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ORIGINAL ARTICLE

Arno Koning · Rob van Lier

No symmetry advantage when object matching involves accidental viewpoints

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Abstract The presupposed advantage of symmetrical objects over asymmetrical objects was investigated in an object matching task, using accidental and non-accidental viewpoints. In addition, the accidental views could be symmetric or asymmetric. When two non-accidental views were presented, symmetrical objects were matched faster than asymmetrical objects. When an accidental view was presented first (followed by a non-accidental view), the matching of symmetrical objects was equal to that of asymmetrical objects. When a non-accidental view was presented first (followed by an accidental view), matching was again equal for the symmetrical and asymmetrical objects, although much faster compared with the opposite sequence of presented views. No effects of image symmetry in the accidental viewpoints were found. Apparently, the advantage of symmetrical objects over asymmetrical objects is only present in object matching when 3-D object structures are visible.

Introduction

It is well known that bilateral symmetry, or mirror symmetry, is easy for the human visual system to detect (Mach, 1886). In perceiving symmetrical objects, it has been argued that there are differences regarding the detectability of various symmetry axes (Barlow & Reeves, 1979; Baylis & Driver, 1994; Kahn & Foster, 1986; Palmer & Hemenway, 1978; Rock & Leaman, 1963; Van der Helm & Leeuwenberg, 1996; Wagemans, 1995; Wenderoth, 1995). Due to the high saliency of symmetry, it can be expected that, all other object properties being identical, symmetrical objects can be identified faster in a perceptual task than asymmetrical objects. Yet, object structure (of which symmetry is part) is not the only factor contributing to the identification of objects. The viewpoint from which an object is perceived is also important. In general, viewpoints are classified as either accidental or non-accidental. Whereas accidental viewpoints typically lack crucial information needed for object identification, non-accidental viewpoints facilitate object identification. For example, in Fig. 1a, a cup is seen from directly above, revealing only a disk-like image (i.e., an accidental viewpoint). From the information present in Fig. 1a, it is very difficult to identify the object presented. In Fig. 1b, the same cup is shown from a non-accidental viewpoint. In contrast to Fig. 1a, a cup is readily seen in Fig. 1b. Because both structural factors and the viewpoint from which an object is shown are important, we wanted to examine whether the presupposed advantage of symmetrical objects can be found across accidental and non-accidental viewpoints. Therefore, in the present study we investigate the matching of symmetrical and asymmetrical three-dimensional (3-D) objects using both accidental and non-accidental viewpoints.

Investigating two-dimensional (2-D) objects, Tarr and Pinker (1990) examined symmetrical versus asymmetrical objects across different viewpoints. The objects were rotated in a plane parallel to the frontal plane. Relatively simple line drawings were used in an object-naming task. Either the objects had a vertical axis of symmetry, or the objects were asymmetrical. First, participants had to learn the names of the objects as they were positioned in a particular orientation. Next, participants had to identify the objects by their names, but now the objects were rotated in the frontal plane. Tarr and Pinker found that symmetrical objects were identified equally fast across different plane rotations. Asymmetrical objects, in contrast, showed an increase in naming latency as they were rotated farther away from the learned orientation. Similar effects of orientation

A. Koning (✉) · R. van Lier
NICI, University of Nijmegen,
PO Box 9104, 6500 HE Nijmegen, The Netherlands
E-mail: a.koning@nici.kun.nl
Tel.: +31-24-3615590

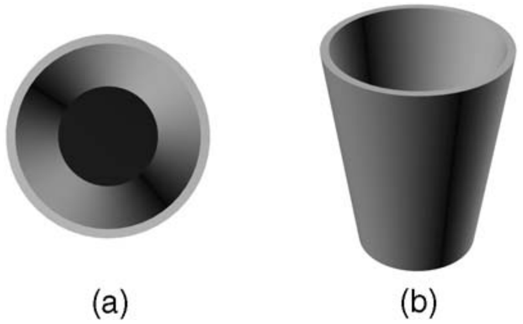

Fig. 1 **a** A top view of a cup resulting in a disk-like image (i.e., an accidental view). **b** A non-accidental view of a cup

with respect to 2-D symmetrical and asymmetrical objects have also been found (Wilson & Farah, 2003). For 2-D objects an advantage has thus been found for symmetrical objects over asymmetrical objects across different (i.e., plane rotated) viewpoints. In the case of 3-D objects, such objects can be rotated either in the frontal plane (cf., the plane rotations used by Tarr and Pinker, 1990), or these objects can be rotated in depth. When 3-D objects are rotated in depth this may lead to an accidental viewpoint, as different parts of the object may become visible or parts may become occluded. In addition, when 3-D objects are rotated in depth (leading to an accidental viewpoint), the resulting viewpoint can be symmetrical or not. As a result, with regard to 3-D objects and viewpoints, a distinction can be made between object (i.e., 3-D) symmetry and image (i.e., 2-D) symmetry.

With respect to 3-D and 2-D symmetry, it has been argued that accidental views of 3-D objects often possess 2-D symmetry (both vertical and horizontal) that may not be present in the 3-D structure (Lawson & Humphreys, 1998; Verfaillie & Boutsen, 1995). However, Lawson and Humphreys argued that such information (i.e., 2-D symmetry) would not be encoded as accidental views are encountered only rarely. Based on this suggestion, the presence of symmetry in an accidental view is unlikely to influence object matching. Alternatively, Vetter and Poggio (1994) have suggested that symmetry in an accidental viewpoint will hinder matching of 3-D symmetrical objects. Vetter and Poggio proved that a bilateral symmetrical 3-D object can be recognized from a single non-accidental viewpoint. This is in line with the findings by Tarr and Pinker (1990) regarding symmetrical 2-D line drawings. Nevertheless, Vetter and Poggio (1994) also suggested that perceiving a bilateral symmetric 3-D object from an accidental viewpoint that shows 2-D symmetry would be worse for object recognition. In this case, according to these authors, generating a new view of a symmetrical object would lead to an identical view. Thus, according to Vetter and Poggio, accidental views in general will hinder 3-D object matching, but accidental views that also show 2-D symmetry are predicted to be even worse for 3-D object matching. In addition, the special status of accidental views showing 2-D symmetry also appears in the research on face recognition. It has been found that a symmetrical accidental view of a face (i.e., a full frontal pose of a face) results in poorer recognition than a non-accidental view of a face (i.e., a three-quarters view of a face; see e.g., Troje & Bülthoff, 1996). Considering these somewhat contradictory results, in the present experiment both 3-D symmetry and 2-D symmetry will be systematically varied to examine their relative influences.

In this study, we investigate whether there is a difference in object matching between symmetrical objects and asymmetrical objects across accidental and non-accidental viewpoints. A sequential matching task was performed in which symmetrical and asymmetrical objects were perceived from different viewpoints. The sequence of presented views was varied using both accidental views (hereafter referred to as A-views) and non-accidental views. The non-accidental views will be referred to as C-views, where 'C' stands for canonical. Notice, however, that this does not mean that the C-views were the best possible views of the objects[1]. It is expected that, regardless of the sequence of presented views, 3-D symmetrical objects will be matched faster than 3-D asymmetrical objects (Van Lier & Wagemans, 1999) as symmetrical objects have a higher structural regularity than asymmetrical objects. In addition, it can be expected that when objects have to be matched from an A-view to a C-view, matching will be slower than objects that have to be matched from a C-view to an A-view. After all, when an A-view is presented first, this is expected to impair object-matching as information about object structure is limited.

Experiment

Participants

Twenty participants (aged 18–29) were given course credit or were paid for their time. All participants had normal or corrected-to-normal vision.

Stimuli

The stimuli were created using 3-D modeling software (3-D Studio Max R2, Autodesk, San Rafael, CA, USA). Sixteen different object sets were created; eight

[1]It has been argued that there is a preferred, or canonical, view for the recognition of objects (Palmer, Rosche, Chase, 1981). Palmer et al. define an object's canonical view as "the view that reveals the most information of greatest salience about it." However, although a person may have a strong intuition as to what the canonical view might be for any given object, this cannot be easily generalized across objects. In the study by Palmer et al., most objects were preferably viewed from slightly above, with both the front and the side of the objects clearly visible. Similar results were found by Verfaillie and Boutsen (1995). Even though the canonical views used here might not be the best possible views of the objects, the term C-view is used to contrast it with the term A-view

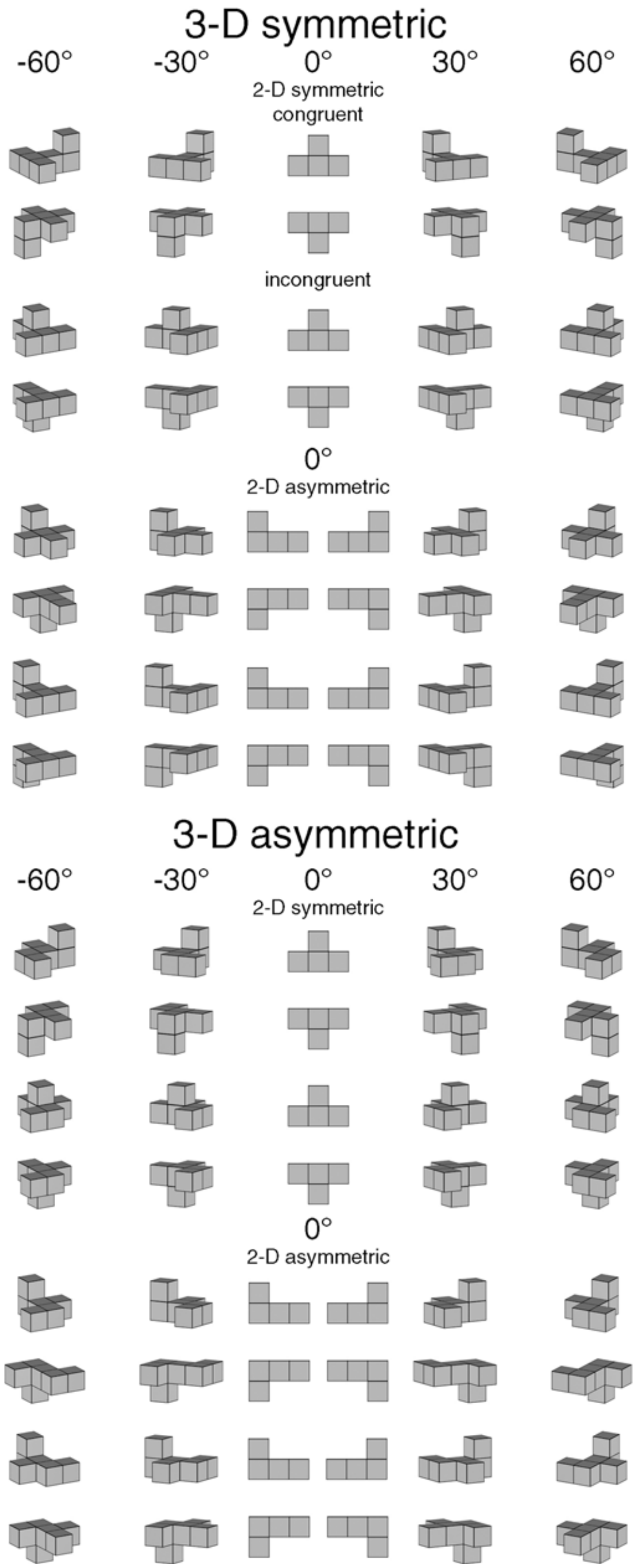

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Fig. 2 The 16-object sets used in the experiment. An object could be either symmetrical or asymmetrical. The 0° views (i.e., the accidental views) could also be symmetrical or asymmetrical. Note that the symmetrical objects could be either congruent or incongruent with the axis of symmetry in the 0° views (see text for details). Each object was positioned in three orientations: 0°, +30°, and +60°. For control purposes, the 0° views showed 2-D asymmetry, and the +30° views and the +60° views were mirrored around the vertical axis. This was done to create trials that required matching from an accidental view to a canonical view, as well as the opposite sequence of presented views, for which both a clockwise and a counterclockwise rotation were required

symmetrical object sets and eight asymmetrical object sets (see Fig. 2). An object consisted of six equal-sized cubes. The symmetrical objects always had a vertical plane of symmetry. Each object was positioned in three different orientations: 0° (i.e., the A-view), +30°, and +60° views. These rotations were designated as positive rotations. Additionally, for the +30° views, the objects were rotated about 8° around the horizontal axis. For the +60° views, the objects were rotated an additional 8°. This was done to make object structures more apparent in the C-views. Next, for control purposes, the 0° views showing 2-D asymmetry, the +30° views, and the +60° views were mirrored around the vertical axis (see Fig. 2), as will be explained further on (see "Procedure"). The resulting views were designated as negative rotations (i.e., the −30° and −60° views). Thus, in total, each object set consisted of either five or six different views (i.e., each row in Fig. 2 is one object set).

As can be seen in Fig. 2, the A-views could be either symmetrical or asymmetrical, for both the symmetrical and the asymmetrical objects. It is important to note that the plane of 3-D symmetry in the C-views could be either congruent (see first and second row in Fig. 2) or incongruent (see third and fourth row in Fig. 2) with the axis of 2-D symmetry, i.e., the axis of 2-D symmetry in the A-view suggests a vertical plane of 3-D symmetry that is perpendicular to the frontoparallel plane. If this suggested plane of 3-D symmetry corresponded to the plane of 3-D symmetry when the object was rotated (as can be seen in the first two rows in Fig. 2), the planes of symmetry were referred to as congruent. The planes of symmetry were referred to as incongruent when the suggested plane of 3-D symmetry appeared not to be the plane of 3-D symmetry when the object was rotated (as can be seen in the third and fourth rows in Fig. 2).

Procedure

The experiment was conducted in a dimly lit room at the University of Nijmegen. Trials were presented on a 19" monitor (at a resolution of 1,024 × 768 pixels), controlled by a Pentium III computer. The participants were seated 1 m from the screen. The software used was SuperLab Pro (Cedrus, San Pedro, CA, USA). A response box (Cedrus) with 1-ms accuracy was used.

A fixation cross (750 ms) preceded each trial. Next, an object was presented on the left side of the screen or on the right side of the screen. After 1,500 ms, a second object was presented on the opposite side of the first object. Both objects remained on the screen until a response was given. Note that the current task is not strictly a sequential matching task, or a simultaneous matching task, but rather a mix of the two, as the first presented image remained on the screen. This was done to exclude the effects of memory. When two images were presented on the screen, they covered an area of about 24.5 × 5.5 cm (i.e., a visual angle of approximately 13° by 3°). If the first object was presented on the *left* side of the screen, it could be either the −60°, −30°, 0°, or +30° view, followed by either the −30°, 0°, +30°, or +60° view respectively, presented on the right side of the screen. The participant was instructed to decide whether the second view could be a possible view of the object, given the first view of that object. The participant consequently had to mentally rotate the first presented object counterclockwise (and slightly upwards or downwards) and compare it with the second object. If the first object was presented on the *right* side of the screen, it could be either the +60°, +30°, 0°, or −30° view, followed by either the +30°, 0°, −30°, or −60° view respectively, presented on the left side of the screen. Now, the participant had to mentally rotate the first presented object clockwise (and slightly upwards or downwards) to compare it with the second object. The variable Sequence thus consisted of four levels: matching from a 0° view to a |30°| view (referred to as accidental to canonical [AC] matching), matching from a |30°| view to a 0° view (referred to as canonical to accidental [CA] matching), matching from a |30°| view to a |60°| view (referred to as CC_1 matching), and matching from a |60°| view to a |30°| view (referred to as CC_2 matching). The kind and amount of mental rotation that was required for each sequence was explained to the participant.

To explain the use of the mirrored views, consider the following case. When a +30° view was presented on the right side of the screen (to be followed by a 0° view presented on the left side of the screen), this would result in a CA trial for which a clockwise rotation was required. To establish a comparable CA trial for which a counterclockwise rotation was required, the +30° view was mirrored horizontally. The resulting −30° view would then be presented on the left side of the screen to be followed by a 0° view on the right side of the screen. The same procedure was performed on the +60° views and the 0° views that showed 2-D asymmetry.

Match trials were created by pairing views from the same object set. Nonmatch trials were created by combining the views from each object set with the views from two different object sets, one symmetrical, and one asymmetrical object set, to balance object structures in the nonmatch trials. Consequently, to balance the number of match trials and nonmatch trials in the experiment, all match trials were presented twice. It is important to note that, as the A-views showed only limited structural information, these views could effectively be 'mapped' onto the objects in more than one way. Nevertheless, the kind and amount of rotation needed for each different type of trial (i.e., AC, CA, CC_1, and CC_2) was explained to the participant in such a way that other mappings were not allowed (i.e., mapping the A-view onto an object by rotating the object by more than |30°| around its vertical axis was not allowed).

After showing examples of both a match trial and a nonmatch trial, a practice task was started. During the practice task, visual feedback was provided as to whether the response was correct. During the main task no feedback was given. Instead, a blank screen appeared for 750 ms, followed by the fixation cross and the next trial. A total of 512 trials were used: 16 object sets, 4 pairings of views (AC, CA, CC_1, and CC_2), 2 positions of the first presented view (left side or right side of the screen), 2 presentations of each object set, and 2 kinds of trials (match trials and nonmatch trials). The practice task consisted of 20 trials, selected randomly from the 512 trials. The experiment took about 45 min to complete. All trials were presented randomly in a single session. A label below each button indicated same or different. Half of the participants used their dominant hand for same responses, while the other half used their non-dominant hand for same responses. Reaction times (RTs) were measured to the nearest millisecond. The measurement of RTs started when the *second* view was presented.

Results

All analyses were performed on the correct match trials (with a 6.2% error rate over all participants in the match trials). Preliminary analyses revealed no differences between accuracy data and RT data; from now on, we will focus on RT data only. There was no speed–accuracy trade-off. RTs were measured as the dependent variable in a two-factorial design with the following independent variables: 3-D Symmetry (2 levels, symmetrical and asymmetrical objects) and Sequence (4 levels, AC, CA, CC_1, and CC_2 matching). A repeated measures ANOVA revealed that the two main effects were significant. See Table 1 for the mean RTs (M) and standard errors of the means (SEM) for the two main effects.

First, the main effect for 3-D Symmetry was significant, $F(1,19) = 25.50$, $p < .001$. Symmetrical objects were matched faster than asymmetrical objects. Second, the main effect of Sequence was significant, $F(3,17) = 9.87$, $p < .005$. Contrast comparisons revealed that objects in the AC condition were matched slower than objects in the CA condition, $F(1,19) = 19.73$, $p < .001$. The objects in the AC condition were also matched slower than objects in the CC_1 condition, $F(1,19) = 4.95$, $p < .05$, and objects in the CC_2 condition, $F(1,19) = 7.61$, $p < .05$. Objects in the CA condition were matched faster than objects in the CC_1 condition, $F(1,19) = 11.26$, $p < .005$. Matching of objects in the CA condition did not differ significantly from the matching of objects in the CC_2 condition ($p = .057$). An interaction effect between the two variables was also found, $F(3,17) = 7.73$, $p < .005$. Contrast comparisons showed that there were no differences between the symmetrical objects and the asymmetrical

Table 1 Means (*M*) and standard errors of the means (*SEM*) for the main effects 3-D Symmetry and Sequence. *AC* accidental to canonical, *CA* canonical to accidental, CC_1 canonical to canonical (i.e., |30°| to |60°|), CC_2 (i.e., |60°| to |30°|)

	M (ms)	SEM (ms)
3-D Symmetry		
Symmetric	1,237	22.80
Asymmetric	1,362	28.71
Sequence		
AC	1,499	34.62
CA	1,126	22.71
CC_1	1,301	21.09
CC_2	1,270	24.06

objects in both the AC and the CA conditions ($F < 1$). The symmetrical objects were matched faster than the asymmetrical objects in both the CC_1 condition, $F(1,19) = 25.38$, $p < .001$, and the CC_2 condition, $F(1,19) = 23.31$, $p < .001$. Figure 3 shows the graph of the mean RTs as a function of 3-D Symmetry and Sequence.

To more closely examine the effects of 2-D symmetry in the A-views, an additional analysis was performed. Only the AC and CA conditions were used, as there was no 2-D symmetry present in the CC_x conditions. The new variable Sequence' thus consisted of only two levels. A three-factorial repeated measures ANOVA was performed, with 3-D Symmetry (symmetrical and asymmetrical), 2-D Symmetry (symmetrical and asymmetrical), and Sequence' (AC and CA) as the independent variables. The dependent variable was RT. Table 2 shows the means and SEMs for each condition. Only a main effect for Sequence' was found, $F(1,19) = 19.34$, $p < .001$, indicating that AC matching was performed more slowly than CA matching. Thus, the presence of symmetry in an A-view did not lead to differences in matching between symmetrical and asymmetrical objects. In addition, the symmetrical objects could be either congruent or incongruent with the axis of symmetry in the A-view. Therefore, another analysis was performed for the symmetrical objects to examine effects of congruency.

A two-factorial repeated measures ANOVA was performed for the symmetrical objects only, with Congruency (2 levels, congruent and incongruent) and Sequence' (2 levels, AC and CA) as the independent variables and RT as the dependent variable. The main effect of Congruency was not significant ($p = .076$), that is, the congruent symmetrical objects (M = 1,277, SEM = 26.79) were matched only marginally faster than the incongruent symmetrical objects (M = 1,428, SEM = 37.62). A main effect was found for Sequence', $F(1,19) = 15.35$, $p < .001$, indicating that matching in the AC condition (M = 1,528, SEM = 37.11) was slower than matching in the CA condition (M = 1,177, SEM = 28.23). The interaction effect between Congruency and Sequence' was not significant ($F < 1$).

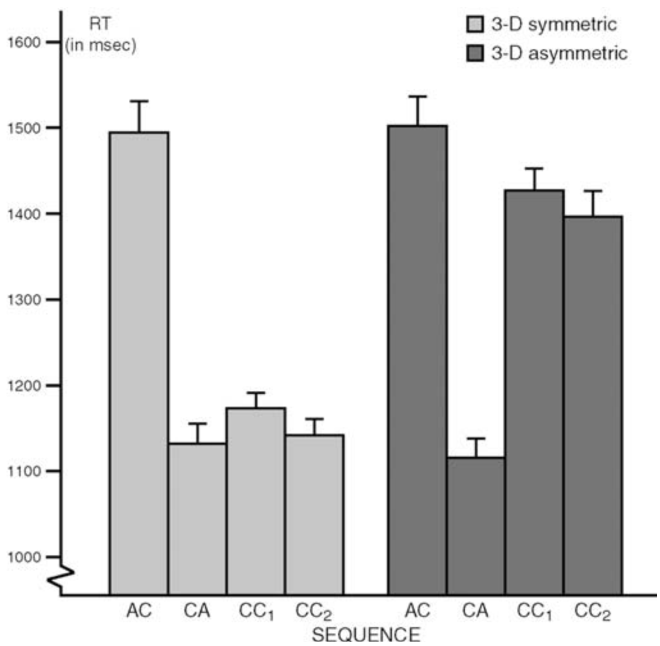

Fig. 3 Graph of mean reaction times (RTs) as a function of 3-D Symmetry and Sequence. The objects were either 3-D symmetric or 3-D asymmetric. The variable Sequence consisted of four levels: AC matching (accidental to canonical), CA matching (canonical to accidental), CC_1 matching (canonical to canonical, i.e., |30°| to |60°|) and CC_2 matching (canonical to canonical, i.e., |60°| to |30°|). Error bars represent one standard error of the mean

Discussion

In a sequential matching task, objects had to be mentally rotated in order to judge whether two views resulted from the same object. Both A-views and C-views were used, and the matching of symmetrical objects versus asymmetrical objects was examined. Additionally, 2-D symmetry in the A-views was varied. In the AC and CA conditions, no differences were found between symmetrical and asymmetrical objects. Thus, the matching of symmetrical objects is not always faster than the matching of asymmetrical objects. This finding is somewhat counterintuitive. When two C-views were presented, we found that symmetrical objects were matched faster than asymmetrical objects. In addition, the presence of symmetry in an A-view (in the AC and CA conditions) did not

Table 2 Means (*M*) and standard errors of the means (*SEM*) for the analysis 3-D Symmetry × 2-D Symmetry × Sequence'

3-D	2-D	Sequence'	M (ms)	SEM (ms)
Symmetric	Symmetric	A–C	1,513	35.67
		C–A	1,159	25.89
	Asymmetric	A–C	1,468	38.14
		C–A	1,112	21.86
Asymmetric	Symmetric	A–C	1,491	34.68
		C–A	1,178	25.65
	Asymmetric	A–C	1,501	34.03
		C–A	1,060	20.90

lead to differences in matching performance for both the symmetrical and asymmetrical objects. Finally, whether the symmetrical objects were congruent or incongruent with the suggested axis of symmetry in the A-view did not influence object matching in the AC and CA conditions, although there was a marginal advantage for the congruent symmetrical objects.

We will first discuss the results of the two CC conditions. In the two CC conditions, an advantage for symmetrical objects over asymmetrical objects was found, which is in line with previous work on 3-D symmetrical and asymmetrical objects (Large, McMullen, & Hamm, 2003; McMullen & Farah, 1991; Van Lier & Wagemans, 1999). Although the order in which the C-views were shown differed between the two CC conditions, the angular difference between the views of the two conditions was the same. As there were no differences between these two CC conditions, this indicated that there was no effect of direction of mental rotation. Similar to the results by Tarr and Pinker (1990), we also found that symmetrical objects can be matched faster across different (i.e., non-accidental) viewpoints. Whereas Tarr and Pinker used 2-D stimuli and only plane rotations, however, we used 3-D objects and depth rotations. It is important to note that the viewpoint-dependent effects that were found in the two CC conditions cannot be taken to mean that the objects in question also have a viewpoint-(in)dependent representation, that is, based on viewpoint-specific effects alone (e.g., in a mental rotation task), it cannot be said for certain that representations of objects are in fact viewpoint dependent (see e.g., Bar, 2001; Jolicoeur, Corballis, & Lawson, 1998; Lawson, 1999; Willems & Wagemans, 2001). However, the focus here is on differences between symmetrical and asymmetrical objects across accidental and non-accidental viewpoints, not whether symmetrical objects have a viewpoint-(in)dependent representation compared with asymmetrical objects.

With respect to the AC condition, it may be argued that participants did not perform a matching from the A-view to the C-view. Instead, it is possible that participants waited for the C-view to appear before matching was started. As the A-views lacked information regarding object structure, this caused the generation of an object representation to be difficult. However, whether the participants did perform such a "delayed CA" matching or not, the crucial comparison here is between the symmetrical and the asymmetrical objects. Also in the CA condition, no differences were found between the symmetrical objects and the asymmetrical objects. As the first presented view was a C-view, a representation of the object could have been generated for both the symmetrical and the asymmetrical objects. Additionally, because the participants knew what kind of rotation was required, the view that was to be presented next could also be generated. Given the fast and equal response times, the A-views were apparently highly accessible for both the symmetrical and the asymmetrical objects.

Next, we will consider the results of 2-D symmetry in the A-views. We did not find an effect of 2-D symmetry for the symmetrical objects or for the asymmetrical objects. In addition, no effect of congruency with respect to the symmetrical objects was found, that is, although the congruent symmetrical objects were matched faster than the incongruent symmetrical objects in both the AC and CA conditions, this effect was non-significant. As the results showed that 2-D (a)symmetry does not influence object matching, it seems to contradict the suggestion by Vetter and Poggio (1994), who argued that symmetry in an A-view would hinder object matching, and to be in line with the suggestion by Lawson and Humphreys that the presence of symmetry would not hinder object matching.

In conclusion, the presence of 2-D symmetry in an accidental view does not influence 3-D object matching for asymmetrical objects or for congruent or incongruent symmetrical objects. In addition, there is no advantage for symmetrical 3-D objects over asymmetrical 3-D objects when accidental viewpoints are involved. Using A-views in an object-matching task can abolish the advantage that symmetrical objects have over asymmetrical objects, that is, when an accidental view of an object is presented first (followed by a non-accidental view), there is a relative disadvantage for symmetrical objects compared with when two non-accidental views are shown. When a non-accidental view is presented first (followed by an accidental view), there is a relative advantage for asymmetrical objects compared with when two non-accidental views are shown. In this case, there is apparently a relatively high accessibility of accidental views for both symmetrical and asymmetrical objects. Thus, accidentalness in an image may help or hinder object-matching depending on the order of the presentation sequence of views. The advantage for symmetrical objects over asymmetrical objects seems to be present only when the 3-D structures of the objects are apparent in the views that are to be matched.

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