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The utility of different object properties in change detection

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Abstract

Previous research has shown that changes to the configuration of an object's parts are better detected than changes to the shape/arrangement of those parts. This finding suggests that configural, rather than shape, information plays a critical role in object change detection. The current study investigated configural and shape changes in greater detail to determine what aspects of these two types of object properties, if any, were more or less important for change detection. Specifically we investigated configural changes in terms of the orientation of the part change and shape changes in terms of the non-accidental properties of the part change. Using a one-shot change detection task with a single object display, we manipulated: (i) the orientation of a configuration change (0°, 90° or 180°) and (ii) both the number and the type of non-accidental object properties (NAPs) involved in each shape change (3 NAPs were manipulated in total: curvature of axis, curvature of edges, and constancy of size). We found that changes to the curvature of the axis were better detected than changes to either the curvature of edges or to the constancy of size. Detection accuracy was better when there were more NAPs involved in a change. Configural changes involving 180° were more accurately detected than changes involving either 0° or 90°. These results suggest that the axes and basic layout of parts is critical information in change detection. Implications for theories of object recognition are discussed.

Keywords

utility, different, object, properties, change, detection

Disciplines

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Abstract

Previous research has shown that changes to the configuration of an object's parts are better detected than changes to the shape/arrangement of those parts. This finding suggests that configural, rather than shape, information plays a critical role in object change detection. The current study investigated configural and shape changes in greater detail to determine what aspects of these two types of object properties, if any, were more or less important for change detection. Specifically we investigated configural changes in terms of the orientation of the part change and shape changes in terms of the non-accidental properties of the part change. Using a one-shot change detection task with a single object display, we manipulated: (i) the orientation of a configuration change (0º, 90º or 180º) and (ii) both the number and the type of non-accidental object properties (NAPs) involved in each shape change (3 NAPs were manipulated in total: curvature of axis, curvature of edges, and constancy of size). We found that changes to the curvature of the axis were better detected than changes to either the curvature of edges or to the constancy of size. Detection accuracy was better when there were more NAPs involved in a change. Configural changes involving 180º were more accurately detected than changes involving either 0º or 90º. These results suggest that the axes and basic layout of parts is critical information in change detection. Implications for theories of object recognition are discussed.

Keywords: change detection; 3D objects; non-accidental object properties.

Introduction

Detection of configural changes made to parts of novel geon-like objects is quicker and more accurate than detection of changes involving either the shape or a switching of object parts (Favelle, Hayward, Burke & Palmisano, 2006; Favelle, Palmisano, Burke & Hayward, 2006; Keane, Hayward, & Burke, 2003). This finding suggests that configuration is a key component in object representations. Configuration is defined as the spatial layout of object parts (i.e., the overall positioning or placement of the parts within an object). Importantly, configuration does not rely on semantics or the identity of the constituent parts (Hochberg, 1968; Pomerantz, 1983). Thus, information about the spatial configuration and part shape appears to be differentiated in object representations. The aims of the current study were to examine these global and local object properties in greater detail and determine what aspects, if any, provide useful information for change detection and object recognition in general.

A configuration change involves a part moving to a previously unoccupied location on an object body. A shape change involves one of the parts changing shape. One issue with research examining change detection for different object properties is that the "amount" of change differs with each change type. In our previous studies, analysis of the raw pixel change data showed that the configural advantage for change detection was not due to a magnitude difference between the change types (Favelle, Hayward, et al 2006; Keane, et al 2003). Another way to address this issue is to compare configuration changes that result in large outline changes with configuration changes that result in minimal changes to the outline of an object. Hayward (1998) found that object recognition was determined by changes to outline shape, where outline shape is defined as the bounding contour of an object from a given viewpoint. In the current experiment, we examined the effect of outline shape on object change detection with configural changes involving either 0°, 90°, or 180° rotation of an object part (see Figure 2).

If the configural advantage is due to a greater degree of change to an object's outline, then 90° changes should be detected most accurately since this condition involves the largest change to the outline. That is, one of the parts shifts from the front of the body to the side (or vice versa) involving a foreshortening or elongating of the axis. As a result, the outline (as well as the silhouette) becomes noticeably larger or smaller (see Figure 2). Both 0° and 180° part rotations involve a shifting of a part to a new location, but neither involves any axis foreshortening or elongation and thus, minimal overall change to the outline.

Previous findings of a configural advantage in change detection suggest a lesser role for local part shape information in object recognition. However, prominent models of object recognition such as Biederman's (1987) Recognition-by-Components and Biederman and Gerhardstein's (1993) Geon Structural Description theory argue for a critical role of parts or "geons" in object representations. Geons are a set (N = 36) of volumetric components into which an object may be decomposed. The central organizational principle of geons is that certain properties of edges in a 2D image are taken as evidence that those properties exist in a 3D world. These properties are

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called non-accidental properties (NAPs) and include symmetry, edge collinearity and curvilinearity. NAPs are highly robust to changes in observer viewpoint and are argued to be better candidates for inclusion in object representations than metric properties (Biederman, 1987; Biederman & Bar, 1999).

If geons are critical for object recognition, then detecting changes to NAPs of object parts should be accurate. While previous research suggests part shape is not as important for change detection, NAPs have not been directly manipulated to determine this. In the current study we examined changes to three different NAPs: axis curvature, edge curvature, and cross-sectional size constancy. These changes were made to one part only and occurred alone or in combination. It is possible that some NAP changes are more salient than others in a change detection task, and/or that NAP changes have an additive effect. In line with arguments made above, NAP changes that result in greater changes to an object's outline may be better detected than changes that result in minimal outline change. In terms of the three NAPs investigated here, this suggests that changes to the cross-sectional size constancy of a part (which result in an increase or decrease in outline size) may be better detected than changes to the curvature of a part's axis (which changes the shape of the outline) with detection of edge curvature changes faring worst.

To summarise, the present experiment examined detection of configuration changes involving a 0°, 90°, or 180° rotation of an object part and of shape changes involving of 1, 2 or 3 different NAPs. If outline change determines change detection performance, then we would expect that: (i) changes involving a 90° part rotation will be better detected than changes involving either a 0° or 180° part rotation, and (ii) changes to cross-sectional size constancy and perhaps axis curvature will be better detected than edge curvature changes.

Method

Participants

A total of 30 undergraduate students from the University of Wollongong participated and were tested individually. Subjects received course credit for participating.

Stimuli

Stimuli were rendered images of three-dimensional novel objects. Each object was composed of a main body with three appendage parts. The appendages attached to the body at three of six possible positions. Objects varied in terms of: (1) part shape; or (2) part configuration[1]. Part shape changes could involve one, two or three non-accidental properties of the part changing (see Figure 1): (a) axis curvature (AC - straight or curved); (b) cross-sectional size constancy (CSC - constant or expanding); and (c) edge curvature (EC - straight or curved).

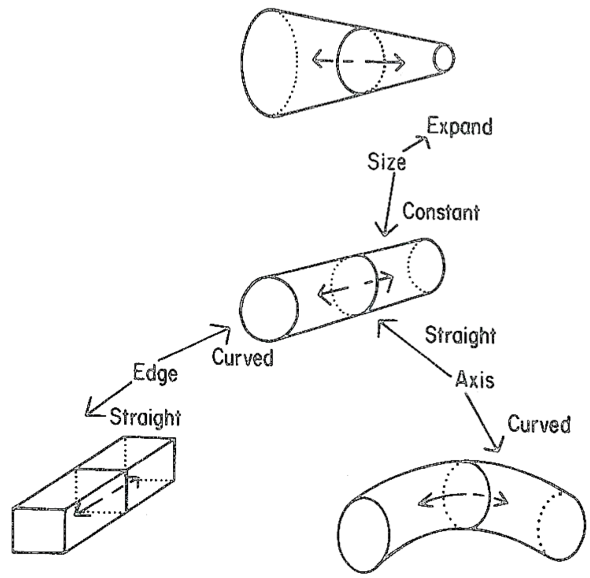

Figure 1: An illustration of the variations in the three non-accidental properties manipulated in the current study (adapted from Biederman, 1987, p.122).

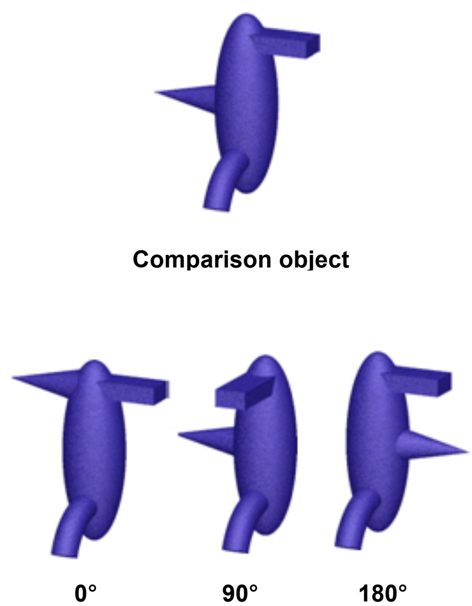

Figure 2: An example of the stimuli used in the experiment and the three different configuration changes: 0°, 90°, or 180° part rotation.

As shown in Figure 2, configuration changes could involve a part moving either up or down (0° rotation in depth), from

[1] In order to minimise any bias in strategy toward detecting shape changes (there are seven shape/NAP change conditions versus three configuration change conditions), a switch condition (as in Keane et al, 2003) was included. A switch change involved any two of the object parts switching location. This condition was not included in the data analysis.

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one side to the front of the main body or vice versa (90° rotation in depth) or from one side to the other (180° rotation in depth). A total of 63 different object exemplars were used in the current experiment. All objects were photorealistically rendered with the same colour and texture. The entire background screen was white.

The objects were all of similar size, with the average dimensions of each object being 200 pixels wide and 230 pixels high. The mask used in this experiment was 425 by 330 pixels in area and consisted of elements from a variety of object images.

Procedure

The experiment was controlled by RSVP software (www.tarrlab.org) on Power Macintosh 7200 computers. The experiment consisted of 240 randomly ordered trials in which subjects viewed objects on a computer monitor. Each object was randomly placed at a position 50 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 for 2 s, immediately followed by a mask appearing centrally on the screen for 2 s, and finally another object which remained on the screen until the subject responded. The trial timed out after 5 s. The next trial began 1 s after the subject made a response or the trial timed out.

The second object was either identical to the first or different in terms of: (1) part shape; or (2) spatial configuration. Part shape changes could involve one (AC, EC or CSC), two (AC and EC, AC and CSC, or EC and CSC), or three (AC, EC and CSC) non-accidental properties. Configuration changes could involve a part moving either up or down (0° rotation in depth), from one side to the front of the main body or vice versa (90° rotation in depth) or from one side to the other (180° rotation in depth). 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 “different”. Feedback was given in the form of a beep to incorrect trials.

Results

Accuracy (proportion correct) and reaction time (RT) data were collected. RT data analysis was conducted using accurate responses. Analyses were performed on the different trials (i.e., trials in which something changed). The mean proportion correct for same trials was 0.88 (SEM= 0.014), the mean RT was 1129 ms (SEM = 56). Greenhouse-Geisser corrections were applied to the *df* wherever the assumption of sphericity was violated. The alpha level was .05. All post hoc comparisons were Bonferroni adjusted pairwise comparisons.

Analysis of the Configuration Condition

Two separate one-way repeated measures ANOVAs were conducted on the configuration change factor (0°, 90° or 180° rotation) for the accuracy and RT data. The ANOVA on the accuracy data showed a significant effect of configuration change, $F(2,58) = 8.82$, $p < .01$, MSE = .003. As seen in Figure 2 and confirmed with post hoc comparisons, a 180° change was more accurately detected than either a 0° or 90° change (both $p < .01$). There was no significant difference in accuracy between 0° and 90° changes ($p = 1.0$). The ANOVA on the RT data showed no effect of configuration change, $F < 1.1$, $p = .37$ (see Table 1).

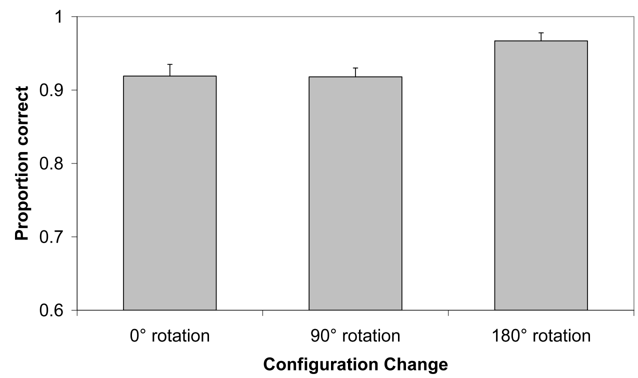

Figure 2: Mean change detection accuracy as a function of configuration change. Error bars represent one standard error of the mean.

Table 1: Mean RT (ms) for the different levels of configuration change.

Configuration change	Mean (standard error)
0° rotation	998 (45)
90° rotation	1028 (53)
180° rotation	987 (55)

Analysis of the NAP Condition

Two separate one-way repeated measures ANOVAs were conducted on the NAP change factor (AC, EC, CSC, AC/EC, AC/CSC, EC/CSC, AC/EC/CSC) for the accuracy and RT data. There was a significant effect of NAP change on detection accuracy, $F(6,174) = 31.5$, $p < .01$, MSE = 0.03. Post hoc comparisons showed that all single NAP changes were detected less accurately than changes involving either two or three NAPs (all $p < .01$), except that no difference was found between AC and EC/CSC changes ($p = .33$) (see Figure 3). Of the single NAP changes, AC changes were detected more accurately than either EC or CSC changes (both $p < .05$). There was no difference in detection accuracy between EC and CSC changes ($p = 1.0$) and neither of these change types was significantly different to chance (both *t*s < 0.9, $p > .4$). There was no significant difference between any of the changes involving two or three NAPs (all $p > .71$).

The ANOVA on the RT data showed an effect of NAP change, $F(6,174) = 5.01$, $p < .01$, MSE = 24850 (see Table

2). Post hoc comparisons showed that the only differences in RT were that AC/EC changes were detected faster than any of the single NAP changes (all p < .05). There were no other significant differences in RT (all p > .18).

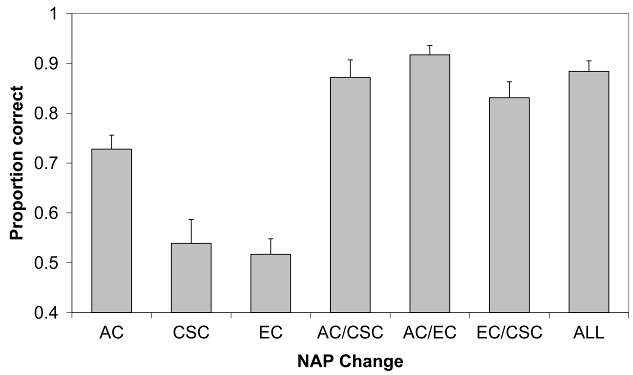

Figure 3: Mean change detection accuracy as a function of NAP change. Error bars represent one standard error of the mean.

Table 2: Mean RT (ms) for the different levels of NAP change.

NAP change	Mean (standard error)
AC	1099 (52)
CSC	1187 (69)
EC	1098 (65)
AC/CSC	1037 (60)
AC/EC	978 (53)
EC/CSC	1085 (47)
AC/CSC/EC	1058 (56)

Discussion

For configuration changes, 0° and 90° changes were equally detectable and 180° changes were detected best. No differences were found in RT between the different orientations of configuration change. However, the pattern reflects the accuracy data suggesting no speed-accuracy trade-off. While the outline or silhouette of an object has been shown to be important for object recognition (Hayward, 1998), our findings suggest that the amount of outline change is not the determining factor in configuration change detection. If it was the case that differences in silhouette or outline determined change performance, then 90° part rotation changes should have been detected most accurately (since this condition involves the largest change to the outline). Instead, we found that the 180° part rotation condition was the best detected configural change. Why? Because there was a salient categorical difference in the layout of objects parts following a 180° rotation change - instead of there being one part on three different sides (left, front and right) there were two parts on one side (left or right) and one part on the other (left or right) with no parts ever on the front side. By contrast, there was no side that was reliably left without parts following a 90° rotation change (two parts would be on one side and one part on the other, but the side with the two parts could be the left, front or right) and a 0° rotation change did not involve a categorical change to the number of parts on any side. Thus, we conclude that these categorical differences were responsible for the change detection advantage found for the 180° rotation conditions. However, since there was no difference in change detection performance between 0° and 90° changes, these categorical differences cannot completely account for the pattern of results found.

The configural advantage found in previous research (Favelle, Hayward, et al, 2006; Favelle, Palmisano, et al, 2006; Keane, et al, 2003) was replicated in the present study in so far as all three configural changes were detected more accurately than single NAP changes (there was also a trend in that direction when configurations conditions were compared to the NAP combination conditions). This highlights the importance of considering the properties of shape changes in more detail in future studies.

For shape changes, one NAP change was less accurately detected than 2 or 3 NAP changes. There was no difference in the detection of the different combinations of parameters, that is, no difference between the AC/CSC, AC/EC, CSC/EC and AC/CSC/EC conditions. Further, when that one NAP was the curvature of the edges (EC) or the level of cross-sectional size constancy (CSC), detection was worse (in fact at chance) than if the changed parameter was the curvature of the axis (AC). Again, these results suggest that outline change, at least in terms of the amount of outline increasing or decreasing, is not a major determinant of change detection performance. An AC change conserves the size of the outline but does change the shape of it. Thus, the overall shape of the whole object axis may be important in object representations used for change detection. A detection advantage for changes to the shape of the axis might be expected if global object information is based on a medial axis representation (Blum, 1967, 1973) or some kind of general skeletal structure. A medial axis representation is derived from an object's silhouette or bounding contour, thus preserving information about the curvature of parts. Using the geons in Figure 1 as an example, the medial axis representations of the cylinder, cone and rectangular prism are very similar, if not identical, whereas the medial axis representation of the curved "pipe" is distinguished by its curved shape.

Taken together, these findings suggest that in detecting changes to objects, global information is important, particularly that involving the layout of an object. This is consistent with the idea that the visual system bases object representation on a "part skeleton" that emphasises structural properties over metric properties (Barenholtz, Cohen, Feldman & Singh, 2003; Barenholtz & Tarr, 2007; Blum, 1973; Kimia, Tannenbaum, & Zucker, 1995).

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