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Contour symmetry detection: the influence of axis orientation and number of objects

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Abstract

Participants discriminated symmetrical from random contours connected by straight lines to form part of one- or two-objects. In experiment one, symmetrical contours were translated or reflected and presented at vertical, horizontal, and oblique axis orientations with orientation constant within blocks. Translated two-object contours were detected more easily than one, replicating a "lock-and-key" effect obtained previously for vertical orientations only [M. Bertamini, J.D. Friedenberg, M. Kubovy, Acta Psychologica, 95 (1997) 119–140]. A second experiment extended these results to a wider variety of axis orientations under mixed block conditions. The pattern of performance for translation and reflection at different orientations corresponded in both experiments, suggesting that orientation is processed similarly in the detection of these symmetries. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

In previous work, we investigated the role of objects in detection of symmetrical contours (Bertamini, Friedenberg & Kubovy, 1997). Two symmetrically related

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contours were connected to straight lines at their endpoints to create the perception of belonging to one or two closed objects. Subjects responded faster to reflected contours when part of one-object. Translated contours were responded to faster when part of two-objects. This latter result was described as a "lock-and-key" effect, in which it is easier to compare two contours of opposite polarity by imagining them fit together, much the same way the grooves of a key fit into a lock. Baylis and Driver (1995), using similar contour figures and similar task demands, obtained comparable results. This result for translation is interesting, since it runs contrary to theories of object-based attention, where attention is distributed preferentially within perceptually defined objects, predicting better performance for single objects (Baylis & Driver, 1993; Behrmann, Zemel & Mozer, 1998; Duncan, 1984).

It is not certain if these object findings hold for axis orientations other than vertical. Fast responding to a single reflected object should occur at other orientations according to the object-based account if the contours continue to be perceived as part of a unitary object. It is also not clear whether the lock-and-key finding generalizes to other axis orientations. Comparison of two translated contours across a vertical axis may be substantially easier than for other orientations. Wagemans, van Gool, Swinnen and van Horebeek (1993) found detection of horizontally translated dot patterns better than those translated across vertical or oblique directions. Such an effect might be expected in their account, given that stereo disparity and motion usually occur in a predominantly horizontal direction.

The role of objects in symmetry perception has not been systematically investigated. This is surprisingly so, given that symmetry rarely occurs outside an object context in the natural world. Object boundaries may be useful in detecting symmetry because they can help specify axis orientation through a frame of reference (Palmer, 1985). Several studies have investigated the influence of frames and cues on detection performance. These studies generally show a facilitative effect of frames and cue lines aligned at the symmetry axis (Herbert & Humphrey, 1994; Pashler, 1990; Zimmer, 1984).

Far more research has focused on the perception of symmetry, especially mirror symmetry, at different axis orientations. Mach (1886, 1959) was among the first to notice the salience of vertical symmetry. Vertical bilateral symmetry has in several studies since been confirmed as more easily detected than symmetries at other orientations (Wenderoth, 1994). Corballis and Roldan (1975) asked subjects to discriminate reflected from translated dot patterns with an explicit symmetry axis drawn in. They found responding was quickest to vertical, followed by oblique orientations and then horizontal. The results suggested a mental rotation of the patterns to the vertical. A different and more frequent finding for reflectional symmetry is an oblique effect, by which we mean that detection is easiest for vertical, followed by horizontal and then obliques (Barlow & Reeves, 1979; Masame, 1984; Palmer & Hemenway, 1978; Royer, 1981; Wagemans, Van Gool & d'Ydewalle, 1992). This may be due to orientation-specific channels, for the vertical and horizontal that have larger receptive fields, are more finely tuned, or are more numerous (Atkinson, 1972). These channels may mediate symmetry perception and in conjunction with attentional factors, help to explain the oblique effect (Jenkins, 1985; Wenderoth, 1995).

Fewer studies have investigated translated stimuli at different axis orientations. A mental rotation effect of vertical fastest followed by obliques and horizontal has been found (Corballis & Roldan, 1975; Corballis, Zbrodoff & Roldan, 1976). Kahn and Foster (1986) reported an oblique effect of better performance for vertical and horizontal than left and right diagonals for reflection, but not translation, although the general pattern of results for both symmetries was similar. They proposed that translated patterns of the sort they used involve a simple position comparison, whereas reflection necessitates a more elaborate directional relabeling at oblique orientations.

A major aim of the current study was to further examine the symmetry by object interaction obtained previously at a vertical axis orientation (Bertamini et al., 1997). Specifically, we are interested in whether this interaction generalizes to other axis orientations. This interaction can best be described as the result of two effects. The first is defined and referred to throughout this paper as the lock-and-key effect. Here, translated contours attached to two separate objects are detected better than when they form part of one-object. The second we call the single object effect. It is characterized by better detection performance for two reflected contours belonging to one-object in comparison to two. In all cases, the symmetrical contours are linked by contextual lines to form perceptual objects (see Fig. 1) via the Gestalt principle of closure (Wertheimer, 1937).

Another goal of the study was to examine the influence of objects on symmetry detection at different axis orientations for reflection and translation. The presence of

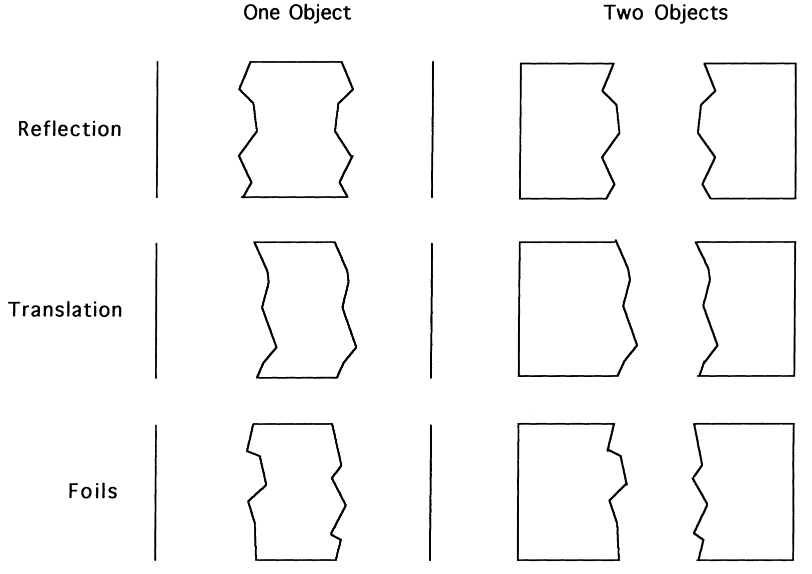

Fig. 1. Schematic representations of the stimuli employed in both experiments. Axis orientation is vertical. The first and second rows depict reflected and translated contours in one- and two-object contexts. The third row contains nonsymmetrical one- and two-object foils.

objects with explicit lines may induce a mental rotation to the vertical. If this were the case, we would expect performance for vertical to be best, followed by oblique and then horizontal. If not, the pattern of results should follow the more commonly obtained oblique effect of best performance at vertical, followed by horizontal and then oblique. Given the somewhat inconsistent findings from the literature, it is not certain if orientation effects will be identical for translation and reflection.

2. Experiment 1

In the first experiment, subjects detected symmetrical contours forming part of one- or two-objects. The symmetrical contours were either translated or reflected. Orientation of the symmetry axis was vertical, horizontal, and oblique. Axis orientation was constant within blocks of trials. If the influence of objects on detection is unaffected by axis orientation, we would expect the same symmetry by object interaction obtained previously for vertical. This interaction showed reflected one-object contours detected faster than two-object contours, and translated two-object contours detected faster than one.

2.1. Method

2.1.1. Participants

Eighteen undergraduates from Manhattan College and The College of Mount Saint Vincent participated to receive extra class credit. Their average age was 19 years. Vision was normal or corrected to normal.

2.1.2. Apparatus and stimuli

The stimuli were randomly generated contours embedded in one- or two-object contexts. Fig. 1 shows examples of all the conditions. The figures subtended 4.3° visual angle in height and 8.6° visual angle in width, a 2:1 aspect ratio. Approximately 3.0° separated the contour. Average viewing distance was 46.0 cm. The stimuli were presented on a 21′ Apple monitor under dim illumination. Contours and lines were black against a white background.

An Apple Macintosh computer generated the contours by drawing lines in linear steps (a constrained random walk). For the vertical condition for example, a line moved by six fixed vertical steps and its horizontal position was chosen randomly within a region 1.4° wide. In the nonsymmetrical trials (foils), the pair of contours was generated by two independent random walks. For translation trials instead, the second contour was a copy of the first, and for the reflection trials the second contour was a reflected copy. Note that the only difference between signal and foil is the relationship between the two contours.

Two straight lines connected the contours at either end to form the one-object condition. Three straight lines attached to either contour formed each object in the two-object condition. Two additional straight lines were added to the outside regions in the one-object shapes to equate them in overall extent to the two-object condition. Note that this context was irrelevant for the purpose of answering correctly. Stimuli were presented at four symmetry axis orientations: vertical (0°), horizontal (90°), left oblique (−45°), and right oblique (+45°).

2.1.3. Design and procedure

Each participant was run through two programs in a single experiment session. Within a program, type of symmetry was constant while number of objects varied. Order of symmetry was counterbalanced over subjects, half received translation before reflection, the other half reflection prior to translation. A program contained four orientation blocks presented in a different random order. All stimuli in a block had the same axis orientation. Each orientation occurred randomly and equally often as one- or two-objects. There were 96 trials per block, 48 symmetric and 48 nonsymmetric. Preceding every block were five practice trials to familiarize participants with the upcoming orientation.

Stimulus duration was response-terminated. Participants were instructed to press the "z" key on the keyboard if the contours were symmetrical, i.e., if they were translated or reflected, and the "/" key if nonsymmetrical. They were told to respond as quickly as possible while at the same time minimizing errors. The computer recorded response time and controlled the presentation of the stimuli using the VideoToolbox subroutines (Pelli, 1997).

2.2. Results

Reaction time (RT) and percent errors were the dependent variables. Only RTs for correct responses to symmetric trials were analyzed. The raw RT distribution was positively skewed. The distribution was therefore normalized using a log transformation.

A randomized block factorial analysis of variance (RBF) with subjects as the random factor was used to analyze the RT data. TYPE OF SYMMETRY (translation and reflection), NUMBER OF OBJECTS (one and two), and AXIS ORIENTATION (vertical, horizontal, and oblique) were within-subject factors. Preliminary analyses showed left and right oblique orientations did not interact differently with TYPE OF SYMMETRY or NUMBER OF OBJECTS. For this reason, they were combined to create a single oblique orientation. TYPE OF SYMMETRY, $F(1, 17) = 35.32$, $P < 0.01$, and AXIS ORIENTATION, $F(2, 17) = 3.93$, $P < 0.05$, were significant. So was the two-way interaction between TYPE OF SYMMETRY and NUMBER OF OBJECTS, $F(1, 17) = 76.62$, $P < 0.01$. Because of the within-subject design, we followed Loftus and Masson (1994) in computing standard errors. In particular, the omnibus standard error was computed (0.014 in log units) under the assumption of sphericity. This standard error is plotted as the error bar of Fig. 2.

The means reported here are back-transformed to raw RT values for ease of interpretation. Note that because of the log transformation, these arithmetic means

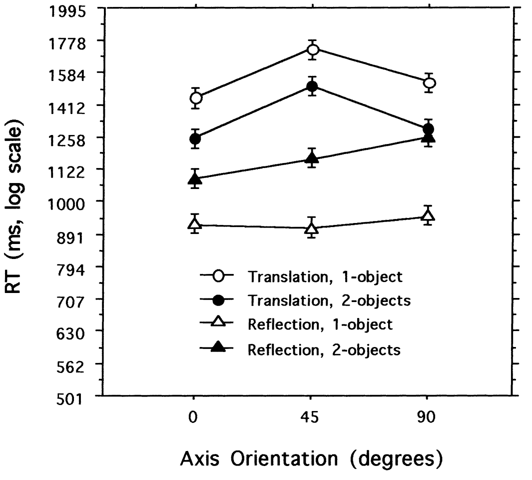

Fig. 2. Mean RT to detect translated and reflected symmetric contours in one- and two-object contexts in Experiment 1. The values of the ordinate axis have been backtransformed to ms for clarity. Orientation of symmetry axis is vertical (0°), oblique (±45°), and horizontal (90°). Error bars indicate the within-subject omnibus standard error of the mean.

of the transformed data are geometric means of the raw data. On an average, responses were faster to reflected (1,035 ms) than to translated (1,485 ms) contours. Response time was lowest at vertical (1,156 ms), higher to horizontal (1,233 ms), and highest at oblique orientations (1,273 ms). A Scheffé post hoc test revealed vertical faster than oblique as the only significant pair-wise difference. For translated contours, the two-objects condition (1,386 ms) was faster than the one object (1,603 ms). For reflected contours, the one-object condition (922 ms) was faster than the two-objects (1,166 ms). Fig. 2 shows mean RTs with the within-subjects standard error for TYPE OF SYMMETRY and NUMBER OF OBJECTS at each orientation.

Percent errors from each subject were also analyzed. The main effects of TYPE OF SYMMETRY, $F(1, 17) = 16.70$, $P < 0.01$, and AXIS ORIENTATION, $F(2, 17) = 12.98$, $P < 0.01$, were significant. So was the TYPE OF SYMMETRY by NUMBER OF OBJECTS interaction $F(1, 17) = 26.84$, $P < 0.01$. In addition, the three-way TYPE OF SYMMETRY by NUMBER OF OBJECTS by AXIS ORIENTATION interaction was marginally significant, $F(2, 17) = 3.64$, $P < 0.05$.

There were fewer errors to reflection (5.46%) than to translation (11.79%). Fewer errors were made to translated two-object contours (8.80%) than to one (14.78%), while one-object reflected contours were detected with fewer errors (3.28%) than two (7.64%). Overall, fewer mistakes were made to vertical (6.71%) than to horizontal (7.76%) or oblique (11.40%). A Scheffe' post hoc analysis showed obliques differed significantly from horizontal orientations.

2.3. Discussion

The RT and error rate data together show a general vertical advantage. Vertical orientations are responded to faster for both symmetries. Fewer errors are also made to vertical. However, there is no obvious difference between vertical and horizontal or between horizontal and oblique when both measures are taken into account. If one considers the overall trend in orientation means, vertical is faster than horizontal, which is faster than oblique. Likewise, accuracy of responding overall is best to vertical, followed by horizontal, and then oblique. The data are thus more suggestive of an oblique effect ($V < H < O$) than of a mental rotation ($V < O < H$) process (< indicates a lower RT or error rate).

The results successfully replicated our previous finding. The lock-and-key effect holds for horizontal and oblique axis orientations. The lock-and-key hypothesis postulated earlier applies to the detection at these other orientations as well. For reflection, the advantage for a single object is also not limited to the vertical.

3. Experiment 2

In the current experiment a greater number of axis orientations were employed and axis orientation was randomized within blocks. This was done first to see if the symmetry by object interaction holds at these additional orientations. Wenderoth (1994) has shown that symmetry detection varies based on the range and frequency of orientations presented, which may alter subject's attentional and scanning strategies. Secondly, when axis orientation is fixed, it is possible for subjects to adopt an orientation specific detection strategy. For instance, they may be able to prepare for the upcoming stimulus knowing its orientation in advance. Wenderoth (2000) obtained a reduction in response times when reflected dot patterns were blocked by orientation. He found blocking to be more effective even than cueing. An orientation-specific strategy cannot be used when axis orientation varies on a trial to trial basis. The results obtained here under these conditions could thus reveal a more general-purpose detection mechanism.

3.1. Method

3.1.1. Participants

Fourteen participants, five males and nine females, volunteered to receive extra class credit. All were undergraduates at either Manhattan College or The College of Mount Saint Vincent. Average age was 19 years. Their vision was normal or corrected to normal.

3.1.2. Apparatus and stimuli

The stimuli were generated in the same fashion as Section 2. Patterns were presented at 12 axis orientations from the vertical in 30° intervals. This resulted in six clockwise orientations (0°, 30°, 60°, 90°, 120°, 150°), and six counterclockwise orientations (180°, 210°, 240°, 270°, 300°, and 330°). Size and viewing conditions were the same as in the first experiment.

3.1.3. Design and procedure

Participants first viewed 10 practice trials. A block contained 96 trials, eight at each orientation, with four trials of one-object and another four trials for two-objects. Six blocks of one symmetry type were followed by six blocks of another, counterbalanced across subjects. With a short rest break halfway through, a session lasted about 1 h.

3.2. Results

Only correct RTs to symmetrical trials were analyzed. The RT distribution was again positively skewed and so normalized with a log transformation. TYPE OF SYMMETRY, NUMBER OF OBJECTS and AXIS ORIENTATION were factors. Prior to the main analyses, separate ANOVAs were performed for clockwise and counterclockwise equivalents. The pattern of significance for each did not differ, so clockwise and counterclockwise equivalents were collapsed together. TYPE OF SYMMETRY was significant $F(1,\ 13) = 22.94$, $P < 0.01$, as was NUMBER OF OBJECTS $F(1,\ 13) = 5.74$, $P < 0.05$, and AXIS ORIENTATION $F(5,\ 13) = 4.76$, $P < 0.01$. The TYPE OF SYMMETRY by NUMBER OF OBJECTS interaction was significant, $F(1,\ 13) = 60.00$, $P < 0.01$, as well as the NUMBER OF OBJECTS by AXIS ORIENTATION, $F(5,\ 13) = 3.50$, $P < 0.01$, interaction. The omnibus within-subject standard error for this experiment was 0.018.

On an average, reflected patterns (812 ms) were responded to faster than translated ones (1,120 ms). Responding overall was faster to one-object (933 ms) than two (977 ms). Two-object translated patterns (1,047 ms) were speeded in comparison to one (1,148 ms), one-object reflected patterns (741 ms) were faster than two (891 ms). With the oblique orientations combined, responding to vertical was fastest (912 ms), followed by obliques (977 ms), and then the horizontal (1,023 ms). Scheffé post hoc comparisons on the individual orientation means showed responses to vertical (0°) significantly faster than to 60° or the horizontal (90°). Fig. 3 shows mean RTs for both symmetries and objects at each orientation. Because of the log transformation, these arithmetic means of the transformed data are geometric means of the raw data. The within-subject omnibus standard error was used similarly to the analysis of Section 2. The 180° orientation is shown for purposes of clarity only, it was combined with 0° in all the analyses.

Percent errors from each subject were also analyzed. AXIS ORIENTATION was significant, $F(5,\ 13) = 3.48$, $P < 0.01$, as was the TYPE OF SYMMETRY by NUMBER OF OBJECTS interaction $F(1,\ 13) = 24.31$, $P < 0.01$.

On an average, fewer errors were made to reflection (10.31%) than to translation (13.43%). Translated double objects were less difficult (8.44%) to respond to than

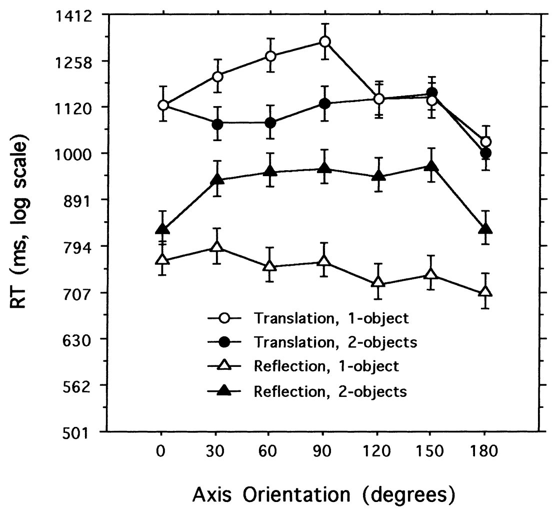

Fig. 3. Mean RT to detect symmetry as a function of axis orientation for translated and reflected contours in one- and two-object contexts. The values of the ordinate axis have been back-transformed to ms for clarity. The data are from Experiment 2. Error bars indicate the within-subject omnibus standard error of the mean.

single objects (18.42%), while one-object was easier (7.54%) than two (13.10%) for reflection. When the oblique orientations were averaged together, accuracy was best for vertical (9.38%), followed horizontal (10.39%), and then oblique (12.79%). Scheffé post hoc tests among the orientation means revealed significantly fewer errors to vertical than 60°.

3.3. Discussion

The results obtained here are similar to those from the first experiment. Detection of both symmetries is best at a vertical axis orientation. However, as was also the case in Section 2, there is no clear differentiation in response between vertical and horizontal or between horizontal and oblique. Although the trend in orientation means for errors fits that predicted by the oblique effect ($V < H < O$), the same is not true for the RT data, which more closely approximate a mental rotation explanation ($V < O < H$).

Once again, the symmetry by object interaction consisting of the lock-and-key effect for translation and the single object effect for reflection were obtained. This was the case for multiple orientations at 30° intervals, both clockwise and counterclockwise, demonstrating the effect is not orientation-specific. The interaction additionally remains under conditions of orientational uncertainty, where subjects could not predict axis orientation. This precludes as an explanation the use of any orientation specific detection strategy.

4. General discussion

There were several consistent findings across the two experiments. First, comparison of translated and reflected contours is better at vertical-axis orientations. Both symmetries were detected more easily at vertical than at any other axis orientation, as assessed by RT and accuracy measures. This finding confirms the vertical advantage in symmetry detection (Mach, 1959; Wenderoth, 1994). Second, overall detection performance was better for reflected than translated contours, also based on RT and error rates. This superior performance for reflection reported previously (Baylis & Driver, 1994; Bertamini et al., 1997), is found here in one- and two-object surrounds and for multiple orientations.

When orientation of the symmetry axis is vertical, reflected one-object contours are detected more easily than two. This single object effect was obtained in the current study at a variety of other axis orientations when orientation was fixed (Section 2) or variable across trials (Section 3). According to object-based theories of attention it is easier to orient attention, and so compare contours, within single object boundaries. Apparently, subjects continued to perceive the one-object reflected patterns as unified objects at nonvertical orientations.

A translation lock-and-key effect formerly found for vertical only was also obtained here under multiple orientation conditions. According to the lock-and-key explanation, translated contours on separate objects are compared by imagining them fit into one other, perhaps under some conditions through a linear translational motion in the picture plane (Bertamini et al., 1997). This lock-and-key matching process remains as a possible explanation for detection of translated contours independent of axis orientation.

When the orientation data from both experiments are taken into account, the trends seen in the means tend to support an oblique effect rather than mental rotation. In fact, the predicted ordering for the oblique effect ($V < H < 0$) appears everywhere except the RT data from the second experiment. The mental rotation effects found by Corballis and Roldan (1975) are generally acknowledged to be the result of an explicit axis line (Leone, Lipshits, McIntyre & Gurfinkel, 1995). This line may have produced in their dot patterns a strong intrinsic orientation, inducing a compensatory rotation to the vertical. The contour stimuli in this study, although lacking an axis line, contain straight context lines parallel and perpendicular to the axis. These lines may have also induced a mental rotation. There is the suggestion of rotation to the vertical, particularly in the RT data of Section 3, but it is not well pronounced. Perhaps a rotation process occurred on some trials but was not used as a consistent strategy. This would explain the absence of a horizontal benefit for contours.

An interesting finding from both experiments was that, type of symmetry did not interact with axis orientation. The pattern of result over orientation for translation and reflection was the same. This was true for both RT and error data. This suggests that location of the axis or compensation for orientation are performed similarly for both symmetries. It does not imply that the entire detection process is the same, since some evidence suggests each symmetry may be detected differently (Baylis & Driver, 1994; Wagemans, 1995).

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