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Abstract

The present study investigated the time course of visual information processing that is responsible for successful object change detection involving the configuration and shape of 3-D novel object parts. Using a one-shot change detection task, we manipulated stimulus and interstimulus mask durations (40–500 msec). Experiments 1A and 1B showed no change detection advantage for configuration at very short (40-msec) stimulus durations, but the configural advantage did emerge with durations between 80 and 160 msec. In Experiment 2, we showed that, at shorter stimulus durations, the number of parts changing was the best predictor of change detection performance. Finally, in Experiment 3, with a stimulus duration of 160 msec, configuration change detection was found to be highly accurate for each of the mask durations tested, suggesting a fast processing speed for this kind of change information. However, switch and shape change detection reached peak levels of accuracy only when mask durations were increased to 160 and 320 msec, respectively. We conclude that, with very short stimulus exposures, successful object change detection depends primarily on quantitative measures of change. However, with longer stimulus exposures, the qualitative nature of the change becomes progressively more important, resulting in the well-known configural advantage for change detection.

Disciplines

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**The time course of configural change detection for novel 3-D
objects.**

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Short title: Time course of change detection

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Abstract

This study investigated the time course of visual information processing responsible for successful object change detection involving the configuration and shape of 3D novel object parts. Using a one-shot change detection task, we manipulated stimulus and interstimulus mask durations (40-500 ms), respectively. Experiments 1A and 1B showed no change detection advantage for configuration at very short (40 ms) stimulus durations but the configural advantage did emerge with durations of between 80 - 160 ms. Experiment 2 showed that at shorter stimulus durations the number of parts changing was the best predictor of change detection performance. Finally, in Experiment 3, with stimulus duration of 160 ms, configuration change detection was found to be highly accurate for each of the mask durations tested, suggesting a fast processing speed for this kind of change information. However, switch and shape change detection only reached peak levels of accuracy when mask durations were increased to 160 ms or 320 ms respectively. We conclude that with very short stimulus exposures, successful object change detection depends primarily on quantitative measures of change. However, with longer stimulus exposures the qualitative nature of the change becomes progressively more important, resulting in the well-known configural advantage for change detection.

Introduction

Observers are often “blind” to large changes to a scene when these changes occur simultaneously with a brief disruption, a phenomenon referred to as *change blindness* (see Simons & Levin, 1997 and Simons, 2000 for reviews). While there are limits to the conclusions that may be drawn from change blindness studies (Simons & Rensink, 2005), their results do provide important insights into the kinds of visual information that underlie change detection. *Spatial layout* is one type of information likely to be retained in scene representations to support successful change detection and refers to the overall positioning or placement of the items or elements within a scene/image and does not rely on semantics or the identity of those elements (Hochberg, 1968; Pomerantz, 1983). The retention and representation of spatial layout information is well supported by change detection research with scenes (Simons, 1996; Aginsky & Tarr, 2000; Hollingworth & Henderson, 2002; Rensink, 2000a). Simons (1996) investigated change detection for scene displays consisting of multiple objects (both novel and common objects). He found that changes to the spatial layout or configuration of the display were better detected than either changes involving the switching of objects or the replacement of one of the objects. He concluded that the information about the spatial configuration of the scene is easily encoded and represented visually whereas object-specific information is not.

Recent change detection research suggests that spatial layout or configural information is also important in the processing of single, complex three-dimensional (3-D) objects, as well as multi-object scenes (Favelle, Hayward, Burke & Palmisano, 2006; Favelle, Palmisano, Burke & Hayward, 2006; Keane, Hayward, & Burke, 2003). Configural information or *configuration* is used here to refer to the spatial

layout of an object's parts (i.e. the gross part structure of an object). For example, the configuration of one of the objects used in the current study (see Figure 1) could be described as a central body part with 3 smaller parts, one each attached at the top left, bottom middle top right of the body. This is consistent with the idea that the visual system bases object representation on a "part skeleton" that emphasises structural properties (e.g., the number, location and spatial relations of parts) over metric properties (Barenholtz, Cohen, Feldman & Singh, 2003; Blum, 1973; Kimia, Tannenbaum, & Zucker, 1995). Note that the shape of the parts is not included in a description of configural information. The configuration does not depend on the parts being triangular or cigar-shaped, nor does it depend on a triangular part being in a certain location. That is, neither a change to the shape of a part nor a switching of the shape of parts should alter an object's configuration.

Keane et al. (2003) compared the detection of changes made to the configuration of single, novel complex 3-D objects, with changes to the shape of these object's parts. Using a one-shot change detection task, they found that changes to the configuration of the object's parts were more easily detected than changes to the shape of one of those parts or changes involving a switching of the shape of two different parts. In subsequent control experiments, they showed that: (i) simple differences in the number of pixels changing could not explain the detection differences observed following configural, switch and part shape changes; and (ii) increasing the size of the object parts (relative to the body) did not negate the configural advantage. A later study by Favelle, Hayward et al (2006) found that configural changes to novel 3-D objects were detected more quickly and accurately than part shape or switch changes regardless of their orientation in depth. Again, analysis of quantitative measures of

the magnitude of change (pixels and colour) could not explain differences in performance accuracy between change types. Together, these results imply that the differences in performance between conditions are based primarily on the qualitative nature of the changes. In addition, Favelle, Palmisano et al. (2006), using visual search and cueing tasks, found that configural changes in 3-D objects did not attract attention. It was only once the object was attended to that the processing of configural information appeared to be more accurate and faster than the processing of local part shape information.

Configural information has been shown to be important for the perception and recognition of relatively complex 3-D objects, as well as multi-object scenes. While speed is just one aspect of efficient information processing, little is known about the temporal characteristics of the extraction and utilisation of this configural information. The primary aim of this paper is to address this point. Research has previously examined the time course of configural processing in simple 2-D figures. For example, Kimchi (2000) used a primed matching paradigm to investigate the time course of perceptual organisation of simple configurations (line drawings of crosses, squares and diamonds) and the role of uniform connectedness in this organisation. Participants had to make a same-different judgement to a pair of line drawings after they were primed with either connected or unconnected line drawings or control primes. Kimchi showed that regardless of the connectedness of the prime, and even with prime durations of 40 ms, reaction time to targets with similar configurations was faster than to targets with similar components. That is, there is early configural representation of both connected and disconnected line segments. Kimchi's (2000, 2003) results suggest that there is an explicit representation of the spatial layout of

simple 2-D features, such as oriented lines, in early vision. But the question remains as to the time course of processing configural information in more complex or ecological visual stimuli (e.g. 3-D objects).

The current study investigates the time course of configural information processing involved in a relatively simple 3-D object change detection task. If we assume that the internal representation of a visual stimulus develops over time, then only an early representation of the stimulus would be available for use in such a change detection task at very short stimulus durations (Kimchi, 2003). Consequently, detecting changes to information that is available in these early representations of the stimulus should be facilitated. Richer stimulus representations would become available at longer stimulus durations, in which case change detection should be also facilitated for the other types of information available in these representations. Thus, varying the stimulus durations and the type of information changing in a change detection task should reveal the information available in earlier and later representations of the visual stimuli.

In three experiments, we investigated detection of configural and part shape changes using a one-shot change detection task (as in Keane et al., 2003). Stimulus presentation times for our 3-D objects and interstimulus mask durations were varied such that the processes of information extraction and encoding might be interrupted at different stages in their progress. Specifically, in Experiments 1A and 1B we varied stimulus duration (40-500 ms) in order to determine the minimum stimulus exposure required to extract configural object information for successful change detection. In Experiment 2 we compared configural change detection to a quantitative measure of

change in terms of the number of parts changing. In Experiment 3 we varied mask duration (40-500 ms) to explore the time required to process different types of object information for change detection, once it had been fully encoded. If the configural advantage for 3D objects found by Keane et al (2003) and Favelle, Palmisano et al (2006) was the result of configural information being extracted more rapidly or being available earlier in the representation of a visual stimulus than part shape information, then we would expect to find that changes to this type of information are facilitated at earlier stimulus durations in Experiment 1 and 2. We would also expect that change detection decisions based on this type of information to still be facilitated with the shorter mask durations examined in Experiment 3. Alternatively, it is possible that configural change detection is better because the configuration of parts is more “salient” or useful information, in which case we may find that configural advantage is not significantly influenced by manipulating the stimulus duration.

Experiment 1A

The aim of Experiment 1A was to examine the time course of information extraction for novel 3-D objects. In particular, information regarding the configuration and shape of object parts (in terms of either one part changing shape or two parts switching shape) was investigated. Keane et al. (2003) found a configural advantage using a one-shot change detection task. As the stimulus durations used in that study were relatively long, subjects should have been able to fully extract all the object information required to detect these three types of change (the first object stimulus in each trial was shown for 2 s and the second object stimulus remained on screen until a response was made). In the current experiment, we used a one-shot change detection task, but examined much shorter stimulus durations (40-500 ms - with a 160 ms

constant masked interstimulus interval or ISI). The aim was to interrupt information extraction from the object images at different stages of progress. An ISI of 160 ms was selected based on the findings of previous change blindness research with one-shot tasks, which suggested that observers are poor at detecting change whenever displays are separated by an ISI of more than 70 – 100 ms (Pashler, 1988; Phillips, 1974; Simons, 1996).

While this will be the first experiment to examine the effects of stimulus duration on the detection of configural and shape changes, it is not the first experiment to examine the effect of stimulus duration on change detection for object properties. For example, Rensink (2000b) investigated orientation and polarity change detection using 2D stimuli. He manipulated stimulus duration in a “standard” flicker task (with blank fields appearing between successive images) in which the task was to detect the change in a visual search display consisting of 2, 6 or 10 rectangles. Stimulus duration was varied from 80 – 800 ms in this study, with the ISI held constant at 120 ms. Rensink found similar search slopes for detecting changes to the polarity and orientation of target between 80 and 640 ms, which suggested that the processing time for extracting these orientation and polarity properties were approximately constant.

While Rensink found no differences in processing times for orientation and polarity change detection, there is research that suggests an advantage to configuration extraction processing time in change detection. Kimchi (2000, 2003) appears to show that configural properties are used to group line elements (into simple 2-D objects) as early as 40 ms. Thus, it is possible that the configural advantage in change detection will also arise early in the processing of complex 3-D objects. Note, however, that the

change detection task used in the present study is quite different to the priming tasks used in these previous studies. In addition, Kimchi (2000, 2003) refers to configural properties in terms of holistic properties of a group which is different to how we have operationalised the term. In the current experiment we compare change detection performance in a one-shot task at five stimulus durations.

Method

Participants

A total of 53 undergraduate students participated and were tested individually. Subjects received course credit for participating.

Materials

Stimuli were rendered images of three-dimensional novel objects similar to those used by Keane et al. (2003). These novel objects had simple configurations. They were constructed from geons (Biederman, 1987) and as a result had comparable parts (as opposed to many everyday objects). The aim was to control for any innate or learned preferences for particular part shapes or configurations (an example being the configuration of features within a face). Each object was composed of a main body with three adjoining parts. The parts attached to the body at three of six possible positions (see Figure 1 for example). There were 3 "base" objects, each having three configuration, identity and switch changes made to them, giving a total of 30 different object exemplars used in the current experiment (27 changed objects and 3 unchanged objects). Configuration changes always involved one of the three parts changing their location (relative to the body and the two other parts). Switch changes involved two object parts switching positions, with the third part remaining unchanged. Shape changes involved one of the three parts changing shape. All objects were

photorealistically rendered with the same colour and texture. Objects were shown at the same orientation and magnification. They all had a similar size, with the average dimensions of each object being 7.6° of visual angle wide and 7.4° of visual angle high. The mask used in this experiment consisted of elements taken from a variety of object images. The entire background of the screen was white (for both image and mask displays).

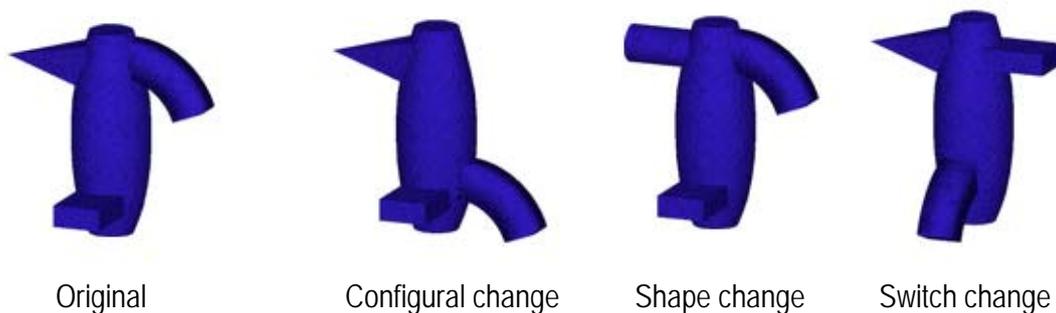


Figure 1. Example of the three different types of change (configuration, shape and switch) used in Experiments 1 and 2.

The experiment was controlled by RSVP software (www.tarrlab.org) running on a Macintosh G4 computer. The presentation timing accuracy of this software was tested using a phototransistor (with a rise/fall time of 6 microseconds) connected via a circuit-board to a Tektronix oscilloscope TD2-220. The input to the phototransistor was isolated using an opaque tube, so that only the light emitted from a 4 cm diameter screen region was received. We measured the temporal responding of this phototransistor during an infinite stimulus-mask loop (with an interstimulus interval of 10 ms, 50 ms or 100 ms). Based on these observations, we concluded that the experimental error introduced by RSVP approximated 10 ms. The primary cause of this experimental error appeared to be the context switching time of the operating

system. This level of experimental error was deemed acceptable, as the minimum stimulus durations examined in the present experiment were 40 ms and 80 ms.

Procedure

Participants were first verbally instructed how to complete the task, with emphasis placed on both speed and accuracy in responding. Written instructions on how to complete the task were also provided on the computer screen. After reading the instructions, participants completed 4 practice trials to familiarise them with the task. Stimuli used in the practise trials were different to the stimuli used in the task. Following the practice trials, participants were given a chance to ask any questions about the procedure, should they have any, before continuing on with the experiment.

The experiment consisted of 270 randomly ordered trials, in each of which subjects viewed sequentially presented pairs of objects on a computer monitor. Each object was randomly placed at a position 25 pixels in any direction from the centre of the screen. Each trial began with a fixation cross appearing for 500 ms at the centre of the screen, followed by the first object which was replaced with a mask appearing on the screen for 160 ms, and finally a second object which was also replaced with a mask. The mask remained on the screen until a response was made or the trial timed out after 5000 ms. Both the first and second objects appeared for the same length of time: 40, 80, 160, 320 or 500 ms. The next trial began 1000 ms after the subject made a response or the trial timed out. The second object was either identical to the first or different in one of three ways: (1) spatial configuration, (2) part shape, or (3) a switching of parts (see Figure 1). Participants were asked to indicate whether the two objects presented to them were the “same” or “different” by pressing corresponding keys on a keyboard. Half of the trials were “same” trials and half were “different”.

The different trials were split equally into the three change type conditions (i.e., 45 trials each) and these were equally split into the five stimulus durations (i.e., 9 trials). Ten self-paced rest periods were interspersed at equal intervals throughout the experimental trials.

Results

No data was removed due to trial timeouts. Change detection accuracy improved as the stimulus duration increased until 160 ms at which point performance appeared to plateau, however, *same* decisions were made with high accuracy across all stimulus durations (see Figure 2). The relative detection performance of the different change types at each of the five stimulus durations was of specific interest to the current study. Thus, planned contrasts between the three change types (configural, switch and shape change) were conducted for each of the 40, 80, 160, 320 and 500 ms stimulus durations. Two sets of contrasts were used to examine the configural advantage: (i) shape changes were expected to be detected less accurately than both switch and configural changes, and (ii) switch changes were expected to be detected less accurately than configural changes.

At each stimulus duration shape changes were detected with significantly less accuracy than either configuration or switch changes (all $p < .01$). Shape change detection was at chance level (51%) at the 40 ms stimulus duration. Performance was above chance for switch and configuration changes at the 40 ms stimulus duration and for all three change types at longer stimulus durations (all $p < .05$). Interestingly, at 40 ms stimulus duration, switch change detection was more accurate than configuration change detection ($p < .05$). At 80 ms stimulus duration, the configural advantage emerged and persisted for 160, 320 and 500 ms stimulus duration conditions, i.e.,

configuration changes were detected more accurately than switch changes (all $p < .05$). See Table 1 for F values.

Table 1. Planned contrast analysis of accuracy data in Experiment 1A. All $df = (1,52)$.

Contrast	MSE	F
Configuration vs switch at 40 ms	.29	7.71
Configuration vs switch at 80 ms	.10	4.21
Configuration vs switch at 160 ms	.11	6.34
Configuration vs switch at 320 ms	.15	18.47
Configuration vs switch at 500 ms	.15	8.38
Configuration & switch vs shape at 40 ms	4.90	35.43
Configuration & switch vs shape at 80 ms	6.19	47.77
Configuration & switch vs shape at 160 ms	4.06	47.59
Configuration & switch vs shape at 320 ms	2.67	33.74
Configuration & switch vs shape at 500 ms	3.30	38.83

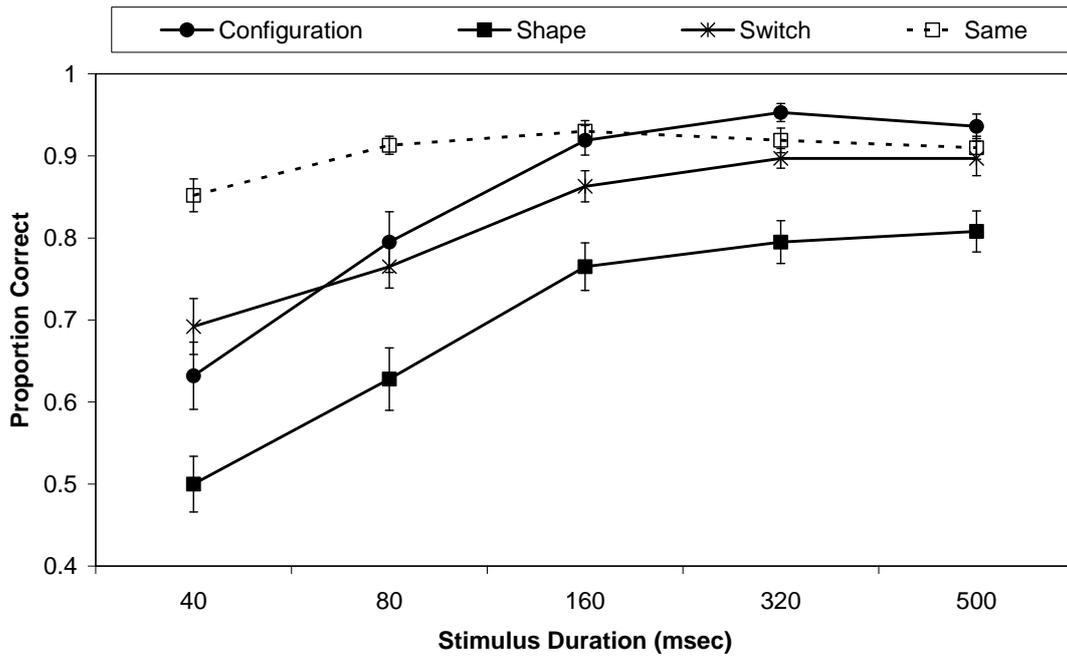


Figure 2. Mean accuracy on the change detection task in Experiment 1A as a function of change type and stimulus duration. Error bars represent standard errors of the means.

Data analysis of reaction time (RT) was conducted on only the accurate responses. The same set of planned contrasts used to analyse the accuracy data was applied to the RT data. Despite a general trend to slower reaction times for shape change detection and faster reaction times to configuration change detection, no significant differences were found between change types at any stimulus duration (all $p > .05$) except that participants were slower to detect shape changes than configural or switch changes at 320 and 500 ms (both $p < .05$ - see Figure 3). See Table 2 for F values.

Table 2. Planned contrast analysis of RT data in Experiment 1A. All $df = (1,52)$.

Contrast	MSE	F
Configuration vs switch at 40 ms	290263.96	2.12

Configuration vs switch at 80 ms	25704.22	.83
Configuration vs switch at 160 ms	4924.38	.47
Configuration vs switch at 320 ms	81.27	.004
Configuration vs switch at 500 ms	6821.96	.45
Configuration & switch vs shape at 40 ms	711995.03	2.20
Configuration & switch vs shape at 80 ms	106809.85	1.87
Configuration & switch vs shape at 160 ms	75740.55	2.49
Configuration & switch vs shape at 320 ms	670124.18	6.71
Configuration & switch vs shape at 500 ms	245558.37	4.43

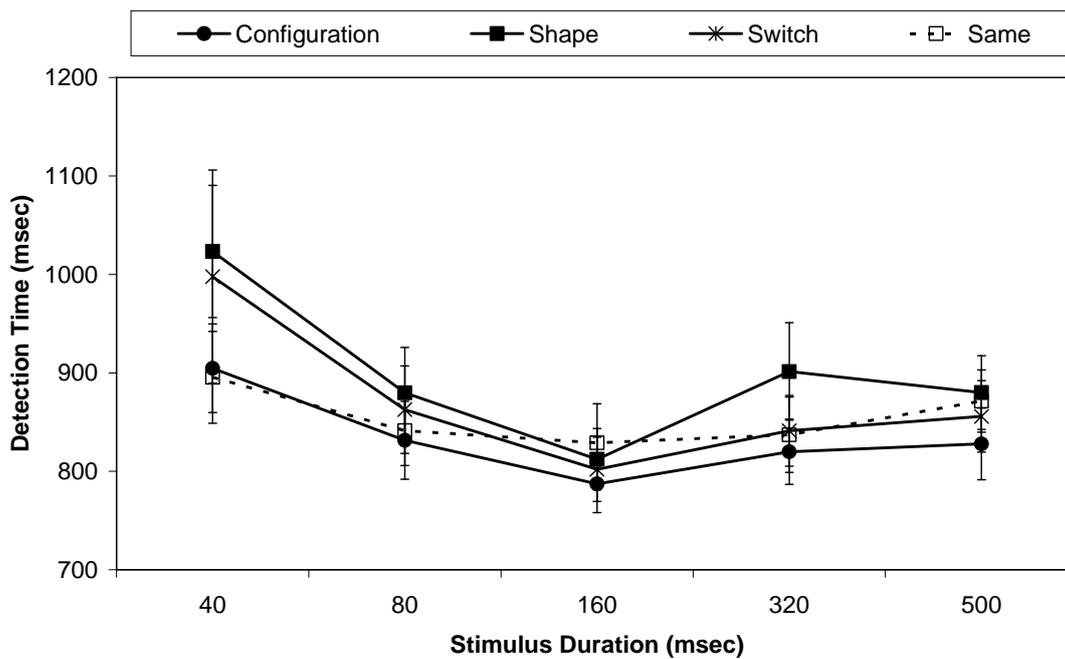


Figure 3. Mean reaction time on the change detection task in Experiment 1A as a function of change type and stimulus duration. Error bars represent standard errors of the means.

Discussion

The three change types investigated in Experiment 1A involve three different types of information about the parts of an object. A configural change involves knowing “where” the parts are; a shape change involves knowing “what” parts are in the image; a switch change involves knowing “what” parts are “where”. We found that subjects could detect both configural and switch changes with above chance accuracy with stimulus durations lasting as little as 40 ms, which corresponds with Kimchi’s (2000, 2003) finding that the configural properties of 2D objects can be utilised in 40 ms. Interestingly, switch changes were more accurately detected than configural changes at 40 ms durations¹. This finding is in contrast to current results with longer stimulus durations (80 – 500 ms) and with previous research using much longer stimulus durations (up to 2500 ms) showing that configural changes are always better detected than part switches (Favelle, Hayward et al., 2006; Favelle, Palmisano et al., 2006; Keane et al., 2003).

One explanation of these findings is that in the very early stages of visual information extraction, when given only 40 ms exposure to a stimulus, change detection may be biased toward some quantitative aspect of the change. In the current study (and also in our previous studies), configural changes to objects produced a greater amount of change in terms of the numbers of silhouette pixels changing than either switch or shape changes. In our previous studies, which used longer stimulus durations, the numbers of silhouette pixels changing could not account for the configural advantage found for change detection (Keane, et al 2003, Favelle, Hayward, et al., 2006).

¹ Looking at Figures 2 and 3, there appears to be a speed-accuracy tradeoff between switch and configuration change at 40 ms stimulus duration, however participants did not take significantly longer to respond to switch changes than to configural changes ($p = .1$).

However, if change detection in the current study was based on this kind of quantitative measure for shorter stimulus durations, we should have found a clear configural advantage at 40 ms, which we do not.

Experiment 1B

Experiment 1A and experiments in previous studies (Favelle, Hayward, et al., 2006; Favelle, Palmisano, et al., 2006; Keane, et al 2003) always randomized trial presentation so that participants were not able to predict the type of change that they would be exposed to on any given trial. This particular design allowed us to examine the types of information which are spontaneously accessed and utilized in a change detection task. By contrast, Experiment 1B examined change detection performance when the type of change (configuration, switch or part shape) presented in each block of trials was completely predictable. It was possible that with this type of blocked design, participants might develop strategies to detect each particular change type, and as a result, performance would improve and differences between the different change types would disappear².

Method

Participants

Both the authors and 22 naïve students were tested individually, giving a total of 24 participants. Student participants received course credit for participating.

Materials

Same as for Experiment 1A.

Procedure

² Thanks to a reviewer for this suggestion.

Same as for Experiment 1A except that change type (configuration, shape and switch) was blocked. The order of blocks was fully counterbalanced between participants. Stimulus duration was randomised within blocks. There was a self-paced rest period between each block and two self-paced rest periods were interspersed at equal intervals within each of the blocks.

Results

The pattern of results was the same as for Experiment 1A (see Figures 4 and 5). No data was removed due to trial timeouts. Similar analyses were conducted, that is, planned contrasts between the three change types (configural, switch and shape change) were conducted for each of the 40, 80, 160, 320 and 500 ms stimulus durations.

At each stimulus duration shape changes were detected with significantly less accuracy than either configuration or switch changes (all $p < .02$). Shape change detection was not different to chance at either the 40 and 80 ms stimulus durations (both $t < 1.2$, $p > 0.2$) and neither was configuration change detection different to chance at 40 ms stimulus duration ($t < 1$, $p > 0.4$). Performance was above chance for all other conditions (all $p < .05$). Although the trend was the same as Experiment 1A in that switch changes were more accurately detected than configuration changes at 40 ms but not at 80 ms, switch change detection was not different to configuration change detection (both $p > .1$) at either of these stimulus durations. At 160 ms stimulus duration, the configural advantage emerged and persisted for 320 and 500 ms stimulus duration conditions, i.e., configuration changes were detected more accurately than switch changes (all $p < .05$). See Table 3 for F values.

Table 3. Planned contrast analysis of accuracy data in Experiment 1B. All $df = (1,23)$.

Contrast	MSE	F
Configuration vs switch at 40 ms	0.10	2.0
Configuration vs switch at 80 ms	0.17	3.03
Configuration vs switch at 160 ms	0.21	5.69
Configuration vs switch at 320 ms	0.17	4.28
Configuration vs switch at 500 ms	0.13	6.24
Configuration & switch vs shape at 40 ms	1.19	7.41
Configuration & switch vs shape at 80 ms	4.55	18.91
Configuration & switch vs shape at 160 ms	1.98	14.63
Configuration & switch vs shape at 320 ms	1.0	13.13
Configuration & switch vs shape at 500 ms	0.91	10.53

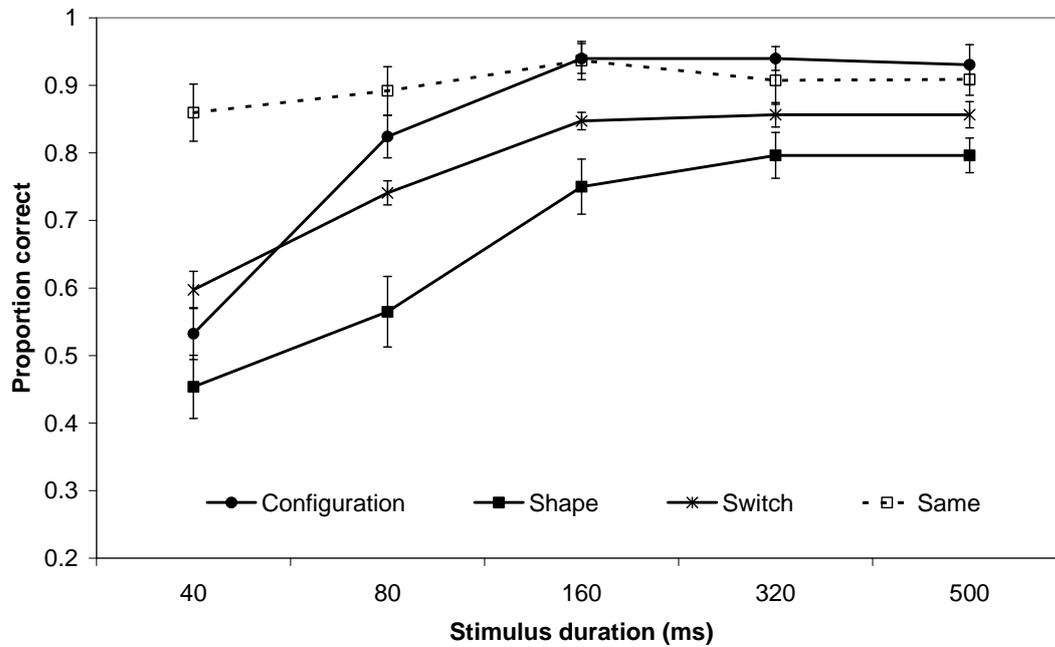


Figure 4. Mean accuracy on the change detection task in Experiment 1B as a function of change type and stimulus duration. Error bars represent standard errors of the means.

Data analysis of reaction time (RT) was conducted on only the accurate responses. The same set of planned contrasts used to analyse the accuracy data was applied to the RT data. A similar trend as Experiment 1A to slower reaction times for shape change detection and faster reaction times to configuration change detection can be seen in Figure 5, but no statistically significant differences were found between change types at any stimulus duration (all $F < 3.7, p > .05$).

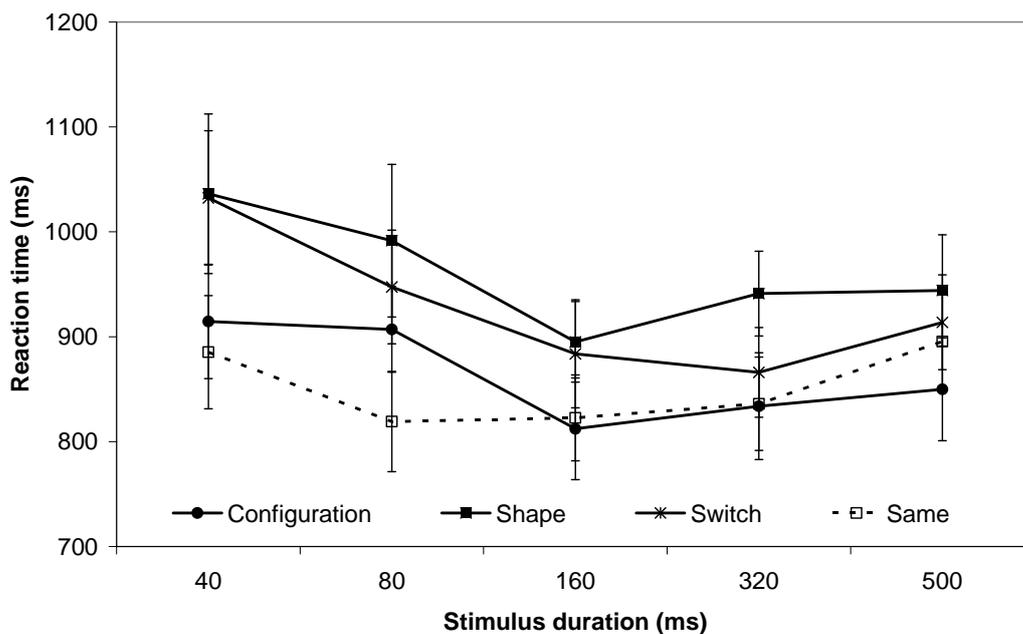


Figure 5. Mean reaction time on the change detection task in Experiment 1B as a function of change type and stimulus duration. Error bars represent standard errors of the means.

Discussion

Experiment 1B show the same pattern of results as Experiment 1A, demonstrating that blocking the change type conditions separately has no effect on the time course of the configural advantage. Thus, allowing our participants to select an optimal strategy for each change type did not appear to significantly influence performance. In the current experiment, the configural advantage remained absent at shorter stimulus durations and still only emerged at about 160 ms, even though participants could focus on the most relevant change detection information (either the parts or the global configuration) for the particular trial. This suggests that the current findings (as well as results from previous studies, e.g., Favelle, Hayward, et al., 2006; Favelle, Palmisano, et al., 2006; Keane, et al 2003) are based on differences in the way that the visual system processes the different object properties of configuration and shape, and not on opportunistic strategy selection.

Experiment 2

It has been shown that the magnitude of change can modulate change detection performance (e.g., Williams & Simons, 2000; Smilek, Eastwood & Merikle, 2000). Some previous studies have employed post-hoc pixel change analyses to demonstrate that configural properties affect change detection in addition to magnitude of change (Favelle, Hayward, et al., 2006; Keane, et al 2003). Others have examined this issue directly, by manipulating the number of parts involved in the change as a quantitative measure of the size of change. For example, with long (greater than 1.5 s) stimulus durations and changes involving the replacement of 1, 2, or 3 novel object parts, Williams and Simons (2000) found that changes involving more parts were easier to detect than changes involving fewer parts.

In Experiments 1A and 1B, switch changes always involved two parts switching location, whereas shape and configural changes always involved only one part. If the object stimulus was not fully encoded during the 40 ms exposure, then there would be a greater likelihood that the partial object representation contains one of the two parts involved in a switch change, compared to the one part involved in a configuration or shape change. Experiment 2 was run to test this idea.

In this experiment, we compared detection performance following configuration changes to that following shape changes involving one, two or three object parts (producing a total of four change type conditions). The 1-part configuration changes and 1-part shape changes were identical to conditions investigated in Experiments 1A and 1B. If it is the case that with 40 ms exposure, the number of parts changing is a greater determinant of change detection performance than the type of change, then configuration change detection should be worse than the detection of 2- or 3- part changes. Based on the findings of Williams and Simons (2000), we might expect that regardless of stimulus duration, changes involving three parts should be better detected than changes involving fewer parts. However, if configural information becomes more important for change detection performance as stimulus duration increases, then we should see a relative configural advantage emerge at 160 ms (and not 40 ms).

Method

Participants

A total of 16 undergraduate students participated and were tested individually. Subjects received course credit for participating.

Materials

Configuration and one-part shape changes were the same as for Experiment 1A and 1B with two additional types of object change: (i) two parts changing shape, and (ii) three parts changing shape. As for shape changes in Experiments 1A and 1B, shape changes in the current experiment saw the body part remained the same within a trial and the adjoining parts were replaced.

Procedure

Same as for Experiment 1A with the following differences. The experiment consisted of 288 randomly ordered trials. Half of the trials were “same” trials and half were “different”. The different trials were split equally into the four change type conditions (i.e., 36 trials each) and these were equally split into the 2 stimulus durations (i.e., 18 trials). The second object was either identical to the first or different in terms of: (i) one part changing location (i.e., a configural change), (ii) one part changing shape, (iii) two parts changing shape, or (iv) three parts changing shape.

Results

No data was removed due to trial timeouts. A 4 x 2 repeated measures ANOVA including change type (configuration, 1-part shape, 2-part shape and 3-part shape) and stimulus duration (40 and 160 ms) was used to analyse the accuracy data (see Figure 4). There was a significant interaction between change type and stimulus duration, $F(3,45) = 5.75$, $p = .002$, $MSE = .05$. Based on Bonferroni adjusted pairwise comparisons, this interaction was interpreted as follows: as the stimulus duration increased from 40 to 160 ms, there was a large and significant improvement in change detection accuracy for configuration changes ($M_{config} = .24$, $p < .01$) with smaller, only sometimes significant improvements found for shape changes ($M_{1-part} = .10$, $p < .05$; $M_{2-part} = .06$, $p = .09$; $M_{3-part} = .09$, $p < .05$). In addition, 40 ms stimulus duration

configuration changes were detected as accurately as one part shape changes ($p = 1.0$) and significantly less accurately than any other type of change (all $p < .05$). But at 160 ms stimulus durations configuration changes were significantly more accurately than one part changes ($p < .05$), and detected as accurately as two part shape changes ($p = 1.0$), but still less accurately than for three part shape changes ($p < .01$). Overall, changes were detected more accurately with 160 ms stimulus durations than 40 ms durations, $F(1,15) = 12.15$, $p = .003$, $MSE = .47$, and there was a significant main effect of change type, $F(3,45) = 62.16$, $p = .000$, $MSE = .54$.

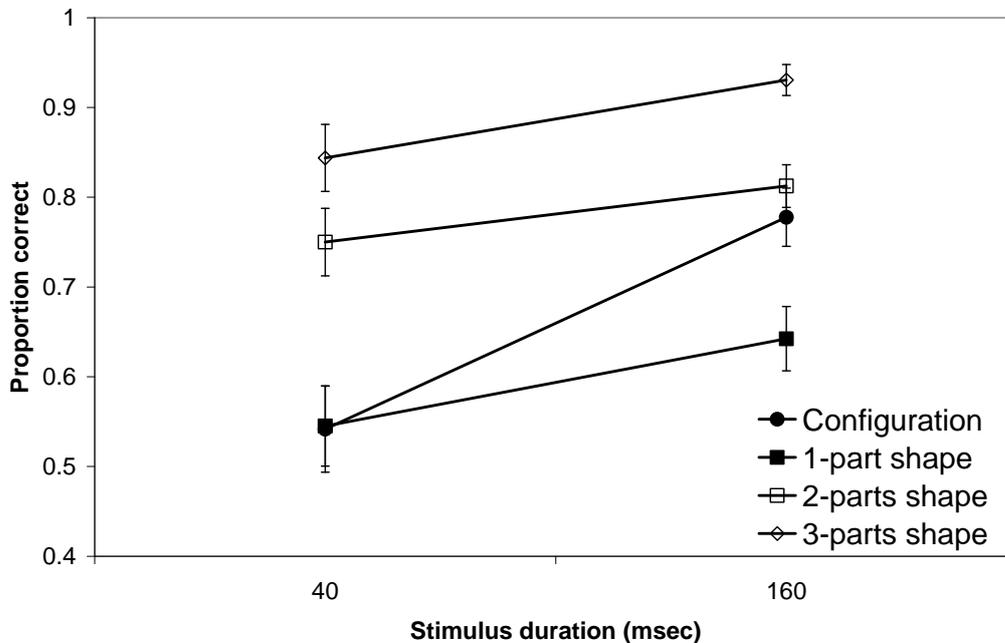


Figure 4. Mean proportion correct on the change detection task in Experiment 2 as a function of change type and stimulus duration. Error bars represent standard errors of the means.

A 4 x 2 repeated measures ANOVA including change type (configuration, 1-part shape, 2-part shape and 3-part shape) and stimulus duration (40 and 160 ms) was conducted on RT data for accurate responses (see Figure 5). There was a main effect

of change type $F(3,45) = 8.1$, $p = .000$, $MSE = 65623$. Bonferroni adjusted post-hoc comparisons showed that 3-part shape changes were detected significantly faster than configuration or 1-part changes (all $p < .05$). No significant differences in RT were found between any of the other change types (all $p > .08$). There was no main effect of stimulus duration on RT, $F(1,15) = 0.7$, $MSE = 8080$. The interaction between stimulus duration and change type also failed to reach significance $F(3,45) = 1.1$, $MSE = 9075$.

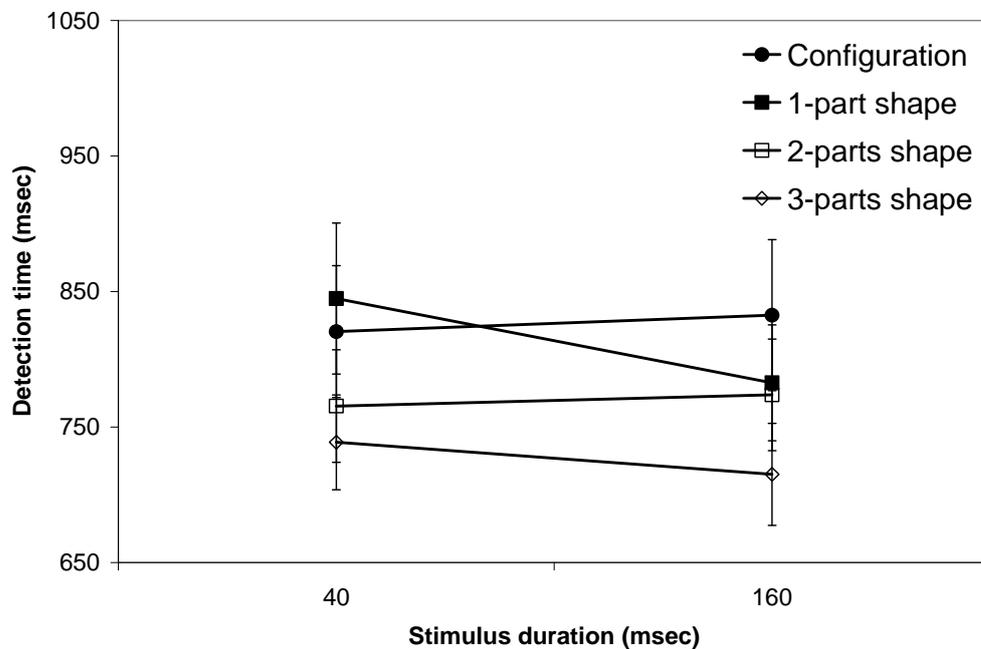


Figure 5. Mean reaction time on the change detection task in Experiment 2 as a function of change type and stimulus duration. Error bars represent standard errors of the means.

Discussion

Overall, Experiment 2 shows that as the number of parts involved in a change increases, the accuracy of change detection also increases. This is in line with findings from Williams and Simons (2000). However, stimulus duration interacts with

configural change detection. The results of Experiments 1A, 1B and 2 suggest that change detection with very short stimulus durations is primarily based on the number of parts changes (one quantitative aspect of the change). However, as the stimulus duration increases, configuration change detection improves significantly, whereas shape change does not (or at least only slightly). These results suggest that while shape changes clearly contribute to change detection performance, it is configural information that becomes progressively more important as the object representation develops with time. It appears that we may need at least 160 ms exposure to a stimulus to reliably extract object layout information and detect changes to configuration.

An interesting difference in detection performance was observed in Experiment 2. While configuration changes were more accurately detected than 1-part shape changes with 40 ms stimulus durations in Experiment 1A and 1B, detection was not found to be significantly different for these two conditions in Experiment 2. This discrepancy is likely to have been due to an overall shift in response bias in Experiment 2 given the presence of larger quantitative changes in this experiment (in particular, the very salient 3-part shape changes). Cross-experimental analyses of hit rates and false alarms provide some evidence that this could be the case (see Appendix A for a full analysis).

Experiment 3

Once the different types of information about an object have been extracted from an image, this information must then be retained and further processed in order to allow subsequent change detection. Experiment 3 examined the time course of this post-

exposure information processing by altering the duration of the ISI on change detection for complex objects. This experiment also aimed to ascertain the amount of time required to process the different types of object information involved in configural, switch and 1-part shape changes. One explanation of the configural advantage is that post-exposure processing of configural information is faster in a change detection task than other types of information. That is, the time required to determine whether two stimuli have different configural properties is less than that required to determine whether two stimuli differ in terms of their shape properties. The results of Experiment 1A and 1B showed above chance accuracy for detecting switch changes at 40 ms stimulus exposure and for detecting configural changes at 40 ms for Experiment 1A (but not in Experiment 1B). However, change detection performance was found to improve and plateau after stimulus duration of about 160 ms for all change types. The latter finding suggests that all three of types of object information can be successfully extracted within this time frame. Since our aim in this experiment was to explore the time course of processing of the different types of object information once they had been extracted, stimulus duration was held constant at 160 ms in this second experiment.

Rensink, O'Regan and Clark (2000, Experiment 2) examined the effect of the duration of the blank fields in a flicker task on the detection of change in central and marginal interest areas of scenes. Their aim was to test whether change blindness was a result of a disruption to the process of consolidating representations necessary for change detection or due to early-level representations being volatile. Rensink et al employed a "standard" flicker task with images presented for 240 ms each, while the duration of the interleaved blank field was varied (40ms, 80ms 160ms, or 320ms).

The pattern of results was complex and did not conclusively support either the volatility or the disruption hypothesis, but in general, Rensink et al (2000, Experiment 2) found that longer blank field durations produced longer RTs, regardless of the type of change (i.e., to central or marginal interest areas of the image). Similarly, we expect in the current experiment that as ISI increases, RT will also increase. As for the effect of ISI duration on the detection of different types of changes, Rensink et al. (2000) found no RT differences in detection between central and marginal changes when ISI was varied. Thus, we might expect that there will be no effect of ISI or mask duration on the RT for detecting the three different change types. However, since we have no evidence relating directly to these three types of changes or to the effects of mask duration on change detection accuracy (as opposed to RT), no firm hypotheses can be made. In a similar fashion to Experiments 1A and 1B, the accuracy and RT data analysis examined planned comparisons of the three different change types at each of the five mask durations used in the current experiment.

Method

Participants

A total of 27 undergraduate students participated and were tested individually. Subjects received course credit for participating.

Materials

The same materials were used as for Experiment 1A and 1B.

Procedure and design

The procedure was identical to that of Experiment 1A with the following exception: Each trial began with a fixation cross appearing for 500 ms at the centre of the screen,

followed by the first object for 160 ms which was then replaced by a mask of variable duration (40, 80, 160, 320 or 500 ms), and next by a second object for 160 ms, which was finally replaced with a mask that remained on the screen until either a response was made or the trial timed out (after 5000 ms). The next trial began 1000 ms after the subject made a response (“same” or “different”) or the trial timed out.

Results

Data from only one trial was removed from analysis due to a timeout. Looking at Figure 6, it appeared that mask duration had little effect on detection accuracy in the *same* and configural change conditions, yet both switch and 1-part shape change detection improved as mask duration increased. Planned linear contrasts showed that detection accuracy did not increase linearly with increasing mask duration within the configuration change condition [$F(1,26) = .41, p = .53$]. However, detection accuracy did increase linearly with increasing mask duration within both the switch and 1-part shape change conditions [$F(1,26) = 10.4, p < .05$, and $F(1,26) = 5.92, p < .05$, respectively]. We conducted the same set of planned contrasts as in the analysis of data in Experiment 1 on the detection accuracy data. The results showed that across each of the mask durations (40, 80, 160, 320 and 500 ms), the detection accuracy for 1-part shape changes was significantly worse than either switch or configuration changes (all $p < .01$). Configuration change detection was also significantly more accurate than switch changes at 40, 80 and 160 ms mask durations (all $p < .05$). However, there was no significant difference between configuration and switch changes at 320 or 500 ms mask durations (both $p > .05$). See Table 3 for F values.

Table 3. Planned contrast analysis of accuracy data in Experiment 3. All $df = (1,26)$.

Contrast	MSE	F
Configuration vs switch at 40 ms	.50	16.73
Configuration vs switch at 80 ms	.18	10.36
Configuration vs switch at 160 ms	.12	5.54
Configuration vs switch at 320 ms	.05	1.99
Configuration vs switch at 500 ms	.03	.91
Configuration & switch vs shape at 40 ms	3.96	19.52
Configuration & switch vs shape at 80 ms	3.87	33.06
Configuration & switch vs shape at 160 ms	4.21	48.06
Configuration & switch vs shape at 320 ms	1.14	9.43
Configuration & switch vs shape at 500 ms	2.37	26.84

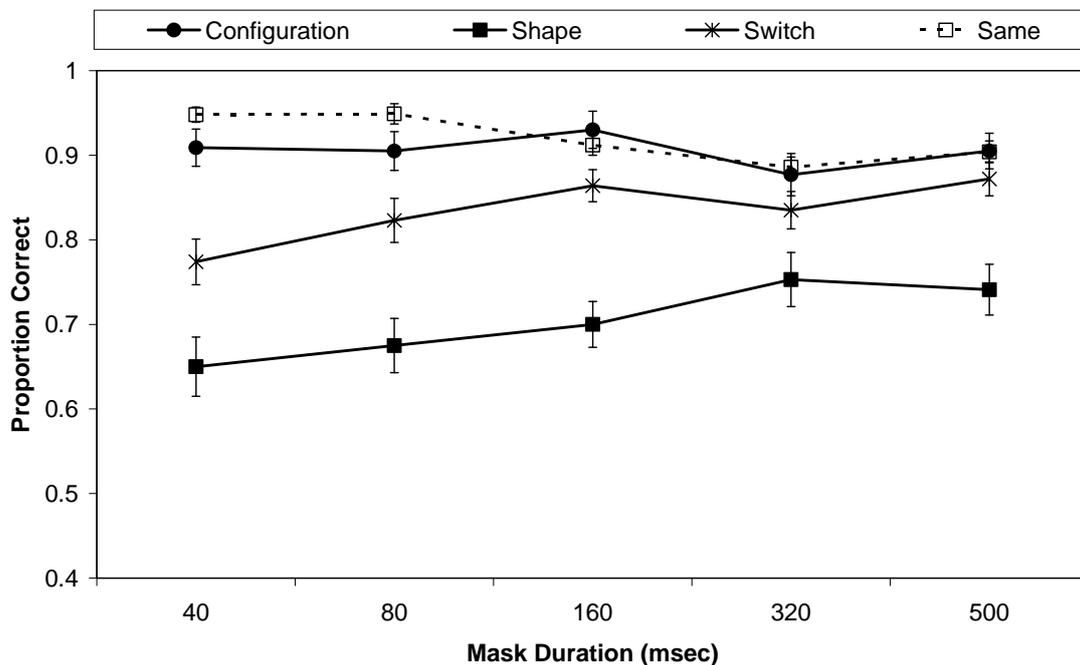


Figure 6. Mean accuracy on the change detection task in Experiment 3 as a function of change type and mask duration. Error bars represent standard errors of the means.

Data analysis of reaction time (RT) was conducted on only the accurate responses. Contrary to expectations, the planned linear contrast analysis showed that RT did not increase linearly with increasing mask duration within any of the change conditions [configuration: $F(1,26) = .21, p = .65$; switch: $F(1,26) = .93, p = .34$, and shape: $F(1,26) = 1.5, p = .23$]. The set of planned contrasts corresponding to those in Experiment 1 showed that configural changes were detected quicker than switch changes at 160 ms mask durations ($p < .05$) and 1-part shape changes were detected more slowly than configural and switch changes at 80, 160 and 320 ms mask durations ($p < .05$) (see Figure 7). All remaining change type differences in RT (i.e. at other mask durations) failed to reach significance (all $p > .05$). See Table 4 for F values.

Table 4. Planned contrast analysis of RT data in Experiment 3. All $df = (1,26)$.

Contrast	MSE	F
Configuration vs switch at 40 ms	1965.60	.13
Configuration vs switch at 80 ms	40871.61	2.48
Configuration vs switch at 160 ms	64358.46	5.48
Configuration vs switch at 320 ms	6291.59	.18
Configuration vs switch at 500 ms	483.60	.03
Configuration & switch vs shape at 40 ms	177930.17	2.68
Configuration & switch vs shape at 80 ms	304680.25	6.14
Configuration & switch vs shape at 160 ms	506670.41	9.51
Configuration & switch vs shape at 320 ms	467038.72	4.62
Configuration & switch vs shape at 500 ms	3253.93	.07

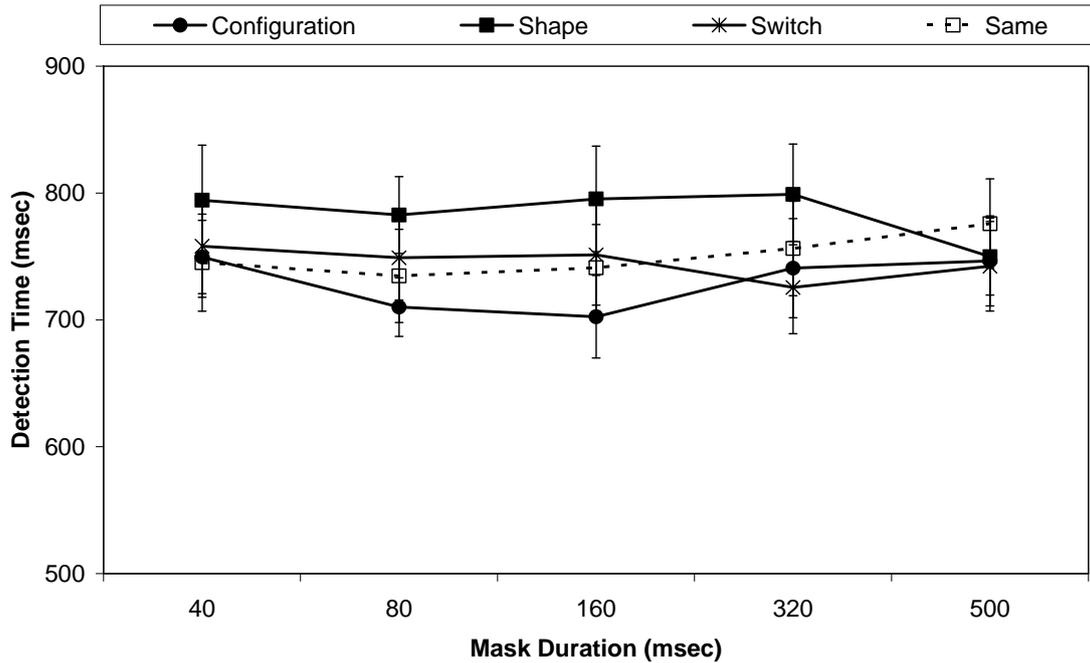


Figure 7. Mean reaction time on the change detection task in Experiment 3 as a function of change type and mask duration. Error bars represent standard errors of the means.

Discussion

The results showed there were differences in the speed with which fully encoded object properties (configuration and shape of parts) could be used to successfully detect change. Configural information for change detection was retained and used accurately across all the mask durations tested. However, switching part shapes and 1-part shape replacement change detection accuracy only reached maximal performance at around 160 and 320 ms mask durations, respectively. This pattern of results suggests that the post-exposure processing time required to accurately detect a switch change or a shape change was four to eight times longer than to detect a configuration change. We failed to find an increase in RT with increasing ISI. This might reflect a

difference in processing scenes (Rensink et al., 2000) as opposed to the single 3-D objects examined in the current study.

General Discussion

The goal of the current study was to determine the time course of extracting and processing configural and component shape properties in 3-D objects using a one-shot change detection task. In Experiments 1A, we manipulated stimulus duration (40-500 ms) in order to determine the stimulus exposure required to extract configural, part shape and arrangement (i.e., switching parts) information. While a detection advantage was found for switch changes over configuration and part shape changes with 40 ms stimulus durations, a configural advantage emerged at 80 ms stimulus durations and persisted for longer stimulus durations. Interestingly, detection performance for all three change types was found to plateau from the same stimulus duration (160 ms). Experiment 1B showed that the same pattern of results was obtained when change conditions were blocked (allowing participants to develop different strategies for different change types). This suggests that change detection performance is determined by the nature of the visual information being processed and not by possible compromise strategies being adopted by participants. Experiment 2 showed that at 40 ms stimulus durations, the number of parts changing was a better predictor of detection performance than the qualitative nature of the change. But at longer stimulus durations, the overall configuration of the object's parts appeared to play an increasingly important role in object processing and change detection performance. Finally, Experiment 3 manipulated ISI mask duration (40-500 ms) to determine the time required to process these different types of object information for change detection, once it had been fully encoded (i.e. stimulus duration was held constant at 160 ms). While configural change detection was unaffected by mask

duration manipulations (performance appeared to be at ceiling levels with ISIs as short as 40 ms), mask durations of approximately 160 - 320 ms appeared necessary for switch and shape changes to reach peak performance accuracy.

In general, we found the expected configural advantage over switch and shape changes – at least when these different change types were similar in terms of the number of parts changing³ (Favelle, Hayward, et al., 2006; Favelle, Palmisano, et al., 2006; Keane, et al., 2003). However, this configural advantage only emerged at stimulus durations of 160 ms or longer. With shorter 40 ms stimulus durations, we instead found a switch advantage over configuration and 1-part shape changes in Experiments 1A and 1B, and no significant difference between configuration and 1-part shape changes in Experiment 2. Thus, we propose that 40 ms is too short an exposure to create a complete representation of “what” and “where” all the parts are of the 3D objects used in this study. Twice as many parts were involved in a switch change compared to either a 1-part configuration change or a 1-part shape change. If one assumes that only a partial object representation can be created with a 40 ms stimulus exposure, then the probability of such a representation containing one of the two parts involved in a switch change will be greater than the probability of it containing the one part involved in a configuration or shape change. Thus, it seems that at very short stimulus exposures, the number of parts or proportion of the object involved in a change is more important for successful change detection than the type of change. This appears to be at odds with findings of configural property dominance over components in early vision (e.g., Kimchi, 2000, 2003), however, in Experiment

³ It should be noted that we did actually find the best detection performance, in terms of both accuracy and RT, for the largest object changes (i.e. 2- and 3-part shape changes) across all stimulus durations as expected from Williams & Simons (2000).

1A configural change detection was both significantly above chance and more accurate than shape change detection at 40 ms stimulus duration.

Experiment 3 revealed significant differences in the length of post-exposure processing required for accurate configural, part shape and switch change detection. Configural change detection was found to be highly accurate and largely unaffected by the duration of the ISI mask, suggesting that very little post-exposure processing was required to successfully detect a configural change. Conversely, both switch and shape change detection was found to improve with ISI durations up to 160 and 320 ms, respectively. These findings indicate that once extracted, configural information is utilised much faster than either shape or location information (at least when generating a change detection decision). This is in line with research by Kimchi and Bloch (1998), who found that when both configural and component properties were available in discrimination and classification tasks, configural properties dominated performance.

Taken together, the current results show that: (i) the amount of change (parts or pixels) determines change detection performance at very brief stimulus exposures, and (ii) some configural information can be extracted with short stimulus exposure but a complete representation of configural information takes time. This is in line with a system whose primary goal is object identification and recognition, where the earliest available information is used to determine the low-level properties of an object (e.g., size, surface parsing, and segmenting of regions on the basis of shared texture) necessary for the development of higher-level properties such as configuration.

As mentioned previously, speed is just one aspect of efficient information processing. We have shown in Experiment 3 that once extracted, configural or structural information appears to be processed quicker than local shape information in 3-D objects. This finding has implications for theories of object recognition in that it suggests that structural and featural information is processed separately and that the representation of structural information may have some priority. Theories in which object recognition is achieved by template matching or with representations that do not individuate (parts or structural) features (e.g., Ullman, 1989) cannot account for the current findings. Likewise, pure featural accounts that do not explicitly encode the position or location of a set of localised features (e.g., Mel, 1997) will also fail to account for these findings. There are, however, a number of theories that ascribe a distinct role to the representation of structural information including structural description theory (Marr & Nishihara, 1978), Recognition-by-Components and its variants (Biederman, 1987; Hummel & Biederman, 1992; Biederman & Gerhardstein, 1993) and Chorus of Fragments (Edelman & Intrator, 2000, 2003). Note that the current results speak to the question of whether structural relations and features are encoded separately and not to the specific nature of the representations themselves (also see Barenholtz & Tarr, 2007).

In conclusion, the current results were generally consistent with previous research demonstrating a configural advantage for object change detection (Keane et al., 2003; Favelle, Hayward et al., 2006; Favelle, Palmisano et al., 2006). However, our experiments have shown that stimulus duration plays a critical role in the emergence of this configural advantage. With short stimulus durations (40 ms), change detection

was best predicted by the magnitude of the change (i.e. not by the type of change, but rather how many parts are involved in the change). Superior configural change detection was only found to emerge when observers were given at least 160 ms stimulus exposure, which thus provides a rough estimate of the minimum amount of time required to extract useful configural object information. Interestingly, while this configural advantage persisted for longer stimulus durations, detection performance plateaued for all three types of change (configural, switch and shape) with stimulus durations around 160 ms. Our results suggest that much of the configural advantage arises during post-exposure processing. While manipulations of the post-exposure processing time had no significant effect on configural change detection (highly accurate performance was evident at all mask durations), peak switch and shape change detection required a minimum of 160 or 320 ms post-exposure processing. Taken together, these findings are consistent with models of visual object processing in which configural properties dominate performance, via their speedier processing and more effective utilisation.

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Appendix A

To determine whether a shift in bias might be responsible for differences in change detection performance in Experiments 1A and 1B, we performed cross-experiment analyses on the hit rate (HR) and false alarm rate (FA) data for the comparable change conditions (i.e. configuration change and 1-part shape change conditions). In the terminology of signal detection theory, the accuracy data for the configuration and 1-part shape change trials corresponds to the hit rates, whereas the accuracy data for the same trials corresponds to the false alarm rates. It should be noted that because the presentation order of same and different trials was fully randomised in both Experiments 1A and 1B (as opposed to being presented in separate blocks), this false alarm rate does not discriminate between the different change type conditions. Calculating a traditional d' measure of sensitivity is not appropriate in this situation. Thus, we checked for evidence of changes in bias between experiments 1A and 1B using two cross experimental comparisons. First we ran a split-plot ANOVA on the hit rate data for comparable conditions in Experiments 1A and 1B - i.e. Experiment type (1A vs 1B) x change type (Configuration vs 1-part shape) x Stimulus duration (40 ms vs 160 ms). Second we ran a split-plot ANOVA on the false alarm rate data for comparable conditions in Experiment 1A and 1B - i.e. Experiment type (1A vs 1B) x Stimulus duration (40 ms vs 160 ms).

The split-plot ANOVA on the HR data (see Figure 6) showed no significant between subjects effect of experiment, $F(1,67) = 2.9$, $MSE = 0.22$, but this factor did interact with both change type (marginally), $F(1,67) = 3.78$, $p = .06$, $MSE = 0.06$ and stimulus duration, $F(1,67) = 6.12$, $p = .02$, $MSE = 0.19$. Bonferroni adjusted post-hoc comparisons were conducted to investigate these interactions further. Even though

equivalent conditions were tested in the two experiments, HR for configuration changes were significantly lower in Experiment 1B than 1A ($p < .05$), while HR was unaffected for 1-part shape changes ($p > .53$). It seems that the new 2-part and 3-part shape change conditions in Experiment 1B impaired performance in the configuration condition (either because participants were exposed to ‘larger’ changes or changed their detection strategy to focus on local, as opposed to global, changes). While there was no difference between Experiments 1A and 1B in terms of HR at 40 ms stimulus durations ($p = .93$), HR were significantly lower in Experiment 1B than 1A at 160 ms stimulus durations ($p < .01$) which was the duration at which the configuration advantage was first found to emerge in Experiment 1A.

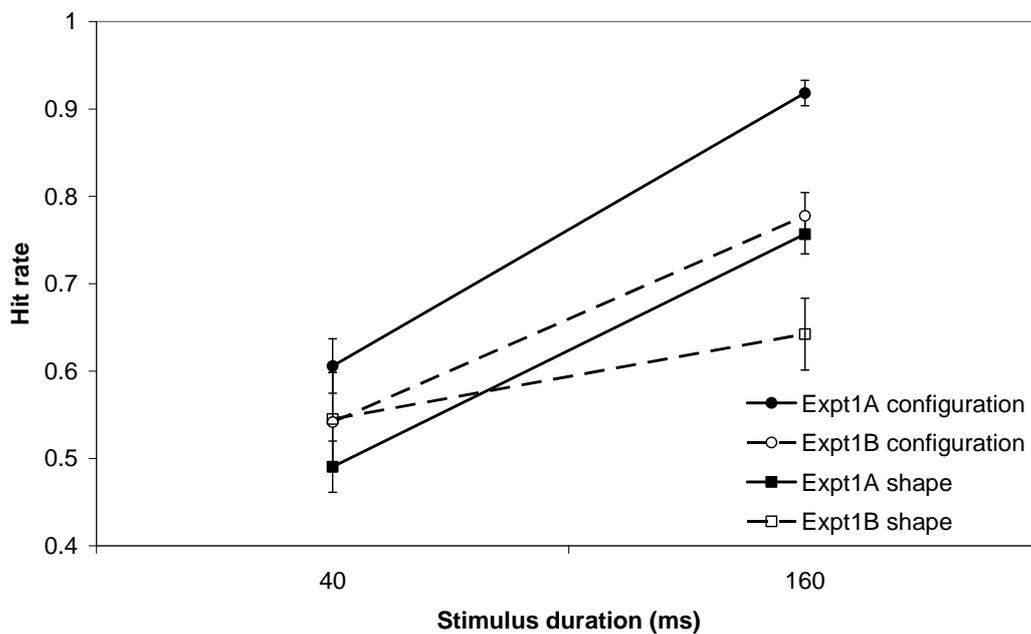


Figure A1. Mean hit rates on the change detection task in Experiments 1A and 1B as a function of change type and stimulus duration. Error bars represent standard errors of the means.

Analysis of the FA data showed that the effect of experiment was marginally significant, $F(1,67) = 3.39$, $p = .07$, $MSE = 0.025$. The trend showed lower mean FA rates in Experiment 1A (0.11) than Experiment 1B (0.14). As expected, FA rates were higher for 40ms (.16) than 160 ms (.09) stimulus durations, $F(1,67) = 20.73$, $p < .01$, $MSE = 0.13$. There was no interaction between experiment and stimulus duration $F(1,67) = 1.14$, $MSE = 0.007$. This result suggests that there was a change in response bias between experiments.