with the onset of the fixation cross; in 2b the cue was presented with the offset of the memory array. Immediate auditory feedback was given following the participant's response. The displays in the memory and test arrays each contained three items, one of which was the probe. In the test array the probe was indicated by a radial cue. The reason for having three items rather than five, as in the previous two experiments was a consequence of the difficulty of the task. A pilot experiment showed found that accuracy tended to be markedly lower in than in the previous two experiments with five item displays leading to floor effects in some conditions. The reduced performance presumably reflects the additional demands of the experiment in terms of the trial-to-trial variability of the required task. With displays containing five items it was found that performance was at or near chance in most conditions. As a consequence, displays were reduced to three items to bring performance into a measurable range without introducing ceiling effects. Other than the difference in set size, the visual displays were the same as in Experiment 1.

## Results

### Experiment 2a (pre-cue)

The same signal detection analysis was performed as described for the earlier experiments. The results for both the accuracy and bias data are presented in Figure 3. The proportion of hits and false alarms for the factoriallly-combined conditions are given in Table 2.

***Insert Fig. 3 about here***

***Insert Table 2 about here***

*Accuracy*

A 2×2 repeated measures ANOVA was performed on the interference data for the d-primes (fig 4b). The two factors were *report condition* (report colour, report shape), and non-probe *irrelevant change* (colour, shape). The analysis found neither main effect to be significant: report condition, $F(1,14)=1.51$, $MS_{error}=0.174$, $p=.239$, *irrelevant change*, $F(1,14)=0.70$, $MS_{error}=0.248$, $p=.417$. There was however a significant *report condition* × *irrelevant change* interaction, $F(1,14)=11.38$, $MS_{error}=0.185$, $p=.005$, $\eta_p^2=.448$.

*Bias*

A 2×2 repeated measures ANOVA was performed for the criterion data (¬CΔ). These two factors again were *report condition* and *irrelevant change*. Neither main effect was significant: *report condition*, $F(1,14)=2.67$, $MS_{error}=0.084$, $p=.124$, *irrelevant change*, $F(1,14)=0.30$, $MS_{error}=0.045$, $p=.592$. However the *report condition* × *irrelevant change* interaction was significant, $F(1,14)=28.69$, $MS_{error}=0.88$, $p<.001$, $\eta_p^2=.672$.

Experiment 2b (post-cue)

The results of the signal detection analysis are presented in Figure 4. The proportion of hits and false alarms for the factoriallly-combined conditions are given in Table 3.

.

***Insert Fig. 4 about here***

***Insert Table 3 about here***

*Accuracy*

The same 2×2 ANOVA analysis was used as described for Experiment 2a. No main effect of *report condition* was found, $F(1,14)=1.66$, $MS_{error}=0.198$, $p=.219$, but there was a main effect of *irrelevant change*, $F(1,14)=20.18$, $MS_{error}= 0.082$, $p<.001$, , $\eta_p^2=.590$. The *report condition* × *irrelevant change* interaction was significant $F(1,14)=15.242$, $MS_{error}=0.011$, $p=.002$, $\eta_p^2=.521$.

*Bias*

A 2×2 repeated measures ANOVA was performed for the change in criterion data (¬CΔ). These two factors again were *report condition* and *irrelevant change*. Neither main effect was significant: *report condition*, $F(1,14)=2.63$, $MS_{error}=0.122$, $p=.616$, *irrelevant change*, $F(1,14)=2.85$, $MS_{error}= 0.042$, $p=.113$. However the *report condition* × *irrelevant change* interaction was significant, $F(1,14)=46.29$, $MS_{error}=0.56$, $p<.001$ $\eta_p^2= .768$.

*Comparison of Experiment 2a and 2b*

To look at the effect of cue position an omnibus ANOVA was conducted incorporating the data from Exp 2a and 2b. In this analysis a three way mixed ANOVA was conducted. The analysis had two repeated measures factors, *report condition* and *irrelevant change*, and one independent measures factor, *cue position* (pre-cue [Exp. 2a], post-cue [Exp. 2b]). The ANOVA found a near significant main effect for *report condition*, $F(1,28)=3.17$, $MS_{error}=0.209$, $p=.086$, $\eta_p^2= .102$, a significant main effect for *irrelevant change*, $F(1,28)=8.78$, $MS_{error}=0.165$, $p=.006$, $\eta_p^2= .239$, and a significant *report condition* × *irrelevant change* interaction, $F(1,28)=25.50$, $MS_{error}=0.147$, $p<.001$, $\eta_p^2= .477$. The independent variable *cue position* variable had no main effect ($F=0.48$, $MS_{error}=0.580$, $p=.496$, and did not interact with any other variable, (largest $F=2.28$, $p = .142$). Furthermore the three way interaction between all factors (*cue position* × *report condition* × *irrelevant change*) was also not significant, $F(1,28)=0.15$, $MS_{error}=0.147$, $p=.754$. Therefore the manipulation of task cue position across Exp. 2a and 2b had no statistically discernible effect on the interference pattern obtained in terms of the accuracy data.

The same omnibus ANOVA analysis described above for the accuracy interference data (Δd') was also performed on the change in bias (¬CΔ) data. In this analysis neither of the main effects were significant, *Report condition* $F(1,28)=0.42$, $MS_{error}=0.103$, $p=.552$, *irrelevant change*, $F(1,28)=2.46$, $MS_{error}=0.043$, $p=.128$. The *Report Condition* × *irrelevant change* interaction was significant, $F(1,28)=71.01$, $MS_{error}=0.072$, $p<.001$, $\eta_p^2=.717$ . The independent variable cue position had no main effect, $F(1,28)=0.49$, $MS_{error}=0.110$, $p=.827$, nor did it interact with any other factor individually (largest $F=2.463$, $p=.128$). Furthermore the three way interaction (*cue position* × *report condition* × *irrelevant change*) was not significant, $F=0.002$, $MS_{error}=0.072$, $p=.968$.

Because none of the interactions with task were significant further comparisons were done between the Exp. 2a and 2b data sets. Specifically performance in the baseline no irrelevant change (none) condition was compared for the two performance measures: $d'$ and $C$. A 2×2 mixed ANOVA (*report condition* × *cue position*) was done to analyse these. For d-prime no main effect of *cue position* was found ($F=1.074$, $p=.309$, nor any *report condition*× *cue position* interaction, $F=0.197$, $p=.661$). For $C$ there was no main effect of *cue position* ($F=0.357$, $p=.555$), however there was a significant *report condition* × *cue position* interaction ($F=4.73$, $p=.038$, $\eta_p^2=.144$). The interaction reflects the fact that with the post-cue experiment (2b) the adopted criterion level in the baseline condition was almost the same value for report colour and shape; however for the pre-cue experiment (2a) there is a notably more conservative criterion adopted when reporting shape compared to reporting colour.

**Discussion**

The same interference occurred irrespective of whether or not the observer knew the relevant dimension prior to the change. Importantly, this was the case for both the sensitivity and bias measures of performance. Thus, the selective effects we found for change interference were not ones associated with attention.

## General discussion

Our interest was in understanding the circumstances in which change interference from irrelevant objects affect change detection performance.  Across the experiments, the basic finding was that these non-probe irrelevant changes tended to interfere most when the changes occupied the same feature dimension as the task-relevant change. However, attentional processes did not seem to be responsible for this interference pattern. Experiment 2 attests to this. Here broadly the same 'crossover' interference pattern was obtained irrespective of whether or not the observer's attention was directed to the task-relevant dimension at the time the changes occurred.

The repeated interaction found between the type of relevant and irrelevant change is evidence against the stimulus-directed attention account, and the single-channel noise account, we proposed earlier. Furthermore, the absence of any obvious effect of top-down attention on interference suggests against the proposed feature-selective attention account.

This leaves the separate-channel noise account as the one we think is most consistent with our experimental results. In this account change interference occurs within feature-selective processing channels, either prior to, or in the absence of, dimensional attentional selection. The interference occurs during an initial comparison process in which perceptual mismatches between the pre- and post-change scene generate transient change signals within the visual system.

On this account the appearance of the post-change array instigates a reflexive and parallel comparison process with representations in VSTM derived from the pre-change array. Any mismatch that is detected between the viewed post-change array and the mnemonic representation of the pre-change array will generate a transient change signal in the visual system (Hyun et al., 2009; Yin, Zaifeng & Xinyi et al., 2011). The parallel-reflexive nature of the comparison process means that the analysis of changes occurs for all items, not just the task-relevant probe. In the comparison process our results suggest that the change signals associated with different perceptual features, such as colour and shape, are segregated in separate channels. Where irrelevant changes occur on the same feature dimension as the task relevant change they substantially increase the noise level in the channel associated with the task relevant change, leading to the task-relevant change signal from the probe having a reduced SNR (Jiang et al. 2000; Stevens, 1975). The loss of SNR has the consequence of reducing the observer's sensitivity to the task-relevant change. When the irrelevant changes are of a different perceptual type, the contribution to noise within the relevant monitored perceptual channel is lower, and the effect on performance is less marked.

*Change perception and response bias*

Our most important result is that the effect of change interference on our *sensitivity* to a task-relevant change. It shows that change interference affected the perceptual quality of the probe changes. However, our results also show that the irrelevant changes also influenced how *biased* observers were in their responding to the probe change. The no interference trials showed a general tendency towards conservative responding. The tendency probably reflects the fact that task relevant changes in the probe occurred on fewer than half the trials. More interesting, is the fact that responding became more liberal when irrelevant changes occurred. Importantly this liberal shift was most marked when the irrelevant changes occurred on the report dimension. The selectivity of this effect on bias can be understood within the within-channel interference account. When the task requires monitoring of a specific feature channel then irrelevant change signals from the non-probe items may sometimes be incorrectly classified as having occurred in the probe itself. As a consequence the likelihood of a false alarm response was increased. Irrelevant changes on a non-report dimension would have less influence on the false alarm rate because their signals affect a perceptual channel which was being ignored under the task instruction.

Differential response bias was also found with respect to the two report dimensions. Specifically there was a tendency to be more conservative when responding to shape changes than colour changes in the probe item. The pattern of data across the experiments suggested that this increased conservative bias for shape changes only occurred when observers knew the report dimension prior to the changes occurring. This can be seen most clearly in the baseline no interference conditions across the experiments. For Exp. 1 and Exp. 2a –experiments where the observer knew the dimension they needed to report on the upcoming trial- this larger conservative bias for shape was evident  in the no interference condition. For Exp 2b. the bias for reporting shape and colour is similarly modestly conservative for the same no interference condition. It is difficult to speculate what the underlying reason is for this without further investigation. However a plausible explanation is that  the differential bias is the consequence of a strategic decision of the observers. It may be that the shape change task was considered by observers as the more difficult of the two; because of this, when observers had prior information that they must report about shape (Exp. 1, Exp 2a) they tended to adopt a more conservative threshold for detection of a change. When the report judgement is retrospective (Exp 2b) then this a-priori criterion shift could not be made, the consequence of this is that the degree of bias became similar for the two dimensions. It would be interesting to test this possibility more directly by giving observers information a priori information about the difficulty of detecting the target change on certain trials and determining how this affects bias compared to when no such prior information is given. The factors governing these sorts of criterion adoption and response bias remains an under-explored area in change detection research.

*Understanding change interference*

It is useful to consider our findings regarding the effects of change interference in terms of the change perception architecture given by Hyun et al. (2009), and described earlier in this paper. To reiterate, Hyun and colleagues essentially propose a two-stage model of change detection. In the first stage VSTM representations are compared reflexively and in parallel with current visual input from the post-change display. The process generates change signals associated with mismatches identified by the comparison, but such signals alone are viewed as insufficient for the change to be consciously perceived. Then, a second, limited-capacity attentional stage serves to give additional processing to the target location to verify the presence of a change at the location and verify that the change is of a type relevant to current goals.

Based on our results, we would accept a modified version of this model. In this modified version different types of feature change result in distinct transient signals which are segregated within the visual system. A second modification we would propose concerns the role of attention. We would view that attention can play different roles depending on the nature of the change detection paradigm involved. In the paradigm given by Hyun et al., task-irrelevant changes always occurred on a task-irrelevant dimension. Consequently, the task-relevant change was always defined by its dimension alone in their study; if the task was to report a colour change the observer had to only decide whether a colour change had occurred somewhere in the display. Under such circumstances it is likely that focused attention would be guided towards the locus of the colour change by weighting the change signal information derived from the comparison process towards the colour dimension (Wolfe, 1994). Consistent with this, Hyun and colleagues reported that relevant change signals tended to influence the observer’s recorded eye movements (Hyun et al., 2009).

In our task, the task-relevant change was not defined only by its dimension, but by a conjunction of dimension and explicitly defined spatial location. Attention is therefore likely to play a somewhat different role in our task. In particular, change signals would play a more limited role in initially guiding attention towards the relevant change location than it did in Hyun et al. This is because attention is already exogenously and endogenously directed towards the relevant location by the presence of our radial probe. We consider that in our paradigm the main role for attention will be in maintaining task set; that is, in mapping the output of the appropriate perceptual decisions associated with the stimulus comparison process with the corresponding behavioural response according to the task instructions or task cue (Chiu & Yantis, 2009; Mackie, Van Dam & Fan, 2013). Our results suggest that manipulation of this task set has few consequences for perception of changes of vulnerability to change interference, at least as far as we are able to discern from our behavioural measures.

*Spatial extent of within-channel interference*

We have identified the importance of feature dimension in change interference. It is reasonable to ask what other sorts of factors might be important. One potential candidate may be the respective spatial distance between the relevant and irrelevant changes in a display. It is possible that interference effects diminish monotonically with distance from the interfering changes, that is in a similar manner to the monotonic decline seen for other interference effects such as visual crowding (Levi, 2011), or flanker effects (Eriksen, 1994). However, it also possible that change interference is independent, or largely independent of the distances between the probe change and irrelevant non-probe changes. Provisional work in our lab in which we have varied this spatial distance has given some initial support to the independence account.[4] If this were confirmed by further work it would indicate that change signals in the brain, though segregated by feature, are not

[4]We have done some preliminary work to try to address the question. We presented displays in which two irrelevant probe changes occurred. No effect was found of whether the irrelevant non-probe changes were presented at locations which flanked the target or ones opposite the target within a circular array. However the range of tested spatial distances was rather small and limited by the possible circumferential distances on the given circular array. It could be that spatial distance effects are more evident when a larger range of distance values within the display are compared.

spatiotopically organised.[5] We suspect, however, that the interference will diminish to some extent when the spatial distances between the probe and non-probe are large enough. We are currently investigating this issue further.

*Feature-selective attention and change interference*

Taken together the three experiments suggest that change interference is a bottom-up process which occurs independently of the attentional state of the observer (*cf*. Rensink, 2000; Schankin & Wascher, 2008). If feature-selective attention was having any effect, it was very modest in nature, and insufficient for our experiments to reveal it.[6] However our results can only reasonably be considered to attest to the circumstances of our specific paradigm. The possibility remains open that feature-specific attention might mediate change interference effects in a robust manner under different task conditions.

If possible, we suspect that such conditions would have to be ones very different to our current experiments. We referred earlier to the contingent capture paradigm (Folk et al., 1992, Lien et al., 2008). This paradigm is one in which top-down attentional capture effects seem to most reliably operate. There are at least two fundamental differences between our experiments and those of the contingent capture paradigm. These may be critical. One key difference with the current experiments is the fact that the contingent capture paradigm typically has a search component, the target has to be located from within a set of (typically four) distractor positions. Our experiments

[5] Even if not spatiotopically organised change signals generated in the comparison process must encode the location of the change event in some way. Were this not the case then they would not guide eye movements in the way they seem to (Hyun et al., 2009), and, more directly, an observer would find it impossible to discern the change in the -spatially defined- probe item from changes in the non-probes in our task.

[6] The interaction between report condition and the type of irrelevant change in the non-probes did persist across Experiment 2a and 2b. However, the interference patterns across these experiments, while not statistically different, are somewhat different when visually compared. This is particularly true for the d-primes. Here the effect of irrelevant change variable is clearly more pronounced for the report shape condition in Exp 2a, than the same condition in Exp. 2b. The fact may indicate that feature-selective attention did play some small role in change interference, but one which our experiments did not have sufficient power to identify. Further study would be needed to test this possibility.

had a non-search task: the target probe item, though varying in location, was always defined in the array by a spatial cue. The presence of the cue may mean that the focus of spatial attention, a key aspect of contingent capture, is unaffected by the irrelevant changes. A second difference of our experiments from the contingent capture paradigm is in the temporal sequence of the events. In the contingent capture paradigm the interfering stimuli are typically presented some 200 ms prior to the to-be-detected event, the key manipulation being whether the target item and the irrelevant item occur in the same or different locations in the two displays. Our experiments had a rather different sequence of events. Our experiments follow other studies of change interference in having the relevant and irrelevant changes occurring simultaneously with one another (Jiang et al., 2000; O'Regan et al., 1998; Rensink, 2000; Hyun et al. 2009; Jiang et al., 2004; Schneider et al. 2012; Washer et al. 2012; Shen et al., 2013).

The fact that relevant and irrelevant changes occurred simultaneously in our paradigm may, in particular, explain why we failed to observe any top-down attentional effects. Belopolsky, Schreij and Theeuwes (2009) argue that top-down attentional set determines the efficiency with which attention is disengaged from the location of irrelevant stimulus events *after* such events have been registered by the visual system. This means that top-down attentional settings tend to influence the processing of stimuli which follow the presentation of the irrelevant stimuli. Indeed Belopolsky et al. argue that top-down attention has no reliable effect in circumstances where the target item occurs simultaneously with the irrelevant items or events. Their claim is that the initial feedforward sweep of information through the visual system associated with a perceptual event is entirely stimulus governed and that top-down control only manifests itself in terms of the effects on the processing of subsequent stimulus events (Belopolsky et al. 2009; Theeuwes, Atchley & Kramer, 2000).

There are some studies involving change interference which have presented conditions which more closely match to the conditions of the contingent capture paradigm (von Mühlenen, Rempel, & Enns, 2005; von Mühlenen & Conci, 2016). For instance, von Mühlenen et al. (2005)

presented a preview display consisting of a several placeholders arranged around a central fixation point. The preview display was then followed by a search array in which a letter occupied each placeholder position. The task was to report the identity of a target letter in the search array. In one condition an irrelevant change occurred in one of the placeholders. For instance, one of the placeholders might briefly change in colour 150 ms prior to the search array onset. The general finding was that these preceding irrelevant changes tended to disrupt the following search task.

It would certainly be possible to modify the previously described paradigm to explore the effect of top-down attention on change interference under these conditions, where the irrelevant and relevant changes occur in different time frames. Our results certainly do not rule out the possible existence of such attentional-mediated capture under these alternative conditions. What we do suspect, however, is that feature-selective attention has little role in circumstances akin to the current experiments -and almost all other experiments involving change interference-where task-relevant and irrelevant changes are placed in simultaneous competition with each other (e.g. Hyun et al., 2009; Jaing et al 2000; O'Regan et al., 1999; Rensink, 2000; Schneider et al., 2012).

We will make one last point concerning our paradigm. We should not that in our paradigm irrelevant changes occurred not just in the non-probes, but on certain trials in the probe itself. These irrelevant changes in the probe were a necessary component of our experiment in order to pursue the questions we asked. These irrelevant probe changes arguably complicate interpretation of our results. However we do not think that they have any bearing on the interpretation of change interference that is given. Observation of the hit and false alarm data from the experiments show that the presence of irrelevant changes in the probe tended to bias the observer towards responding that a change had occurred. However, despite this the effect of the non-probe changes produced a similar pattern for trials in which there was a task-irrelevant change and trials in which the non-probes did not change.

## Conclusion

Our results suggest that, rather than being attention-mediated, change interference is better understood as a consequence of sensory noise emerging from the non-probe changes. This sensory noise degrades the quality of the change signals emerging from the probe itself. We think that this sensory noise, associated with change transients, tends to be segregated within feature-specific channels leading to greater change interference effects when the non-probe irrelevant changes are of the same feature type as the to-be-reported change. Though our results found no discernible effect of attention, we think that attention might be important in mediating change interference in other circumstances, particularly ones in which the interfering changes are ones which proceed the target change within the stimulus sequence.

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**Tables**

Table 1. Mean proportion of hit (p[Hit])and false alarm (p[FA]) responses in Experiment 1. These are shown according to target status and non-probe interference for the two report conditions.

| **Report condition** | **Target change** | **Interference** | | |
|---|---|---|---|---|
| | | None | Colour | Shape |
| Report colour | Change on both dimensions: p(Hit) | .58 | .68 | .57 |
| | Change on relevant dimension only : p(Hit) | .52 | .64 | .60 |
| | Change on irrelevant dimension only: p(FA) | .27 | .52 | .32 |
| | No change: p(FA) | .19 | .47 | .28 |
| Report shape | Change on both dimensions: p(Hit) | .52 | .54 | .58 |
| | Change on relevant dimension only : p(Hit) | .39 | .46 | .56 |
| | Change on irrelevant dimension only: p(FA) | .18 | .32 | .34 |
| | No change: p(FA) | .12 | .22 | .30 |

Table 2. Mean proportion of hit (p[Hit])and false alarm (p[FA]) responses in Experiment 2a. These are shown according to target status and non-probe interference for the two report conditions.

| **Report condition** | **Target change** | **Interference** | | |
|---|---|---|---|---|
| | | None | Colour | Shape |
| Report colour | Change on both dimensions: p(Hit) | .78 | .81 | .76 |
| | Change on relevant dimension only : p(Hit) | .71 | .75 | .71 |
| | Change on irrelevant dimension only: p(FA) | .15 | .35 | .17 |
| | No change: p(FA) | .09 | .29 | .13 |
| Report shape | Change on both dimensions: p(Hit) | .66 | .72 | .78 |
| | Change on relevant dimension only : p(Hit) | .61 | .65 | .70 |
| | Change on irrelevant dimension only: p(FA) | .14 | .18 | .36 |
| | No change: p(FA) | .08 | .13 | .23 |

Table 3. Mean proportion of hit (p[Hit])and false alarm (p[FA]) responses in Experiment 2b. These are shown according to target status and non-probe interference for the two report conditions.

| **Report condition** | **Target change** | **Interference** | | |
|---|---|---|---|---|
| | | None | Colour | Shape |
| Report colour | Change on both dimensions: p(Hit) | .77 | .82 | .79 |
| | Change on relevant dimension only : p(Hit) | .62 | .76 | .71 |
| | Change on irrelevant dimension only: p(FA) | .11 | .38 | .16 |
| | No change: p(FA) | .09 | .34 | .10 |
| Report shape | Change on both dimensions: p(Hit) | .69 | .71 | .81 |
| | Change on relevant dimension only : p(Hit) | .62 | .65 | .76 |
| | Change on irrelevant dimension only: p(FA) | .17 | .27 | .36 |
| | No change: p(FA) | .12 | .16 | .26 |

## Figure headings

**Figure 1.** A schematic depiction of a trial in Experiment 1. In the example the probe item (indicated by the radial cue) changes in colour (from light brown to black). Examples of each of the three non-probe irrelevant change conditions are given: colour (left); none (middle); shape (right).

**Figure 2**. Results from Experiment 1. Accuracy (d') is given for each of the irrelevant change conditions, and separately for the report colour and report shape groups in Figure 2 (A). The interference scores ($d'_{\Delta}$) for the report colour and report shape groups are given in Figure 2 (B). The response bias scores ($C$) for each of the irrelevant change conditions is given separately for the report colour and report shape groups in Figure 2 (C). The change in bias scores ($\bar{C}_{\Delta}$) are given in Figure 2 (D).

**Figure 3.** Results from Experiment 2a. Accuracy (d') is given for each of the irrelevant change conditions in Figure 3 (A). The interference scores ($d'_{\Delta}$) are given in Figure 3 (B). The response bias scores ($C$) are given in Figure 3 (C). The change in bias scores ($\bar{C}_{\Delta}$) are given in Figure 3 (D).

**Figure 4.** Results from Experiment 2b. Accuracy (d') is given for each of the irrelevant change conditions in Figure 4 (A). The interference scores ($d'_{\Delta}$) are given in Figure 4 (B). The response bias scores ($C$) are given in Figure 4 (C). The change in bias scores ($\bar{C}_{\Delta}$) are given in Figure 4 (D).

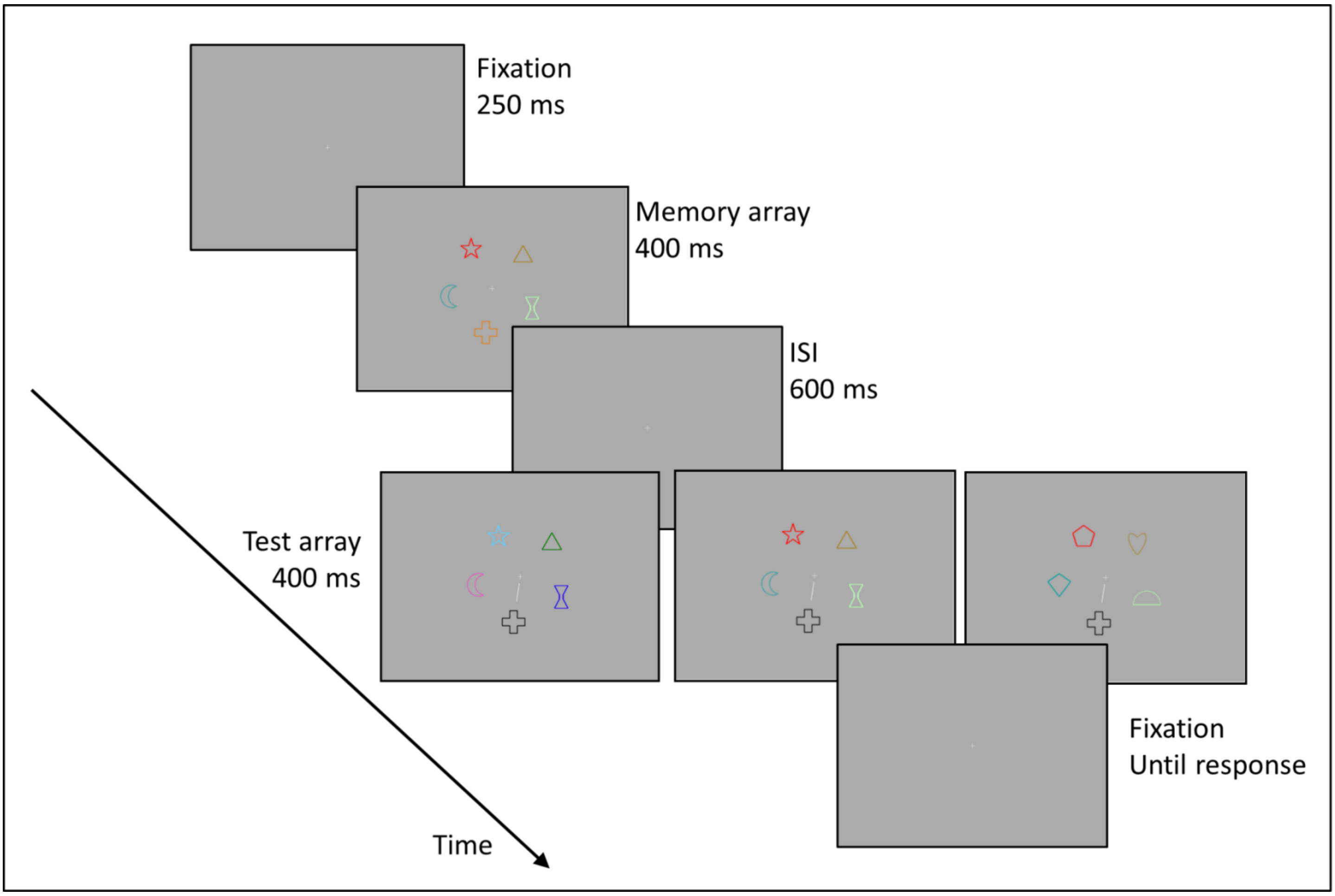
Fixation
250 ms
Memory array
400 ms
ISI
600 ms
Test array
400 ms
Fixation
Until response
Time

Figure 1.

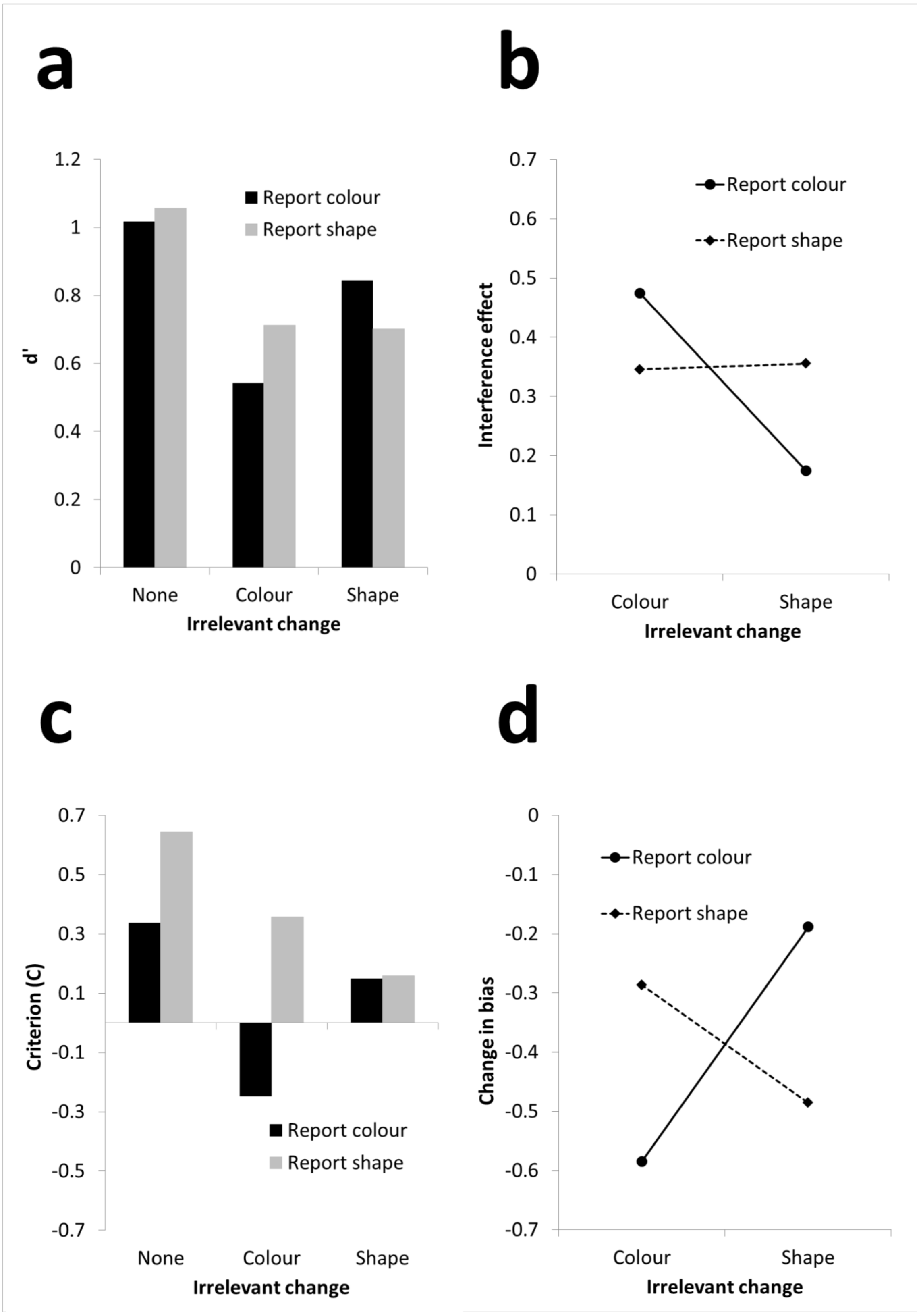
a
1.2
1
0.8
0.6
0.4
0.2
0
d'
Report colour
Report shape
None
Colour
Shape
Irrelevant change
b
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Interference effect
Report colour
Report shape
Colour
Shape
Irrelevant change
c
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
-0.7
Criterion (C)
Report colour
Report shape
None
Colour
Shape
Irrelevant change
d
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
Change in bias
Report colour
Report shape
Colour
Shape
Irrelevant change

Figure 2.

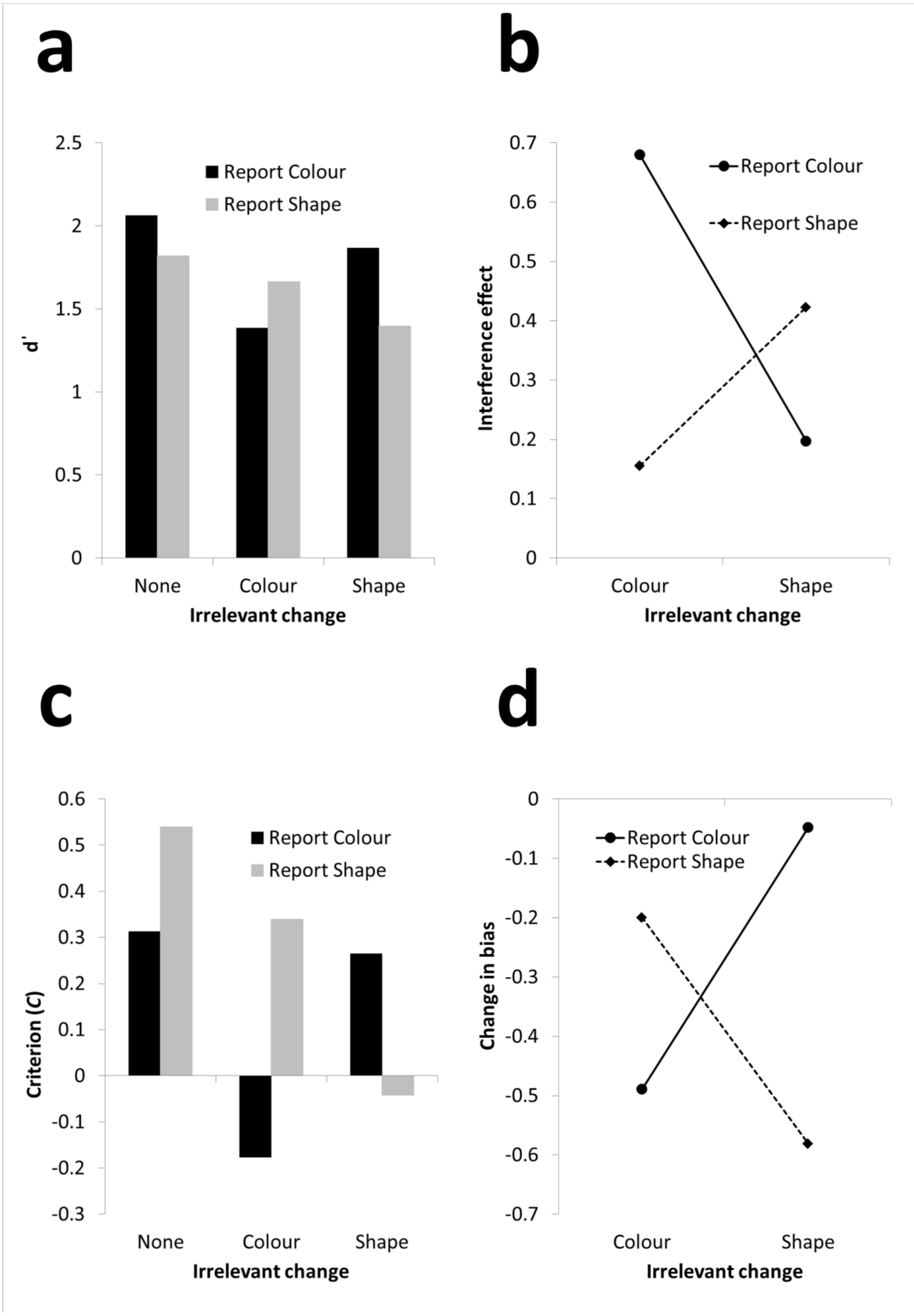
a
b
c
d
2.5
2
1.5
1
0.5
0
d'
Report Colour
Report Shape
None
Colour
Shape
Irrelevant change
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Interference effect
Report Colour
Report Shape
Colour
Shape
Irrelevant change
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Criterion (C)
Report Colour
Report Shape
None
Colour
Shape
Irrelevant change
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
Change in bias
Report Colour
Report Shape
Colour
Shape
Irrelevant change

Figure 3.

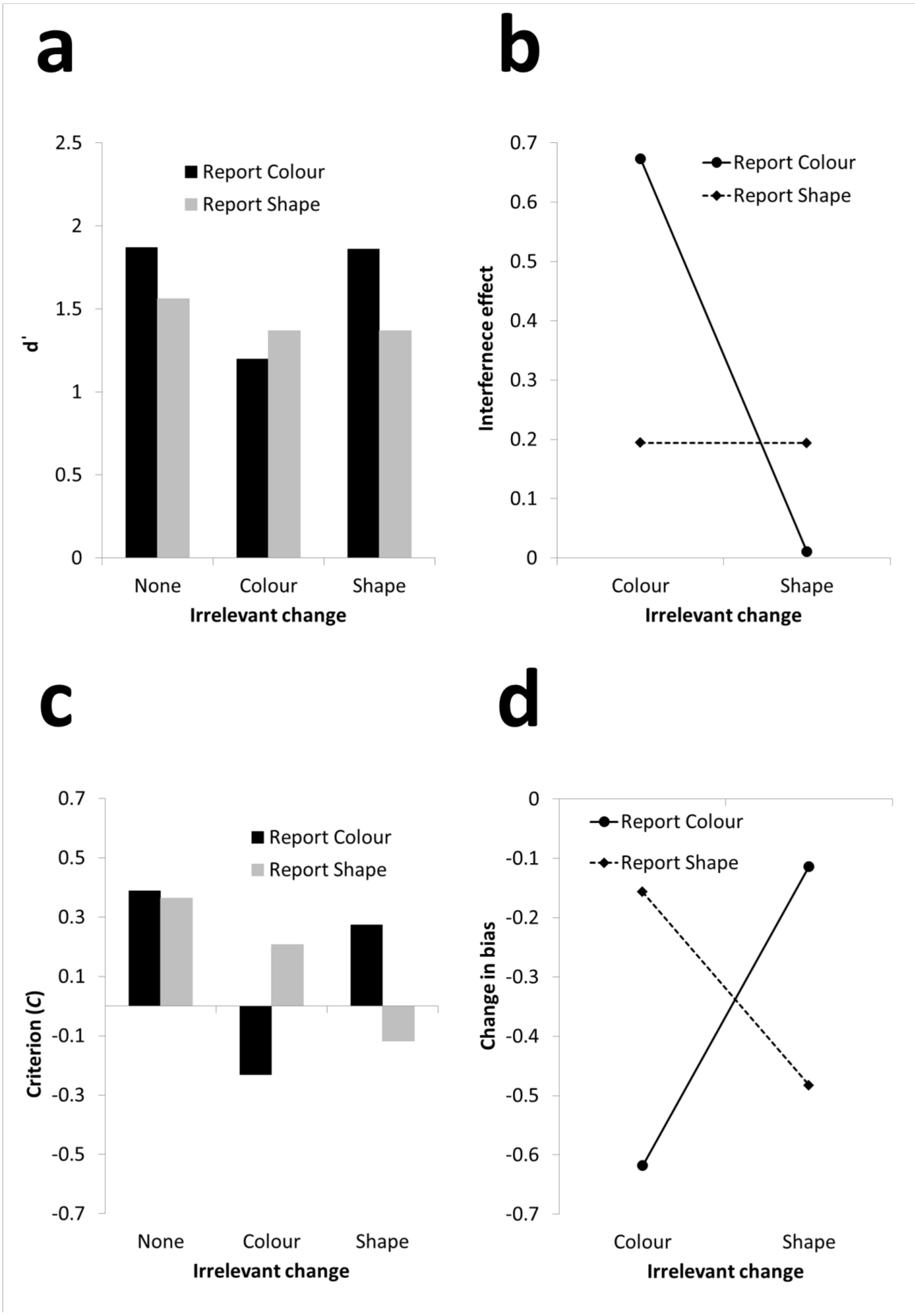
a
2.5
2
1.5
1
0.5
0
d'
Report Colour
Report Shape
None
Colour
Shape
Irrelevant change
b
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Interfernece effect
Report Colour
Report Shape
Colour
Shape
Irrelevant change
c
0.7
0.5
0.3
0.1
-0.1
-0.3
-0.5
-0.7
Criterion (C)
Report Colour
Report Shape
None
Colour
Shape
Irrelevant change
d
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
Change in bias
Report Colour
Report Shape
Colour
Shape
Irrelevant change

Figure 4.