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The influence of absolute and relative spatial cues on change detection performance

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ABSTRACT

Two experiments investigate how absolute and relative spatial cues influence perceptual comparisons between visual short-term memory (VSTM) and current vision. The core question concerned the role of task demands in this process. Two tasks were given across two experiments, differing in the extent they required object-level comparisons. Experiment 1, a feature comparison task, required reporting if any new colour was present in the second of two interleaved displays of four colours inside a surround; Experiment 2, an object comparison task, required report of any changes in colour-shape pairings in the second of two interleaved displays of four coloured shapes in a surround. Absolute and relative spatial organization was manipulated in both experiments by presenting compared displays on the same or contralateral sides, and by having the second display items in the same locations within the surround, in new locations, or repositioned into previous locations of other items. In sensitivity, both tasks showed an advantage for absolute spatial cues, but only the object task showed an advantage for relative spatial cues. In bias, both tasks were similarly influenced by both absolute and relative cues. Results suggest relative spatial cues are always available but only used when making object-level comparisons.

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Change detection; visual short-term memory; implicit spatial organization; perceptual comparisons; object-level processing

Visual short-term memory (VSTM) is the limited-capacity memory system associated with robust storage of visual information over periods up to several seconds (Luck, 2006). VSTM plays an important role in allowing the visual system to compare information separated over space and time (Hyun et al., 2009; Luck, 2006; Scott-Brown et al., 2000). This comparison function of VSTM supports our ability to notice visual changes in our environment when they occur across brief disruptions e.g., eye-blinks, saccades, occlusions from proximal stimuli. Indeed, studies of VSTM often use change detection performance as an operational measure of VSTM (Rensink, 2002). In the standard version of the change detection paradigm (Luck & Vogel, 1997; Pashler, 1988) two displays, memory and test, are presented in sequence, interleaved by a brief pattern mask or long (>500 ms) blank interval to rule out iconic memory involvement (Phillips, 1974); task instructions require report of whether a specified type of change has occurred or not.

An important question concerns the basis on which the visual system maps between VSTM-held information and current viewed input to make comparisons, such as about the presence of a change, across successive glances (Hyun et al., 2009). It is broadly accepted that VSTM representations are predominantly spatial in organization, wherein items are structured according to their positions in the initially observed scene or display (Brady et al., 2011; Luck, 2006; Tsal & Lamy, 2000); research further suggests that these spatial cues play a significant role in determining how VSTM representations are compared with current visual input (Hyun et al., 2009; Pilling et al., 2020; Rensink, 2002; Udale et al., 2018a; Udale et al., 2018b; Treisman & Zhang, 2006; Tam & Wyble, 2023; cf. Woodman, Vogel & Luck, 2012). However, the full nature of spatial encoding of items in VSTM is less clear, as is the question of how such retained spatial information guides perceptual comparisons.

It is possible that the comparison of VSTM-held items with current vision is mainly guided by

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mapping of retained absolute locations in the visual field of individual test items with those in the viewed memory display (Hollingworth, 2006; Hyun et al., 2009; Rensink, 2002). However, a further possibility is that VSTM encodes the relative (allocentric) structure of items in a display, and that such cues – either additionally or alternatively – are used in a spatial mapping process between memory representations and current vision (Burgess, 2006; Jiang et al., 2000). Allocentric spatial relationships are certainly likely to be useful in comparisons because, the visual system often needs to track visual elements which are spatially displaced over time e.g., due eye movements, motion of the viewer or in the environment (Aagten-Murphy & Bays, 2018; Woodman et al., 2012), or when comparing adjacent visual patterns (Huang, 2010; Scott-Brown et al., 2000). The current paper tries to understand the circumstances in which absolute and allocentric location cues are utilized in VSTM-mediated comparisons.

Changes to features or object identity are usually harder to notice when the compared items are in different, randomly selected, screen location across memory and test, compared to when the items retain the same screen positions, even though location is irrelevant to the judgement (Hollingworth, 2006; Hollingworth & Rasmussen, 2010; Pertzov & Husain, 2014; Pilling et al., 2020; Treisman & Zhang, 2006; Udale et al., 2018a). For instance, Pilling et al. (2020), in one experiment, presented a memory display consisting of four coloured disks, each in a unique screen location, followed after a 500 ms interval by a test display also consisting of four coloured disks. On half the trials the memory and test items retained the same screen positions, on the other half of trials all the test items were presented in new, previously unoccupied, positions; on half the trials of each of these two location conditions at least one of the items changed colour. Results showed that participants were substantially less sensitive to the occurrence of colour changes when item locations were different across the two displays, this was despite the task irrelevance of location and explicit instructions to ignore it.

Evidence suggests that such effects of irrelevant location indicate the operation of an initial stage in the perceptual comparison process in which, on presentation of the test display, there is an obligatory point-to-point mapping of items represented in a

VSTM with corresponding locations in the currently viewed test display (Gilchrist & Cowan, 2014; Hyun et al., 2009; Yin et al., 2011). In this initial automatic comparison, the resulting feature-mismatch between VSTM and current input on change trials generates perceptual transients at change locations which alerts spatial attention and brings the feature change into awareness (Hyun et al., 2009).

Other work suggests that VSTM can additionally use cues regarding the *allocentric* (relative) structure of remembered items in the comparison process, and that this can assist change detection in circumstances where such relative spatial relationships between items are retained across memory and test, where absolute spatial relationships are not maintained (Jiang et al., 2000; Olson & Marshuetz, 2005; Sapkota et al., 2011; Treisman & Zhang, 2006). Results from a series of studies by Jiang and colleagues (Jiang et al., 2000) on colour change detection indicated a specific role for relative structure as a cue in change detection. In one set of experiments, a probe change detection task was used in which report was required of whether a single probe colour (indicated in the test display by a white surround box), changed colour from the preceding memory display; on some trials the non-probe items were present with the probe items in the memory display, and on others they were absent. As report was only required of the probe item, the presence or absence of the non-probe items was task-irrelevant; however, despite this, change detection was notably poorer when the non-probes were absent from the display. The authors interpreted this result as indirect evidence of the role of allocentric cues in change detection: the reduced performance without the irrelevant non-probe colours being a consequence of the loss of the spatial contextual information which could otherwise guide perceptual decisions about the status of the probe item.

In the same paper, Jiang and colleagues presented further, more direct, evidence of a role for allocentric cues using a different paradigm. In this other paradigm, two consecutive displays were shown consisting of different geometric shapes randomly positioned on a matrix. Participants had to detect if any new shape or colour was present in the test display that had not been in the memory display. In the test display, all items were either in the same absolute screen locations, or items subjected to a

spatial expansion transformation so that test items retained the same configuration but in different absolute locations, or items spatially shifted by the same physical distances as in the expansion but in a way which did not preserve their relative configuration. Results showed that change detection of both colour and shape items was most accurate in the same location condition, supporting the role of absolute cues. Importantly, accuracy was also better in the same configuration condition than the different configuration condition, supporting a role for relative configuration cues in the change detection process.

Other work, however, has found much more qualified evidence for the role of such relative information. Boduroglu and Shah (2009) used a similar change detection paradigm to that of Jiang et al. (2000) in which items either retained the same absolute locations, or the same relative configuration through expansion, against a different spatial configuration baseline. Unlike the findings of Jiang et al. (2000), Boduroglu & Shah found no effect of relative configuration in the sensitivity to changes, except in a small subset of participants, ones who exhibited an unusually strong response bias on the task. Olson and Marshuetz (2005) used a change detection task in which a single task-relevant item (a face) was given in the context of an array of two task irrelevant (non-face) items, all presented in a surround region shown in one screen quadrant. The absolute and relative positions of these items were varied by presenting them in the same or different quadrant, and with the same or different configuration. Here, the response times to a change did show influence of the relative position of the items, but there was no reliable effect on change sensitivity as measured by response accuracy.

The aim of the current paper was to determine the role played by the type of perceptual comparison required in the utilization of absolute and relative cues. Work by Udale and colleagues (Udale et al., 2018a; Udale et al., 2018b) has shown that the influence of spatial information in perceptual comparisons can depend on the demands that a task imposes. Two different comparison task conditions are investigated in the current paper, a feature comparison task (Experiment 1), and an object comparison task (Experiment 2). A greater set of spatial manipulation conditions is also given than is seen in previous experiments investigating spatial cuing.

This is done to have more contrast points from which to judge the putative effects of these two factors. The extent to which these two task-types are influenced by the different sorts of spatial manipulation will show whether absolute and relative spatial cues are utilized in feature-level and object-level comparison processes.

The experiments of both tasks required a binary forced choice report of a specified type of change occurring across a memory and test display (see Figure 1). The two displays each contained a configuration of four coloured shapes in a surround region. The configuration at test was of one of three types in relation to the memory display. Items maintained the same positions within the surround (*same configuration* condition), occupied new, randomly determined and previously unoccupied positions within the surround (*different configuration* condition), or retained the same overall item configuration within the surround, but with the specific mappings of features to locations changed (*shuffled configuration* condition).

These three configuration-types were presented in two *location conditions*: in one the test display surround was presented on the same side as that in the memory display and in the same screen location (ipsilateral condition), in the other, the test surround was presented on the opposite side of the screen and in a different vertical position (contralateral condition). This vertical position manipulation was done so that memory and test items were not horizontally aligned when presented contralaterally. This meant that it was not possible to perform the task in the contralateral condition by simple comparison of items across the horizontal axis (Matlen et al. 2020). Any advantage found for the same configuration condition in the contralateral case would therefore have to be a consequence of the preservation of relative structure, not from any adopted horizontal comparison strategy.

It is expected that change sensitivity will be highest overall in the *ipsilateral same configuration* condition. This is the only condition in which the item colours are preserved in their original screen positions across memory and test. This condition is therefore the only one in which the test display items can be directly mapped onto the VSTM representations in the comparison process. Because of this any change item will produce a transient which will uniquely

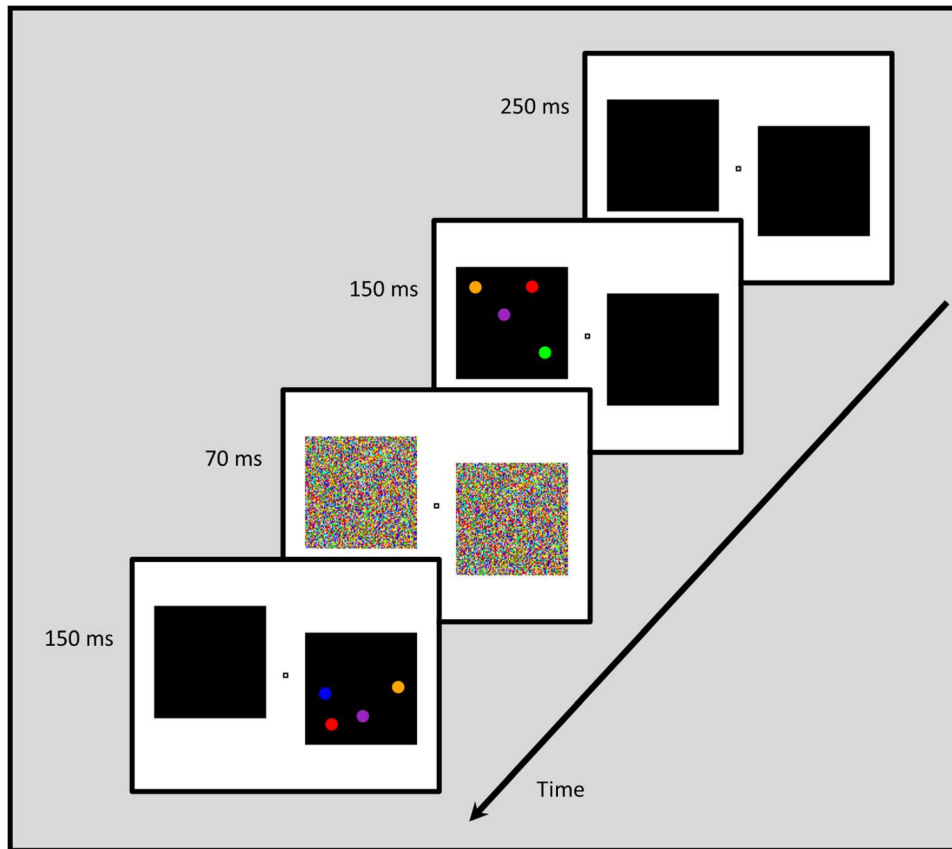


Figure 1. Schematic depiction and timings of the stimulus sequence in Experiment 1. The example shows a contralateral different configuration trial with a colour change (*new colour+*).

draw attention towards it (Hyun et al., 2009). The *ipsilateral different* and *ipsilateral shuffled* configuration conditions are expected to have reduced change sensitivity against the *ipsilateral same* because automatic comparison between test and VSTM would not, in either case, produce a transient which uniquely identified the target within the display, meaning that change detection would lack this potential guidance.

In the contralateral case, test items are always in different absolute positions to that in the memory display. The *contralateral same* configuration condition has items in the same relative configuration, but on the contralateral side of the screen rather than their original screen positions on the ipsilateral side. This condition therefore gives a benchmark from which to measure the effect of relative cues. If relative cues are being utilized in change detection, then change detection in the *contralateral same* condition should be advantaged compared to conditions where the test items are presented in a spatially altered formation. Two important contrasts here are between the *contralateral same* condition and the

two other contralateral side conditions. These two configurations are the same approximate screen distance from the original memory item locations as the *contralateral same* condition, however the relative structural organization of the original items is not preserved in either. If the *contralateral same* condition had better change sensitivity than these conditions, it would be evidence of utilization of relative cues in the change detection process.

A further relevant contrast is between the *contralateral same* condition and the *ipsilateral different* condition. Both these conditions have test items which are spatially displaced from the original memory items; however, for the ipsilateral case, the special displacement from the memory items is much smaller due to the constraint that items still appear in the same surround region as the memory display. If the *contralateral same* condition showed *better* change detection performance than the *ipsilateral different*, this would be evidence of a role for relative cues. Specifically, it would indicate that relative organization is a more important factor in the comparison

process underlying change detection than is local proximity.

Further contrasts of theoretical interest for understanding the perceptual comparison process in change detection, are between the *different* and *shuffled* conditions in the respective ipsilateral and contralateral cases. It was discussed earlier about the putative automatic mapping in the same configuration condition and how this would support change detection. In the *ipsilateral different* condition, the completely different global pattern of the configural means that automatic mapping between the representation of the memory array in VSTM and that of the test display array cannot be done. In the *ipsilateral shuffled* condition, automatic comparison between VSTM and current input will likely occur. Here the occupied screen positions of the items in terms of their global structure in the test display are the same as in the memory display, and therefore item positions are the same as in VSTM. This is likely to trigger direct automatic comparison with VSTM. Such a comparison would generate transients at all item locations – irrespective of whether it is a change or no change trial – because a colour change is occurring in every item location. These colour changes are always task-irrelevant because the task is to specifically report whether any colour changed into a new colour, not whether there was a colour change per se. These task-irrelevant colour

changes mean that the ipsilateral shuffled condition requires change detection to occur in a situation of increased internal noise due to the presence of these competing irrelevant change signals (Hyun et al., 2009; Pilling & Barrett, 2018; Shen et al., 2013). The consequence of this is that change sensitivity is likely to be even lower than in the *ipsilateral different* condition.

Less clear is what would happen in terms of comparative performance between the *contralateral different* and *contralateral shuffled* conditions. Here items have the same relative global item structure across memory and test, but the overall screen locations are different. It is possible that automatic comparison between the test items and VSTM representations occur because there is a possible direct mapping of the two due to the relative organization of the item structures being the same, despite the overall screen positions being different. If that is the case, worse performance would be found in the *contralateral shuffled* condition compared to the *contralateral different* as predicted for the ipsilateral case. If, however, such automatic comparison cannot occur under these conditions of spatial displacement of the test array, then we should find no difference in performance with the contralateral different and shuffled conditions.

A summary of the main predictions with respect to the role of absolute and relative cues is given in [Table 1](#)

Table 1. Predictions for Experiment 1.

	Prediction	Explanation
Evaluation of absolute spatial cues	Sensitivity to change will be higher in the <i>ipsilateral same configuration condition</i> than the <i>ipsilateral different configuration condition</i> .	Absolute screen locations of items are preserved in the former but not the latter condition; if absolute spatial cues guide comparison, then sensitivity to colour changes should be correspondingly higher in the former condition.
	Sensitivity to change will be lower in the <i>ipsilateral shuffled configuration condition</i> than the <i>ipsilateral different configuration condition</i> .	Absolute screen locations of items are preserved in overall configuration in the ipsilateral shuffled condition. However, mapping of individual feature to location is disrupted. The preservation of overall configuration invites the use of absolute cues to guide comparisons, however the point-to-point comparison will be detrimental to detecting the change because of the new positions of all features within the configuration.
Evaluation of relative spatial cues	Sensitivity to change will be higher in the <i>contralateral same configuration condition</i> than the <i>contralateral different configuration condition</i> .	The relative spatial structure of items is preserved in the contralateral same condition, although the absolute locations are not, due to the contralateral screen position. If relative spatial structure guides comparisons, then sensitivity to changes should be correspondingly higher in this condition than the contralateral different condition. In the latter condition there is the same degree of overall spatial displacement from the original absolute locations, however there is no retention of the relative spatial configuration.
	Sensitivity to change will be lower in the <i>contralateral shuffled configuration condition</i> than the <i>contralateral different configuration condition</i> .	The former condition preserves the relative overall configuration of the items, thus potentially inviting the use of relative cues to guide comparisons. However here this point-to-point relative comparison will be detrimental to the process of colour change detection because of the disrupted position of individual feature combined elements within the configuration.

1. Experiment 1 tested the predictions under the task conditions of feature comparison. The experiment used a modified version of the standard change detection task (e.g., Luck & Vogel, 1997). In the task participants had to report if any colour present in the memory array was replaced with a new colour in the test display. All the above-described conditions were presented on trials in which participants had to perform this basic feature change detection task.

Experiment 1

Method

Participants

There were 24 participants. All had normal (or corrected-to-normal) vision and reported no colour vision deficiencies. The experiment was conducted in accordance with Oxford Brookes University ethics procedures. The sample size reflects that of other VSTM studies of similar design complexity from our lab (e.g., Pilling & Barrett, 2016). The sample size also exceeds the requirement calculated from a priori power analysis, (G*Power 3.1.97; Faul et al., 2009 min. $N = 22$ to obtain a power of .95 for a 2×3 repeated-measures design with a medium effect size).

Stimuli and procedure

The displays were viewed on a Sony Trinitron 15-inch CRT monitor running at 100 Hz with a resolution of 1280×1024 . This was controlled by a Pentium Quad Core Windows PC fitted with a *Nvidia* GeForce 8400 GS graphics card. The computer ran bespoke software written in the *BlitzMax* programming language (V 1.5, Blitz Research Ltd.). The software was responsible for stimulus generation, randomization, and response collection. The monitor was viewed at an approximate distance of 500 mm in a darkened and sound-deadened room with backlighting. In the experiment there was a memory display and a test display presented in sequence and interleaved by colour noise masks.

The trial sequence is schematically depicted in Figure 1. Each trial began with a 250 ms frame containing a fixation point consisting of a small (0.77° subtended visual angle at the viewing distance) hollow black square in the centre of the screen, and two black square surrounds ($16.22^\circ \times 16.22^\circ$). These were located on the horizontal plane with their

nearest edge 1.07° from the central fixation. The fixation point remained present across all trial frames. The left and right surround squares were inversely vertically offset from the horizontal midline of the screen and fixation point by 1.93° ; this was done randomly so that either side could be in the higher position. These surrounds denoted the areas where the memory and test stimuli were presented. This initial frame was followed by the memory frame, presented for 150 ms. The stimuli in this memory frame consisted of an array of four coloured disks (of diameter 1.8°). The memory items were all placed within either the left or right surround region. An equal number of left and right-side presentations were given for each of the conditions. The placement of individual items within the surround was done randomly with the constraint that the centroid of each disk was a distance of at least 4.50° from any of the other three disks, and that the disk was inside the surround area without contacting the surround edge. Each disk was one of ten distinct colours selected from the colour set. The given name of these colours and RGB values are as follows: Red (255, 0, 0), Green (0, 255, 0), Blue (0, 0, 255), Cyan (0, 255, 255), Yellow (255,255,0), Orange (255, 165, 0), Pink (255, 192, 203), Brown (165,42, 42), Purple (159, 35, 153), Grey (128, 128, 128) The selection of colours for the array was done randomly without replacement for the memory display.

The memory frame was immediately followed by the mask frame, which was shown for 70 ms. In this frame two colour noise masks were presented. The noise masks were of the same dimensions as the rectangle surrounds and placed in alignment with the surround positions on that trial. The masks were built from blocks of colour consisting of four pixels in a square. The colours of these blocks were randomly generated on each trial, each a colour from the set of 10 colours used for the memory stimuli. The presentation of the masks ensured that any iconic memory representation of the memory array was eradicated after presentation.

The mask frame was immediately followed by the test frame. This was shown for 150 ms., the same duration as the memory frame. The test frame consisted of two black surrounds placed in the same screen locations as the masks and the preceding surrounds in the memory frame. An array of four test stimuli was presented inside one of the two surrounds. The

side in which the array was presented, and the spatial organization of that array depended on the trial type. On *ipsilateral* trials the test array was presented on the same side surround as on the memory trial; on *contralateral* trials the test array was presented on the opposite side as on the memory trial. The spatial configuration of the array within the surround was in one of three forms. On *same configuration* trials the array items were in the same positions within the surround and with the same mapping of colour to individual disk as in the memory array. This meant that on *ipsilateral same configuration* trials the colours were in the exact same screen positions across memory and test. On *contralateral same configuration* trials, the array was in the same relative positions as the memory display within the surround, but within the surround on the opposite side of the screen. On *different configuration* trials the array was in a new spatial configuration to the memory array. The new spatial positions were randomly determined within the surround, this was done with the constraint that the centroids of the chosen new positions were all at least 4.5° subtended angle from the centroid of any disk position held in the memory array and from each other in the test array. This meant that the disk positions were in new screen locations and new configurations on both *ipsilateral* and *contralateral* trials. On *shuffled configuration* trials, the test array positions were the same as in the memory array within the surround (the exact same screen locations for the *ipsilateral*, the same relative positions for the *contralateral*). What was different to the *same configuration* condition was that the disks all exchanged positions (i.e., each disk changed colour). This meant that on *ipsilateral trials*, the disks were in the same screen locations as seen in the memory array, but there was a colour change in every location due to the remapping. On *contralateral trials*, the disks were in the same relative positions but with the colour remapping of the individual disks. Depicted examples of the respective combined conditions for Experiment 1 can be seen in [Figure 2](#).

The task was to report whether there was a new hue in the test display that was not present in the memory display. On *new colour–* trials the same four colours were presented at memory and test. On *new colour+* trials three of the four original memory colours were presented at test together, but the

fourth was replaced with a new colour. The new colour was one randomly selected from one of the nine remaining unused colours in the previously described colour set. There was an equal number of *new colour–* and *new colour+* trials in each of the six individual combination of conditions in the experiment.

Following the position of the test frame there was then a 50 ms blank interval consisting of a white screen followed by the presentation of black text on a white background (in Ariel font, 20 pt) with the message “Was there a NEW colour in the second display (N/Y).” This display remained on-screen until the participant made a response. Responses were made via a PC game controller which had the left and right trigger keys designated “No” and “Yes” respectively. Participants were instructed that the item positions might change on screen, but this is irrelevant to the task and that the only relevant factor is to respond whether there was a new colour in the second display that had replaced a colour in the first display. Participants were instructed to emphasize accuracy not speed. They were shown some demonstration trials and then performed a minimum of 20 randomly selected practice trials before doing the experiment. The experiment contained 576 trials. The different trial conditions were given in a randomly interleaved fashion. Equal numbers of each factorially combined condition were given. The experimental session lasted approximately 40 min per participant. Participants were debriefed as to the purpose of the experiment at the end of the session.

Results

A signal-detection analysis of the data was performed (Green & Swets, 1966). Correct responses on *new colour+* trials were treated as hits and incorrect responses on *new colour–* trials as false alarms. The proportion of hits and false alarms was calculated separately for each of the six separate condition combinations; these are given in [Table 2](#).

The scores were then subject to a correction in accordance with the loglinear approach described by Hautus (1995). The *d-prime* statistic (d') measure of sensitivity and the statistic C , a measure of bias, were computed from these corrected scores (Stanislaw & Todorov, 1999). Positive bias values indicate a

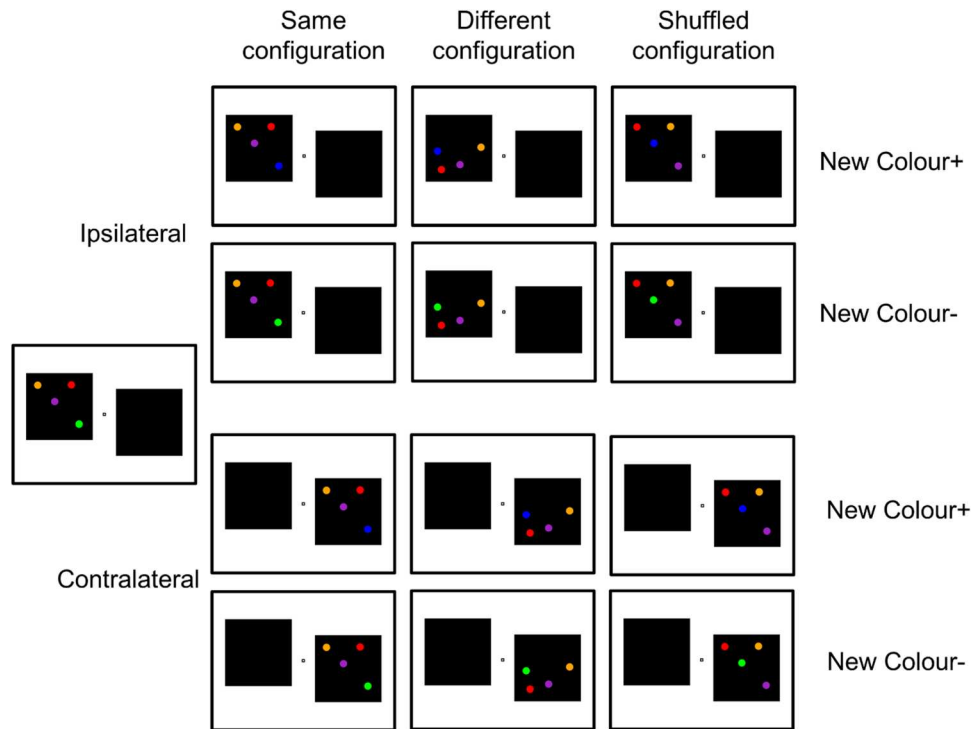


Figure 2. Examples of the respective configuration conditions in Experiment 1. In the given example, the frame on the far left depicts the screen for the memory display, the array of frames to its right show examples of the test display for the three configurations (Same, Different, Shuffled) when presented ipsilaterally and contralaterally, for trials change and no change trials (New Colour+ and New Colour– respectively).

conservative criterion (a tendency to report no change), and negative values a liberal one (a tendency to report a change). The across-participant averages on the sensitivity and bias measures are shown in Figure 3. Analyses are described separately under the respective subheadings.

d-prime scores

An initial analysis was done using one-sample *t*-tests; this showed that performance in all conditions was significantly above zero ($t \geq 8.62$, p all $< .0001$). Scores were then subject to a 2×3 (*side* \times *configuration*) ANOVA. Both factors were repeated measures: *side* (*ipsilateral*, *contralateral*) and *configuration* (*same*, *different*, *shuffled*). Both main effects were significant

for the *d*-prime: *side* ($F[1,23] = 10.42$, $MS_{err.} = 0.08$, $p = .004$, $n_p^2 = .312$); *configuration* ($F[2, 46] = 22.55$, $MS_{err.} = 0.09$, $p < .001$, $n_p^2 = .495$). There was also a significant *side* \times *configuration* interaction ($F[2, 46] = 5.97$, $MS_{err.} = .13$, $p = .005$, $n_p^2 = .206$). Planned comparisons (estimated-marginal means) were performed between the respective configuration conditions for the *ipsilateral* and *contralateral* sides to test the hypothesis.

This analysis showed that for the *ipsilateral* side, the two configuration conditions in which the spatial organization was altered (*different configuration*, *shuffled configuration*), both had lower performance than did the *same configuration* condition ($t \geq 3.78$, both $p < .001$). Performance in the *shuffled configuration* condition was also significantly lower than the *different configuration* condition ($t = 2.78$, $p = .011$). For the *contralateral* side, however, neither of the two altered configuration conditions (*different*, *shuffled*) differed significantly from the *same configuration* condition ($t \leq 1.58$, $p \geq .129$), nor from each other ($t = 0.68$, $p \geq .5$).

Table 2. Proportion of hits ($p[\text{Hit}]$) and false alarms ($p[\text{FA}]$) in each factorially combined condition for Experiment 1 (standard errors are given in parenthesis). All values are given to 2 d.p.

Side	Measure	Same	Different	Shuffled
Ipsilateral	$p[\text{Hit}]$	0.515 (0.028)	0.577 (0.018)	0.66 (0.03)
	$p[\text{FA}]$	0.13 (0.02)	0.278 (0.024)	0.441 (0.028)
Contralateral	$p[\text{Hit}]$	0.453 (0.021)	0.532 (0.021)	0.502 (0.025)
	$p[\text{FA}]$	0.186 (0.021)	0.273 (0.028)	0.269 (0.026)

C (bias) scores

The bias scores were also subject to one-tailed *t*-tests. These were compared against 0 (no bias). The analysis

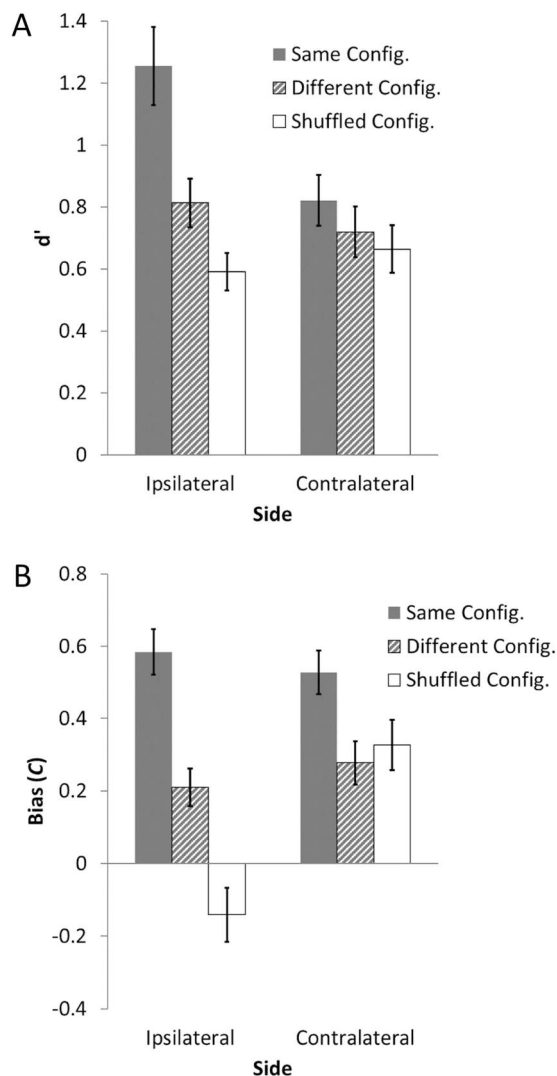


Figure 3. Results from Experiment 1. Plate A shows the mean across participant d-prime scores. Plate B shows the mean across participant bias scores (C). Error bars show ± 1 standard error.

showed that all conditions showed a significant conservative bias ($t \geq 4.04$, all $p < .001$), except for the ipsilateral shuffled condition which exhibited a small liberal bias that did not reach significance ($t = 1.89$, $p = .072$). A two-way ANOVA (*side* \times *configuration*) was performed on the bias data. Both main effects were significant: *side* ($F[1,23] = 8.86$, $MS_{err.} = 0.10$, $p = .007$, $n_p^2 = .043$); *configuration* ($F[2, 46] = 54.41$, $MS_{err.} = 0.05$, $p < .001$, $n_p^2 = .25$). The *side* \times *configuration* interaction was also significant: $F[2, 46] = 19.42$, $MS_{err.} = 0.05$, $p < .001$, $n_p^2 = .084$. The same planned comparisons were performed between the respective interference conditions for the *ipsilateral* and *contralateral* sides.

For the *ipsilateral* side, this analysis showed, compared to the *same configuration* condition, there was a significant liberal shift for the two altered configuration conditions (*different configuration*, $t = 5.37$, $p < .001$; *shuffled configuration* condition, $t = 9.74$, $p < .001$). The contralateral same configuration condition also differed from both contralateral conditions with altered configurations, *different configuration*, $t = 6.08$, $p < .001$; *shuffled configuration*, $t = 5.09$, $p < .001$; but these altered conditions did not differ from each other on the bias measure ($t = 1.23$, $p = .23$).

Discussion

As expected, change sensitivity was highest when the test items were in the same screen positions (*ipsilateral-same configuration*). Sensitivity was reduced when items had a different spatial configuration, but still with ipsilateral presentation; the lowest sensitivity was found when disks retained the same on-screen positions, but the colour-location correspondences of the disks were shuffled (*ipsilateral-shuffled configuration*).

The marked effect of configuration found with ipsilateral presentations was absent when the test items were presented on the contralateral side of fixation. Sensitivity did have the same rank-order position for the three configurations, as with ipsilateral presentations, but the two contralateral altered conditions did not statistically differ from the contralateral same conditions.

The sensitivity data showed clear evidence of the influence of absolute position cues. This is clear from the performance difference between the three ipsilateral configurations. The ipsilateral same-configuration advantage is likely supported by the efficient and automatic comparison of the memory representation items with the test display locations which draw attention to the change item (Hyun et al., 2009). The markedly poor performance in the ipsilateral shuffled condition – in relation to the other ipsilateral presentations – is most likely also a consequence of this automatic comparison process. Here transients would be produced in all locations, giving no useful information about the presence of a new colour, but would add internal perceptual noise and so reducing change sensitivity (Pilling & Barrett, 2018).

There was no clear evidence of an influence of relative cues on change sensitivity. The contralateral

same condition, where the original configuration was maintained but in different laterality and with different vertical positions, did show higher performance, than the other two configuration types on that side. However, neither comparison was significant.

The bias measure showed a general tendency towards conservative responding on the task, despite participants being explicitly told that there were equal numbers of change and no change trials. This is something that we and others have previously reported on VSTM tasks where change and non-change trials are equal in number (e.g., Pilling et al., 2020). This general conservative bias suggests that participants default towards reporting no change on trials in which they are uncertain. Given the item set size would be close to VSTM memory limitations (Cowan, 2001) combined with the brief memory presentations, this means that on some trials only an incomplete representation of the memory display was likely held in VSTM. Given an incomplete VSTM representation not all colour changes would be detectable. This fact itself would shift the bias towards reporting no change, because on many change trials, the target change would not be experienced. Thus, this general positive bias is one which is, arguably, an expected one given the task.

A more interesting point about the bias data concerns the effect of the display manipulations on bias. Notably there is a marked effect of configuration for both *ipsilateral* and *contralateral* presentations. Configuration had a strong effect on bias. For both *ipsilateral* and *contralateral* presentations, responding showed a marked liberal shift (a tendency to report a change) when the configuration was altered in some way (*different*, *shuffled*) compared to when it stays the same. However, there was also an interaction with side of presentation. This interaction was for most part a consequence of a notably large liberal shift specifically in the *ipsilateral shuffled configuration*; for the equivalent *contralateral* condition this liberal shift was no bigger than for the corresponding *different* configuration.

The effects overall show that the bias measure, unlike sensitivity, was influenced by both the ego-centric and allocentric organization of the display. Configuration changes, even when relative structure was preserved, influenced responding. This is

evident in the fact that the *different configuration* condition showed the same negative bias shift compared to the *same configuration* condition for both *ipsilateral* and *contralateral* presentations. The bias shift was more modest in the *contralateral* case but was still clear. We shall return to this point in more detail in the general discussion.

The markedly larger bias for the *ipsilateral shuffled* condition parallels the low change sensitivity found in this condition and is likely also a consequence of the irrelevant change signals that would be produced in that condition: Automatic local comparison between memory and test would generate mismatches at every location, even on trials with no location change. The presence of these irrelevant changes clearly strongly affected responding towards there being a colour change, the same result that Pilling and Barrett (2018) found under different task circumstances. What is notable is that this augmented bias occurred only with ipsilateral presentations of the shuffled configuration. This shows clearly that automatic comparisons are limited to absolute coordinate comparisons.

Our main question was about the effect of absolute and relative configuration. In terms of change sensitivity, Experiment 1 found a clear effect of absolute position but not a statistically discernible effect of relative configuration. At the same time the bias data showed that participants were aware when relative spatial structure was retained. Participants didn't seem to know about just the overall relative spatial pattern created by the four items, but also the colour allocation to those relative positions. This can be seen in the *contralateral* case by the fact that a liberal bias shift occurred compared to the same condition, both when the relative spatial pattern was not retained (*contralateral different* condition), and when the relative spatial pattern was retained but the colour allocation to those positions was altered (*contralateral shuffled* condition). In both these cases the irrelevant change in relative organization is noticed and affects responding.

Why given these effects on bias, was there no statistically discernible effect on sensitivity? The type of colour change detection task given in the experiment is arguably one of the most prototypical and well-established tasks in VSTM research (e.g., Alvarez & Cavanagh, 2004; Hyun et al., 2009; Luck & Vogel, 1997; Pilling & Barrett, 2016; Rouder et al., 2008;

Vogel et al., 2006). It is also a specific form of task which has been used evaluating the role of spatial organization in VSTM (e.g., Boduroglu & Shah, 2009; Hollingworth & Rasmussen, 2010; Jiang et al., 2000). An appeal of the task is that it involves an entirely non-spatial judgement, participants only need to report whether a new hue appears in the test display. The rather simple nature of the judgement means that the task can likely be performed entirely without recourse to comparison of object-level representations. Indeed, it is likely that the detection of a colour change is in large part supported by comparative evaluations of global feature statistics of memory-held and test items (Pilling et al., 2020). This is because the colour change always involves the presentation of a new colour in the display. This means that the summary global average hue is altered between memory and test when a colour change occurs. Such comparative evaluations are inherently non-spatial in nature, and likely to be automatic and rapid (Chong & Treisman, 2003).

Thus, the task used in Experiment one is possibly suboptimal as a candidate for discerning relatively high-level cognitive influences, such as relative configuration cues, on VSTM. A task that explicitly requires object-level comparisons is likely to be more sensitive to high-level influences, more dependent on display structure and consequently show greater performance decrements when this structure is violated. Several VSTM studies have used a task where participants must detect a feature switch across items, i.e., a binding change, instead of just a simple feature replacement (Bharti et al., 2020; Hitch et al., 2020; Allen et al., 2006; Saiki, 2003; Wheeler & Treisman, 2002; Pilling et al., 2020). Detecting switch changes necessarily requires not just of the feature content of the displays, but of feature correspondences at the object level.

Experiment 2

Experiment 2 had a change detection task in which the same four geometric shapes were present on each trial. The shapes each had a different colour drawn from the set used in Experiment 1. On half the trials two of the shapes swapped colour. Participants had to report if such a swap had occurred or not. This task was done under the same condition combinations given in Experiment 1. The critical

question was whether, unlike Experiment 1, there would be any effect of the relative spatial organization staying the same across memory and test when items were presented contralaterally.

Methods

Participants

There were 24 participants, recruited in the same manner described for Experiment 1. This was done with the additional constraint that none had taken part in Experiment 1.

Stimuli and procedure

All aspects were the same as Experiment 1 other than the differences required for the experiment. Rather than there being four disks in the memory and test frames, the displays consisted of four distinct shapes. These were always an equilateral triangle, a vertically-orientated ellipse, a diagonal cross, and a horizontally-orientated rectangle. As in Experiment 1, each of the shapes was of a different colour, each drawn randomly from the set of thirteen previously described colours. In the memory array four coloured shapes were randomly located inside the black surround positioned to the left or right of fixation. The condition was determined by whether the surround was on the ipsilateral or contralateral side relative to the memory array, and whether the item configuration was the Same, Different or Shuffled in relation to that of the memory array. This gave the same six conditions as in Experiment 1. Depicted examples of these conditions for Experiment 2 can be seen in Figure 4.

The task was to report if any of the colour-shape pairings had swapped between memory and test. On colour swap – trials all shapes retained the same colour they had in the memory array; on *colour swap+* trials two of the shapes, randomly selected, would switch colours, for example the yellow triangle and the red ellipse in the memory array, might exchange colours so that the triangle was red and the ellipse, yellow. The other two shapes would retain the same colours between memory and test. There was an equal number of *swap–* and *swap+* trials in each of the six combinations of conditions. Participants had to make a response using the trigger keys of the game controller to indicate whether they thought a colour-shape swap had

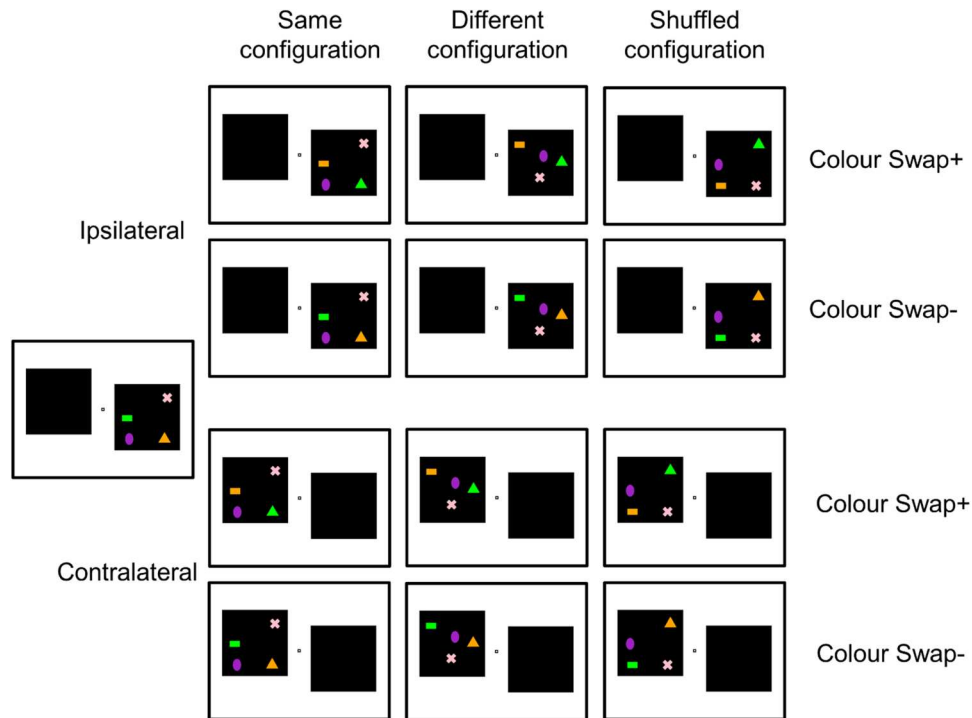


Figure 4. Examples of the respective configuration conditions in Experiment 2. In the example, the frame on the far left depicts the screen for the memory display and the array of frames to the right show examples of the test display in the respective conditions for trials in which there is and is not a swap change (*colour swap+* and *colour swap-* respectively).

occurred or not. Examples of the different conditions for the *swap-* and *swap+* trials are given in Figure 3. Participants were given a demonstration and at least 30 practice trials prior to doing the experiment. The experiment consisted of 576 trials. The combination conditions were given in a random order with the constraint that equal numbers of each factorial combination were given. The whole session took approximately forty minutes to complete.

Results

Initial analysis showed that two participants had performance that was at or worse than chance. These participant data were removed from all further analyses. The same signal-detection analysis was used

as previously described, with correct responses on *colour swap+* trials treated as hits, and incorrect responses on *colour swap-* trials as false alarms. The proportion of hits and false alarms are given in Table 3. The calculated *d*-prime and bias measures are shown in Figure 5.

Sensitivity and bias measures were analysed separately using the same ANOVA analysis described for Experiment 1. These are described in separate sections below.

d-prime scores

As with Experiment 1, an initial analysis was done using one-sample *t*-tests; this showed that performance was significantly above zero in all conditions ($t \geq 2.88$, $p \leq .009$), except for the ipsilateral shuffled condition, where it only approached significance ($t = 1.81$, $p = .085$). Scores were subject to a two-way repeated measures ANOVA (*side* [*ipsilateral*, *contralateral*] \times *configuration* [*same*, *different*, *shuffled*]). Of the two main effects, *side* was not significant ($F[1,21] = 1.39$, $MS_{err.} = 0.07$, $p = .252$); but *configuration* was ($F[2, 42] = 16.79$, $MS_{err.} = 0.13$, $p < .001$, $\eta_p^2 = .444$). The *side* \times *configuration* interaction did not reach significance ($F[2, 42] = 2.77$, $MS_{err.} = .12$, $p = .074$).

Table 3. Proportion of hits ($p[\text{Hit}]$) and false alarms ($p[\text{FA}]$) in each factorially combined condition for Experiment 2 (standard errors are given in parenthesis). All values are given to 2 *d.p.*

Side	Measure	Same	Different	Shuffled
Ipsilateral	$p[\text{Hit}]$	0.427 (0.025)	0.5 (0.024)	0.638 (0.027)
	$p[\text{FA}]$	0.219 (0.034)	0.392 (0.026)	0.586 (0.028)
Contralateral	$p[\text{Hit}]$	0.421 (0.024)	0.462 (0.026)	0.493 (0.026)
	$p[\text{FA}]$	0.26 (0.03)	0.378 (0.028)	0.38 (0.028)

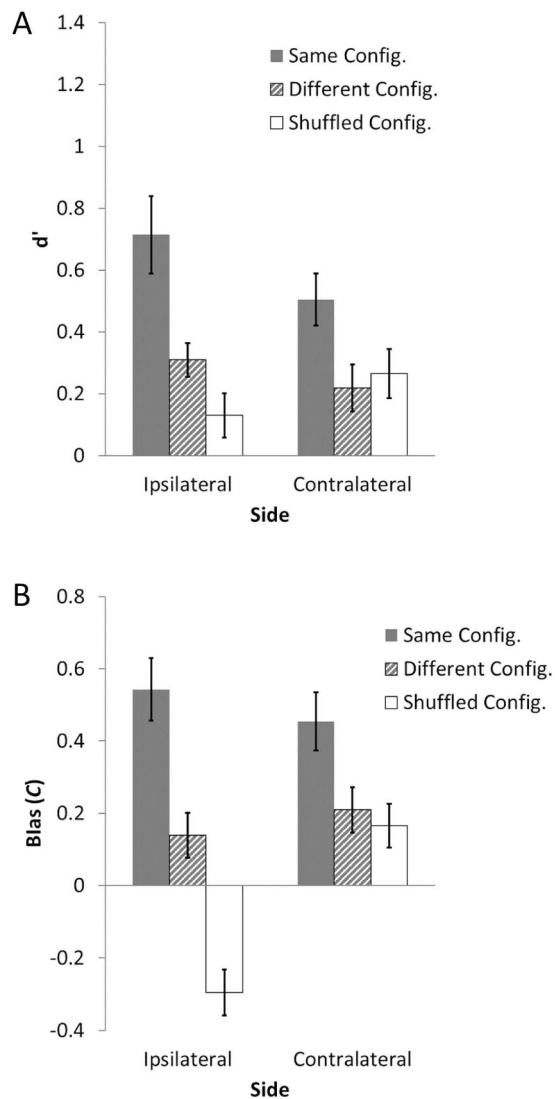


Figure 5. Results from Experiment 2. Plate A shows the mean across participant d-prime scores. Plate B shows the mean across participant bias scores (C). Error bars show ± 1 standard error.

Planned comparisons were performed between the respective altered conditions for the *ipsilateral* and *contralateral* sides in the same way done for Experiment 1. For the *ipsilateral* side the two configuration conditions in which the organization was altered (*different configuration*, *shuffled configuration*), had both lower performance than from the *same configuration* condition ($t \geq 3.18$, both $p \leq .005$). Performance in the *ipsilateral shuffled configuration* condition was also significantly worse than the corresponding *different* condition ($t = 2.40$, $p = .026$). For the *contralateral* side, the *different* condition had lower performance than the corresponding *same* condition ($t = 2.479$, $p < .022$); the shuffled condition also

had lower performance compared to the corresponding *same* condition but did not reach the threshold for significance ($t = 2.073$, $p = .051$). The two altered configuration *contralateral* conditions (*different*, *shuffled*) did not differ from each other ($t = .0594$, $p = .559$). Importantly, the *contralateral same* condition was also significantly higher than in sensitivity the *ipsilateral different* condition ($t = 2.33$, $p = .003$), which was not the case in Experiment 1.

Comparison of d-prime scores across experiments 1 and 2

Experiment 2 showed a different pattern of significant differences and interaction compared to Experiment 1. Planned statistical comparisons were made across the two experiments to determine these more directly, by comparing the relevant contrasts associated with testing the effect of relative configuration.

The difference in d-prime ($\Delta d'$) was first computed for both experiments between the baseline *same configuration* condition and the two respective altered configuration conditions (*different*, *shuffled*); this was done separately for the *ipsilateral* and *contralateral* cases. This resulted in four $\Delta d'$ scores per participant. Independent sample t-tests were then used to compare participants across the two Experiment groups. This performance contrast between the same configuration baseline and the two altered conditions was significant in both cases for the *contralateral* side presentations (*different*, $t[44] = 2.70$, $p = .01$; *shuffled*, $t[44] = 2.26$, $p = .029$). Neither was significant in the case of the *ipsilateral* altered conditions in relation to their *same configuration* baseline ($t[44] \leq 0.48$, $p \geq .63$). A further $\Delta d'$ score was calculated comparing the *contralateral same configuration* condition against the *ipsilateral different* condition for the two experiments. This analysis showed that this contrast was greater for Experiment 2 than Experiment 1 ($t[44] = 2.51$, $p = .037$). Together these comparisons directly show that the advantage for maintaining relative configuration (*contralateral same* condition) was greater in Experiment 2 than Experiment 1.

C (bias) scores

One-tailed t-tests (compared against a 0, no bias), showed a significant conservative bias for all conditions ($t \geq 3.28$, all $p \leq .004$), except for the *ipsilateral*

shuffled condition which exhibited a significant liberal bias ($t = 2.32, p < .03$).

A two-way ANOVA (*side* \times *configuration*) was performed on the bias data. Both main effects were significant: *side* ($F[1,21] = 10.9, MS_{err.} = 0.08, p = .003, \eta_p^2 = .035$); *configuration* ($F[2, 42] = 41.7, MS_{err.} = 0.08, p < .001, \eta_p^2 = .298$). The *side* \times *configuration* interaction was also significant: $F[2, 42] = 23.9, MS_{err.} = 0.05, p < .001, \eta_p^2 = .074$.

Planned comparisons were performed between the respective interference conditions for the *ipsilateral* and *contralateral* sides in the same way as for the previous analyses. For the ipsilateral side, this analysis showed, compared to the *same configuration* condition, there was a significant liberal shift for the two altered configuration conditions (*different configuration*, $t = 6.55$, *shuffled configuration* condition, $t = 7.34$, both $p < .001$). These two *ipsilateral* altered configuration conditions also differed significantly from each other ($t = 4.79, p < .001$).

The *contralateral same* condition also differed from both *contralateral* altered configuration conditions (*different configuration*, $t = 4.50$; *shuffled configuration*, $t = 4.55$, both $p < .001$). The *contralateral same* condition was also significantly different to the *ipsilateral different* condition ($t = 5.3, p < .001$).

Discussion

Sensitivity to swap changes was notably poorer compared to the feature changes in the previous experiment, consistent with previous findings that have shown that swap changes are more difficult to detect (Pilling et al., 2020; Wheeler & Treisman, 2002). For the ipsilateral trials, the same basic significance pattern was found as for Experiment 1. The main difference concerned the contralateral trials. Specifically, a clear effect of configuration was found: The contralateral same-configuration condition was significantly better than the different-configuration condition, while the difference between the contralateral same and shuffled conditions closely approached significance. This shows that representations of the colour-shape conjunction were easier to compare when relative spatial position was maintained. Thus, allocentric organization influence sensitivity in a way not exhibited for the previous task. We shall return to this point in the general discussion.

Despite the obviously harder nature of the task and the different pattern of sensitivity compared to Experiment 1, the pattern of bias was remarkably similar. The same overall conservative bias was found. There was also the same distinct tendency for alterations to the relative spatial configuration to produce liberal response shifts, but no general tendency for the ipsilateral–contralateral manipulation to produce this shift. However, again as with Experiment 1, the same augmented liberal shift occurred in the ipsilateral shuffled configuration. We shall also return to this issue in the general discussion.

General discussion

Both experiments demonstrated evidence of the importance of absolute location in change detection: Though location was task-irrelevant, change sensitivity was markedly reduced when test items occupied different screen positions compared to the original memory display. However, only the binding/swap task of Experiment 2 showed evidence of the influence of the relative location on this measure. Though the two tasks showed notable differences with respect to the sensitivity measure, they showed broadly the same pattern across all conditions on the bias measure, with evidence of influence of both absolute and relative coding effects across both. These aspects of the sensitivity and bias measures in relation to absolute and relative location cues are discussed in more detail below.

Spatial configural information and sensitivity to change

Experiment 1 did not produce evidence that relative configuration cues were being used to facilitate detection of the change. There was clear evidence from the ipsilateral presentations that absolute spatial position played a role. The results suggested that this reflected the operation of a simple comparison mechanism limited to comparing spatiotopic positions between the test display and VSTM representations (Hyun et al., 2009; Pilling et al., 2020). The evidence for relative coding in Experiment 2, however, was much clearer. This indicates that the task processing demands determine whether encoded relative cues are utilized in detecting changes.

The greater difficulty of Experiment 2 than Experiment 1 parallels the differences found in efficiency in other cognitive tasks which compare single features and feature conjunction defined stimuli such as target search and contour detection (Pashler, 1988; Treisman & Gelade, 1980). A likely reason for the higher difficulty of conjunction changes is the absence of any feature statistical cues accompanying the change (Zhang et al., 2012; Chong & Treisman, 2003; Pilling et al., 2020). It may be that this aspect alone of the object task explains the differential effect of allocentric information compared to Experiment 1. Global feature statistics are cues which, by definition, are non-spatial (Wolfe et al., 2006).

If change sensitivity in the feature task of Experiment 1 was driven mainly by comparisons of global statistics – at least where absolute comparisons could not be done, then the lack of influence from relative spatial cues is unsurprising. Experiment 2 presents a different task situation: here item changes do not affect global feature statistics, changes can only be identified by tracking and individually comparing individuated objects across the displays (Saiki, 2019; Treisman, 1982; Wilson et al., 2012). This individuation process may increase the awareness of the relations of display items, resulting in more use of relative structure cues. If there was a stronger apprehension of relative spatial positions in Experiment 2, then we might expect this also to be exhibited in the response bias data as well as sensitivity. However, this bias data showed similar patterns across the two experiments, suggesting against such a possibility.

A second possibility is that spatial attention plays a mediating factor in relative encoding effects, and that is what is driving the difference between the tasks. Sensitivity to change is likely dependent on the efficiency with which attention can compare items in the test display with VSTM (Griffin & Nobre, 2003). Where items retain the same relative positions this may facilitate attentional guidance towards corresponding items between VSTM and the test display. Certainly, it is known that attention can be guided by knowledge about adjacent items (Pöder, 1999). When relative position is disrupted, this may reduce the effectiveness of guidance and result in lower sensitivity. In this interpretation Experiment 1 shows less effect of spatial structure because attention can be directed more efficiently to individual features than to feature conjunctions (Wolfe, 1994).

A third possible factor explaining the differential influence of relative position across the two tasks is simply the number of items involved in the change event. In Experiment 1 task-relevant changes only affected a single item position. In Experiment 2 changes, by necessity, involved a relational swap of features between two item positions. This means that a greater proportion of the display array items were affected by a change event in the second than the first experiment, (respectively 50% and 25%). A consequence of this may be that the value of recognizing the consistency of spatial relations between items may be greater the more items in the display are affected by change. To give an illustrative example, the relative positions of just two of the four memory items might be encoded in VSTM on a particular trial (e.g., that the orange item was to the left of the blue item in the upper portion of the surround display); if it is noticed that the two item colours have the same relative position in the test display then task-relevant information can be inferred from this. It can be taken as evidence, first, that the spatial configuration of items has remained constant from memory to test, and second, that, – as a minimum – these two items have not undergone a swap change with any other memory display item, even though these were not encoded in memory. Thus, if it is recognized that two items are unchanged, this gives an upper-bound probability of less than .17 that a change might have occurred in the remaining array items, even if the change is not actually perceived.¹ In the case of a single feature change, however, the same knowledge that two items have not changed gives a (larger) upper-bound probability of .5 that a change might have occurred when not perceived because the change, when it occurs, is limited to a single item location. This potential advantage in the upper-bound probability of a change may increase the utility of relative spatial cues. Where the relative positions of items are not held constant, it becomes harder to determine if any items have *not* changed. This means that any advantage in knowing the upper bound limits of a change is also lost.

The three explanations described above for the task-dependence of relative spatial encoding are not mutually exclusive. Our data are not sufficient to eliminate the influence of any of them with certainty. Future research could determine the individual contribution of these aspects of the object task to the

sensitivity to relative structure. This could be done by systematic variation of the displays and types of report required. For example, if the proportion of changing items is a critical factor, then having feature changes with two or more items should increase the role of relative spatial position, even though the task does not require detection of a swap. If it is the requirement to individuate items as objects which is important than a simple change to the requirements of the object task should influence the role of relative spatial position (for instance requiring report on specific feature-bindings, e.g., “*did the triangle change colour?*,” compared to requiring report only of the general presence of a change “*did any shape change colour?*”).

It is important to note that the effect of relative spatial encoding was first reported in a feature change task like our Experiment 1 (Jiang et al., 2000). This was despite the sample size of our study exceeding that of Jiang et al. Boduroglu and Shah (2009) also failed to generate the evidence of relative encoding that Jiang et al. reported, despite in one case performing a direct replication of the original study. Boduroglu & Shah argued, based on further experimentation, suggested that Jiang et al.’s original finding was driven by the strategic decision of a subset of participants to adopt a highly conservative responding criterion, and that this affected how items were bound with locations.

As we note above, in our data, the differential sensitivity to relative positions across our two experiments are not easily explained as due to different response criteria adoption between the two tasks. One difference between the current studies and those of both Jiang et al. (2000) and Boduroglu and Shah (2009) is in the manner of spatial transformation used to assess relative encoding. In the experiments of Jiang et al. (2000) and Boduroglu and Shah (2009), the same configuration condition with different absolute locations was achieved by having items with a *resizing transformation* (expansion or contraction) which preserved the relative arrangement. In our experiment this was achieved by a *translation transformation* (items all shifted by the same amount in the same direction). Using a translation rather than resizing has the advantage of maintaining allocentric relations as well as absolute inter-item distances. This is arguably a more sensitive test of relative encoding: translation is a geometrically less

complex transformation than a resizing transformation. Despite this we still found no clear evidence of relative encoding influencing change sensitivity in the situation of the Experiment 1 task.

Spatial configuration and bias

Our experiments produced generally conservative responding but with significant liberal shifts in responding when the spatial configuration was altered. Curiously, for both experiments, the laterality manipulation had only a modest effect on bias. This was despite the transformation always involving much larger spatial displacements of the items than found with the configuration shifts. This seems to suggest that the bias shifts were more a consequence of modifications to the relative positions of items than the absolute ones.

The bias data also gives some insight into the nature of what is implicitly spatially encoded. Bias shifts might only have been sensitive to alterations to the global configuration of the item array (i.e., the overall polygon shape formed by the item positions, e.g., Yantis, 1992), and not the actual specific feature positions within that configuration. Instead, clear bias shifts are found for both alterations to global shape (seen in the bias shift between the same and different configuration conditions), and to feature mappings where the global polygon shape was unaffected (seen in the bias shift between the same and shuffled configuration conditions). This was observed for both ipsilateral and contralateral presentations. This bias pattern shows that in both experiments participants had either implicit or explicit awareness of the global spatial organization of the stimuli and the individual colour positions within it.

The dissociation between the bias and sensitivity data across the two experiments suggests that the two reflect different aspects of the perceptual comparison process underlying change detection. Bias, overall, was more greatly influenced by modifications to the relative configuration of features. Bias seems to reflect, in part, the extent to which it was possible to map the VSTM representation of the memory array onto the test display; on trials where this was not possible (due to the configuration being different or reordered) a more liberal criterion being adopted. Several studies have described what is called the *spatial congruency bias* (SCB): a tendency to report

“same” when item spatial configurations are detected as same, where spatial location is task-irrelevant (Cave & Chen, 2017; Golomb et al., 2014; Shafer-Skelton et al., 2017).

The SCB has mainly been studied using simple delayed same-different discrimination tasks with single-item displays, rather than the multi-item displays of VSTM studies; the SCB effect seems, at first blush, to be analogous to the pattern of biases we observe in the sense that observers are more likely to report that something is the same (or, more precisely that there was “no change”) to the relevant display properties, when the location of the compared elements was the same compared to where it was different. However, evidence suggests that in the SCB, spatial congruency is tightly associated with retinotopic position. In our data the pattern of bias depended strongly on the relative position of the compared elements but there was no effect of the side of presentation. This suggests that while the organization of the elements was important for bias, the retinotopic position was not. This suggests that the SCB, though superficially similar, likely arises from a different mechanism. It suggests that the biases in our experiment, for most part, arose at a later processing stage after such information is computed. It remains to be seen whether these relative position bias effects do reflect the operation of a perceptual mechanisms, as the SCB seems to, or just reflects decision interference at the response stage. Further research could investigate this by determining whether, like the SCB, the relative bias effect is also found in outside of simple forced-choice responding, such as in similarity ratings (Golomb et al., 2014). It would be possible to adapt this to our paradigm by having participants rate the similarity of hues across the memory and test array, rather than just reporting if one is new. If the relative bias persisted under such conditions, it would be evidence of a perceptual component in the effect.

Bias and automatic comparisons between VSTM and perceptual input

Another aspect of the bias data warrants further discussion. In both experiments a particularly marked liberal shift was found when the shuffled configuration was presented on the ipsilateral side. The shift was distinctly larger than that for the different configuration condition

and did not occur with contralateral presentations. This effect seems to reflect a different process than the just-described relative bias effect. We view this ipsilateral-shuffled effect, in being specific to absolute screen locations, as being a much clearer example of being a perceptual rather than a response-related effect. As was noted earlier, this ipsilateral-shuffled bias is best interpreted as reflecting the outcome of a local comparison mechanism (Hyun et al., 2009) which generates change signals when different colours are presented in all four of the screen positions. In this condition the subjective perception is of all four colours changing. With such a strong colour change signal it is unsurprising that it results in an increased the tendency to report a target colour change having occurred. The absence of a similar shift with contralateral presentations shows this effect to be location dependent, not just configuration dependent. Indeed, the specificity of this shift suggests it might be useful as a signature marker for the putative reflexive comparison mechanism.

Our experiments tried to limit eye movements by having rapid successive masked presentations of the memory and test arrays. However, we had no measure of or control over eye movements.² Consequently, we cannot determine if this comparison process is one which operates in retinotopic or spatiotopic coordinates. One possibility is that the mechanism automatically compares features in the same retinal positions, analogous to the retinotopic nature of the SCB. Another possibility is that VSTM compares features in spatiotopic coordinates, independent of any changes to eye position. VSTM plays an important role in integrating across eye movements (Hollingworth et al., 2008), given this, it would make sense for such automatic comparisons to operate in coordinates in external viewed space. Evidence from other paradigms however has been mixed about the extent to which VSTM operates this way (Golomb & Kanwisher, 2012; Huynh et al., 2017; Ong et al., 2009; Prime et al., 2007). It would certainly be worth establishing the extent to which the reflexive comparison mechanism operates in retinal versus external space by looking at this signature ipsilateral-shuffled bias shift.

Summary and conclusion

The first experiment, using a standard change blindness task in which it was required to detect an item colour change, found clear evidence of absolute

position, but not of relative position, on sensitivity to the change. Performance was generally better when memory and test items occupied the same screen positions, but it was not discernibly better when items were in different screen positions but still retained the same configuration. We suggested this lack of influence of relative position was because the standard change detection task can still be performed based on comparisons of (intrinsically non-spatial) global statistical cues. In Experiment 2, with a colour swap task, in which the features present are the same on change and no change trials, and which therefore requires individual object-level comparisons, the advantage of relative configuration was clearly apparent. In contrast to the sensitivity data, the pattern of biases was markedly similar across the two tasks. In both tasks, for the bias data, there was clear evidence of the influence of absolute and relative cues. The fact that the bias data is so similar across the two tasks while the sensitivity data diverges, suggests that the effect on sensitivity was likely not strategic, at least in the sense of different response criteria being induced (*cf.* Boduroglu & Shah, 2009). Instead it suggests that effects of relative structure are dependent on the extent to which a task requires object-level comparisons of the stimulus elements. This is consistent with findings from Udale and colleagues (Udale et al., 2018a), which has also shown how the conditions of the task can influence how spatial information is utilized in the comparison process.

Notes

1. With four items (1-4) then there is a total of six swap combinations in which items swap colours (1-2, 1-3, 1-4, 2-3, 2-4, 3-4). If items 1 and 2 are unchanged from their original memory position combinations, then there is only one swap which leaves items 1 and 2 unaffected (3-4). In other words, there is only a probability of $(1/6) = 0.167$ that a swap change could have occurred in this situation.
2. Indeed, it might be argued that our results can wholly be accounted for by differences in eye movements across the two experiments. In this explanation, the enhanced performance of the contralateral same configuration condition is not because of the greater use of relative spatial cues, but because of lateral eye movements contaminating the Ipsilateral and Contralateral conditions. Although eye movements were not monitored, there is no good reason to assume that such putative lateral

eye movements could explain the data. Firstly, the presentation rates of the memory and test arrays in the trial sequence are too rapid for voluntary eye movements to occur, and the task gives no incentive to make such anticipatory eye movements in any case, nor does it give any specific incentive under the task conditions of Exp. 2. Finally, this eye movement account struggles to explain why the bias data is not similarly contaminated. The core difference between Exp. 1 and 2 was in the sensitivity data with respect to the side manipulation, for the bias data there was a clear asymmetry across the configuration conditions with respect of the side manipulation, but this was similarly the case across both Experiments. We cannot categorically rule out the lateral eye movement explanation, but it does not seem a plausible one given the task conditions and the results obtained.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The raw data and code is available at <https://osf.io/y42s5/>.

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