

RIGID AND NONRIGID OBJECTS IN CANONICAL AND NONCANONICAL VIEWS: HEMISPHERE-SPECIFIC EFFECTS ON OBJECT IDENTIFICATION

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We compared the performance in a picture-name matching task of 10 patients suffering from left cerebral hemisphere (LH) damage and 10 from right hemisphere (RH) damage. The tasks showed detailed figures of nonrigid objects (animals) and rigid objects (artefacts), and each object was shown in two separate views: a noncanonical view (an unusual perspective for rigid objects or a contorted pose for the nonrigid ones) and a canonical view (a typical perspective and pose). Patients with LH damage were specifically impaired in identifying noncanonical (contorted) poses of nonrigid objects (animals). In a second picture-name matching experiment, using the divided visual field technique, normal subjects matched names to images of nonrigid shapes (animals) shown in canonical and noncanonical perspectives of noncontorted, typical poses of the animals. It was found that the normal subjects' RH identified these perspectives better than their LH. We conclude that computationally different problems are solved by different cerebral mechanisms when identifying flexible objects and when identifying rigid objects. We propose the idea that identifying flexible objects when their shapes contort relies on accessing stored descriptions of objects' parts and their "categorical" spatial relations and that both types of information are encoded better by the LH. In contrast, we propose that the RH is more adept at identifying different perspectives of rigid objects (and flexible objects when their shapes do not contort) because of this hemisphere's superiority in encoding specific global shapes and their views, and in coordinate spatial transformation.

Very few objects project the same or a highly similar shape image onto our retinæ when seen from different viewpoints. Yet, all these different images

must somehow be recognised as arising from the same object. According to one theoretical account, we recognise objects despite such extraordinary

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variation of viewing conditions by using a “structural description” that specifies parts and their connections or spatial relations (e.g., cf. Biederman, 1985, 1987; Marr, 1982). However, according to another theoretical view, the brain stores a large number of images or views for each shape and can retrieve them in a parallel manner (cf. Koenderink & Van Doorn, 1979; Logothetis, Pauls, & Poggio, 1995; Perrett et al., 1985; Poggio & Edelman, 1990; Tarr & Bülthoff, 1995; Ullman, 1996).

These multiple images, belonging to the same object, would be stored while we experience a shape through changes in viewpoint and rotations in depth. Thus, when the object is flexible and dynamic in shape (e.g., a human being, an umbrella), it would also seem necessary to store the different poses (e.g., for animate objects, the deformations of its surface across different types of movements or actions; cf. Kourtzi & Shiffrar, 1999). Clearly, animals and other flexible objects



Figure 1. *Contorted human body (from Lois Greenfield: Breaking Bounds. London: Thames and Hudson, 1992).*

(e.g., plants) have joints that can bend or surfaces that can be stretched, creased, and folded, either by internal or external forces (e.g., a cat curling up asleep). Rigid objects also project different images with changes of viewpoint, but their parts and surfaces always remain at fixed locations relative to one another. Thus, it would seem that computationally different problems must be solved by a system that identifies flexible objects rather than by one that identifies rigid objects, and different mechanisms may be used in the two cases.

Our hypothesis is that structural descriptions will be most useful in recognising flexible objects, since parts and surfaces of flexible objects change their relative locations when these objects contort and therefore their global shape is altered. However, some spatial relations descriptions remain invariant across changes in the relative locations of parts and surfaces (i.e., when these objects contort). This spatial information is of an abstract kind, describing qualitative properties of the connections (that one part is to the side of another or end-to-end connected, etc.; cf. Hummel & Biederman, 1992; Richards, Dawson, & Whittington, 1988); accordingly, the structure of an object remains invariant at such an abstract spatial level and different views of the same parts will end up with the same abstract description. Indeed, several theories of structural descriptions have posited that qualitative classes of spatial relations are an integral part of the representation (cf. Biederman, 1987; Marr, 1982, pp. 305–307). Stephen Kosslyn has labelled such abstract spatial representations “categorical” because they define an equivalence class, independent of any precise position (Kosslyn, 1987, 1994; Laeng, Chabris, & Kosslyn, in press).

We specifically propose that when the viewed shape does not match a global template in visual memory, as when a familiar flexible object is seen in a novel contortion (e.g., see Figures 1 and 2), an active “top-down hypothesis-testing” mechanism will come into play and this will make use of categorical spatial relations, stored with the object’s structural description, in searching for a flexible object’s parts in the perceived image. Alternatively, when the object is rigid and this is also seen in a novel or less familiar view (e.g., see Figure 3), the

visual system could attempt to transform, within coordinate (quantitative) space, an internal canonical description of the candidate shape. This strategy would also be engaged by a perceptual hypothesis but it would be characterised by the mental alignment (e.g., a rotation) of a stored, possibly holistic, object’s model to the perceived image (cf. Jolicoeur, 1985, 1988, 1990; Tarr, 1995; Ullman, 1996). This visual matching method would be based on coordinate spatial transformations and it would seem an effective strategy for recognising *rigid* objects from noncanonical views (e.g., a water bucket seen perpendicularly from above or from the bottom so that its main axis is foreshortened) as well as noncanonical perspectives of flexible objects when these appear in typical poses (e.g., see Figure 8). However, and crucially, this method would not be successful in matching a flexible object seen in an unusual contortion.

Given these considerations, it is then relevant to note that parts and categorical spatial relations among them are both encoded better by the left cerebral hemisphere (LH) than the right hemisphere (RH). Studies of patients with unilateral brain damage have revealed a LH selective deficit in the encoding of constituent parts of objects, and normal subjects can encode local elements of a hierarchical display (cf. Navon, 1977) better when the stimuli are presented in the right visual field (hence encoded initially by the LH) than in the left visual field (Delis, Robertson, & Efron, 1986; Robertson & Delis, 1986; Robertson & Lamb, 1991; Van Kleeck, 1989). Moreover, there is evidence from clinical and normal lateralisation studies and brain imaging studies, as well as studies of nonhuman primates, that categorical spatial relations representations are encoded better by the LH (e.g., Baciú et al., 1999; Banich & Federmeier, 1999; Bruyer, Scailquin, & Coibon, 1997; Dépy, Fagot, & Vauclair, 1998; Hellige & Michimata, 1989; Kessels, Kappelle, De Haan, & Postma, 2002; Kogure & Hatta, 1999; Kosslyn, 1987; Kosslyn, Chabris, Marsolek, & Koenig, 1992; Kosslyn et al., 1989; Laeng, 1994; Laeng & Peters, 1995; Laeng, Peters, & McCabe, 1997; Parrot, Doyon, Demonet, & Cardebat, 1999; Trojano et al., 2002). In contrast, the RH’s perceptual specialisations can

be described as complementary to those of the LH. Namely, in spatial tasks where it is necessary to specify the precise metric distances among objects or parts (also defined as “coordinate” spatial relations; Kosslyn, 1987), RH damage disrupts performance (Laeng, 1994). Normal subjects also show better encoding of this type of spatial relation in their left visual field (hence, by the RH) than in the right visual field (e.g., Hellige & Michimata, 1989; Laeng & Peters, 1995; see Chabris & Kosslyn, 1998, for a review). In addition, global forms are encoded better when presented in the left visual field and RH lesions selectively disrupt the memory of the global form of a hierarchical structure but not of its constituent parts (Delis et al., 1986; Robertson & Delis, 1986; Robertson & Lamb, 1991). Finally, there is also evidence that the visual representations of specific shapes are matched more effectively in the RH and that lesions to this hemisphere’s temporal lobe disrupt the memory of specific pictures of objects more than lesions to the LH (Marsolek, Kosslyn, & Squire, 1994a; Marsolek, Squire, Kosslyn, & Lulenski, 1994b; Metcalfe, Funnell, & Gazzaniga, 1995; Milner, 1968; Phelps & Gazzaniga, 1992; Vilkkii, 1987; Warrington, 1984). Therefore, we expect that if people are very familiar with a shape (and likely to have stored it as such) they identify it more effectively in the RH (Laeng, Shah, & Kosslyn, 1999).

In the present study, we investigate the effects of unilateral brain damage on the recognition of nonrigid objects (animals) as well as of rigid objects (artefacts) seen at different perspectives or poses. Based on the evidence, mentioned earlier, that the LH is specialised for parts and abstract spatial relation representations, we hypothesise that the LH plays a key role in supporting structural descriptions and that these are most effective for the recognition of difficult or unusual views but not for the recognition of conventional and familiar views of objects. Hence, lesions to the LH should cause a deficit in the recognition of unconventional poses but not of conventional poses of objects. Specifically, we hypothesise that the effect of LH damage should be most clear when patients identify unusual views of *flexible* objects (e.g., animals viewed in contorted poses) than when seeing *rigid* objects (e.g.,

artefacts), even when the latter forms are seen in unusual noncanonical perspectives. Previous work by Warrington and colleagues (e.g., Warrington & James, 1986; Warrington & Taylor, 1973, 1978) has revealed perceptual impairments of patients with lesions to the RH (especially those with damage to the parietal lobe) when they identified *rigid* objects seen in noncanonical views. Within our account, RH damage would also be expected to affect rigid objects’ recognition. In particular, dorsal damage to the RH could affect (1) the extraction of depth cues, such as slant or shading, from two-dimensional pictures (cf. Carmon & Bechtold, 1969; Durnford & Kimura, 1971; Humphrey, Symons, Herbert, & Goodale, 1993; Layman & Green, 1988; Sakata, Taira, Kusunoki, & Tanaka, 1997) or (2) the mental transformation of a stored model to match the input (e.g., alignment and rotation; cf. Alivisatos & Petrides, 1997; Cohen, 1975; Corballis & Sergent, 1989; Ditunno & Mann, 1990; Harris et al., 2000; Layman & Green, 1988; Ratcliff, 1979; Tagaris et al., 1997; Wendt & Risberg, 1994; Zacks, Rypma, Gabrieli, Tversky, & Glover, 1999). Moreover, dorsal lesions to the RH can result in deficits in coordinate space representation (Laeng, 1994), which in turn could affect the ability to perform rigid transformations of stored models. Finally, we surmise that ventral lesions to the RH could disrupt either the memory for specific views of objects or the matching of the object’s perceptual image to stored, viewer-centred, global representations of the same object (or of an object in the same class; cf. Tarr & Pinker, 1989).

EXPERIMENT 1

Two groups of unilaterally damaged patients and a group of control subjects were examined in two picture-name matching tasks where objects appeared in either the canonical view or in one noncanonical view. In each trial a name was presented along with the picture; half of the time the names matched the objects and half of the time they named other objects. Each subject decided whether the word correctly named the picture or not. Specifically, in the Animals task, subjects saw on a computer screen

figures of individual animals (e.g., a giraffe) while hearing words that could be appropriate names for the pictured objects or not (e.g., “horse”). In some instances, the body position of the animal was unfamiliar and clearly “contorted” (e.g., the animal could bend its torso or limbs, thus causing unusual juxtapositions and occlusions of relevant body parts; see Figure 2). In the Objects task, the subjects saw figures of common objects (e.g., a teapot) while again hearing words that could be appropriate names or not (e.g., “frying pan”). In some instances, the view was either from a perpendicular angle to

Table 1. *Details of experimental subjects*

<i>Group/Subject no</i>	<i>Area of lesion</i>	<i>Sex</i>	<i>Age</i>
<i>Left-hemisphere lesion</i>			
1	P+T	F	31
2	P	M	59
3	P	F	61
4	P+T+F	F	62
5	P+T	F	64
6	P+T+F	M	68
7	P	M	70
8	P+T	M	71
9	P+O	M	75
10	T+O	F	76
<i>Right-hemisphere lesion</i>			
1	T	F	57
2	P	F	66
3	P+T+O	M	66
4	(p)	M	67
5	P+T+F	M	68
6	P	M	69
7	P	M	70
8	P	F	70
9	P+T	M	73
10	P+T	M	76
<i>Control</i>			
1	-	M	31
2	-	F	61
3	-	F	62
4	-	M	66
5	-	M	68
6	-	M	70
7	-	M	70
8	-	F	73
9	-	F	75
10	-	M	76

F = frontal lobe; T = temporal lobe; O = occipital lobe; P = parietal lobe; (p) = putamen.

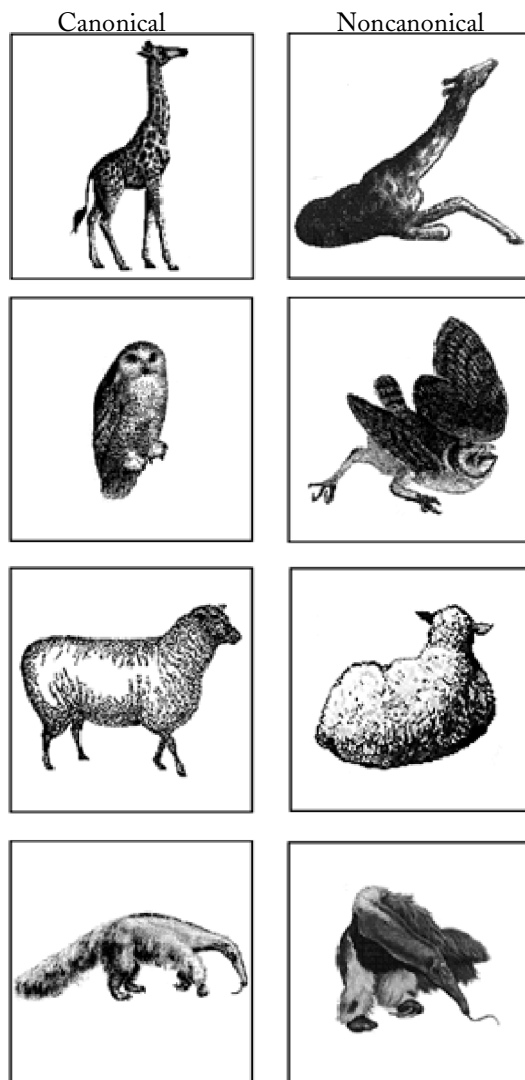


Figure 2. *Nonrigid objects. In the left column: canonical views of animals; in the right column: noncanonical views (contorted poses) of the same animals.*

the top or bottom of the object, so that the projected shape was noncanonical (i.e., there were occlusions of relevant parts as well as foreshortening of the object’s main axis; see examples in Figure 3). In other instances, the view was either from the side or slightly from above, so that the most relevant parts as well as the object’s principal axis were clearly visible.

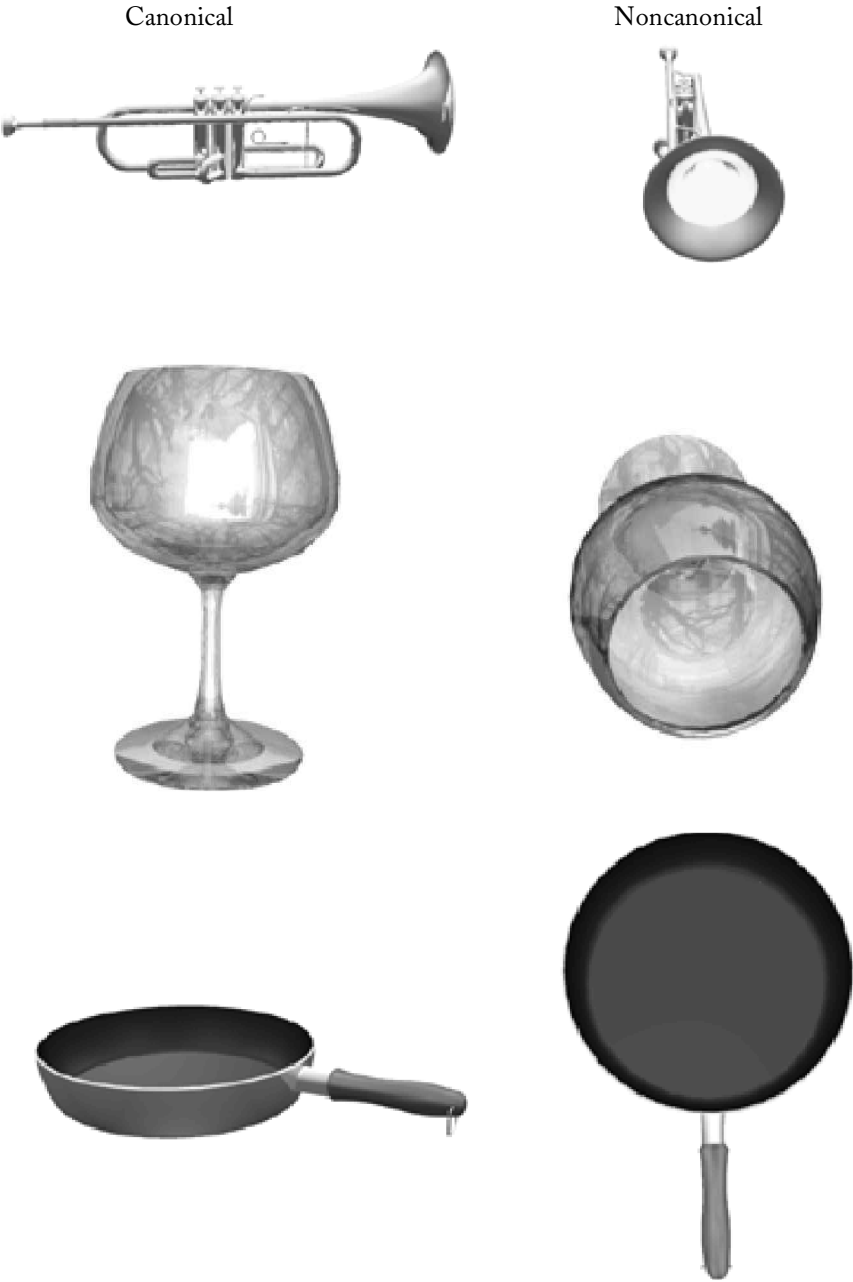


Figure 3. Rigid objects. In the left column: canonical views of artefacts; in the right column: noncanonical views of the same artefacts.

Because we hypothesise that the LH supports recognition processes that are essential for the identification of novel images of *nonrigid* objects, we predict that performance should be worse for LH patients than RH patients (and control subjects) in matching the name of a *nonrigid* object or animal to a contorted pose. In contrast, we hypothesise that each hemisphere supports recognition processes that are complementary for the identification of novel images of *rigid* objects; therefore, we predict less impairment in identifying unusual views of artefacts than animals for both patient groups. Because several of the recognition mechanisms that are supported by RH lateralised processes may be effective for rigid object recognition, we are also led to predict that LH patients should be less impaired than RH patients in the identification of noncanonical images of *rigid* objects. Finally, we expect that conventional pictures of either nonrigid or rigid shapes should cause no specific problem to any of the unilateral brain-damaged patient groups, since these views are over-learned, easily identifiable by definition, and likely to be matched equally well by each hemisphere's pattern recognition processes.

Method

Subjects. Twenty unilateral stroke patients with lesions confined to one cerebral hemisphere according to brain imaging analyses (i.e., CT and MRI) were recruited in the IRCCS S. Lucia Hospital and the Gemelli Hospital of the Università Cattolica (Rome, Italy). Ten neurologically normal individuals (five females and five males), in the same age group as the patients (mean age = 65 years, $SD = 13$), were recruited as controls subjects in Tromsø, Norway. Table 1 shows each subject's age, sex, and the patients' area of lesion. The two groups of patients did not differ in terms of age (LH: mean age = 63.7, $SD = 12.9$; RH: mean age = 68, $SD = 5.0$), $F(1, 18) = 1.1$, $p < .32$.

Stimuli and apparatus. The pictures used in the animal task were the same set of pictures used in a study by Laeng et al. (1999); that is, black and white line drawings of animals (either engravings or fine ink pen drawings) selected from zoology books

(e.g., Buffon, 1993; Harter, 1979). These drawings are realistic depictions in which the correct proportions, natural texture, and shading of the animals' bodies are clearly represented (see Figure 2). In Laeng et al.'s study, three independent judges chose, from several pictures of each animal, one conventional pose in which the animal's body appeared in a natural standing position (from either a side or $\frac{3}{4}$ "canonical perspective", cf. Palmer, Rosch, & Chase, 1981) and one contorted, or highly unconventional, unfamiliar (noncanonical) pose. The pictures used in the Objects' task were selected from the Tarlab image database (Brown University). These are computer-rendered pictures of several common objects, mostly artefacts (see Figure 3). Each object's views were selected according to the same criteria for the Animal task. All images were presented in gray-scale at a distance so that each image occupied approximately 5 degrees of visual angle, the animals' heads towards the right side of the screen. Laeng and colleagues have found that the head was most often rated as the most informative part of the body for identity judgments. Animals' and objects' names (in Italian or Norwegian) were recorded digitally for auditory presentations, while spoken slowly and clearly by two native speakers. On foil trials, names of dissimilar animals/objects used in the task were paired with an inappropriate picture (e.g., a picture of a lion and the name "horse"); each name appeared equally often as a distractor and a target. The foil figures in both the Animals and Artefacts tasks were selected on the basis of structural similarity (which also correlates with semantic neighbourhood) between the perceived and named objects.

Procedure. Each task was divided in two blocks, and these blocks were presented in ABBA order, beginning with the Animal task for each subject. Each block showed the complete set of pictures once (i.e., all animals or artefacts in both views) and presented the stimuli in the same order; however, the truth or falsity (50% likelihood) of the name matches for one drawing in one block were reversed in the other block. There were no practice trials. Subjects sat upright at a distance of about 45 cm away from the computer screen. For a few RH

patients, who had evidence of spatial neglect from independent neurological testing, the computer screen was moved about 40 cm towards the right side of the patient's body midline; all patients reported seeing a stimulus in every trial and gave a yes/no response to the verbal match. Each trial had the following sequence of events: (1) a blank screen; the subject initiated a trial by pressing the space bar of the computer's keyboard; (2) a visual stimulus (e.g., an animal in a box) appeared in the centre of the screen; an auditory stimulus (e.g., an animal name) was presented simultaneously; (3) the subject indicated whether the name was appropriate, as quickly and accurately as possible, by pressing one of two adjacent keys (B or N) marked "yes" and "no" in their language. The computer recorded each answer together with its latency from the onset of the picture. Following each response, the picture would disappear from the screen and the subject could initiate a new trial.

Results

We first obtained descriptive statistics for each subject. Mean percentage of (%) errors and response times (RTs) were calculated for each combination of the factor of View (canonical versus noncanonical). The data were pooled over type of match (yes versus no), since a preliminary analysis showed that this factor did not interact with any of the other factors. Data were also pooled over the two separate blocks, since there was no evidence for a reduction of error rates in the second block. Times from trials on which errors occurred were excluded from computation of the RTs. In addition, trials with RTs longer than 3 SDs from each individual's mean RT for that condition were excluded from all the statistics (on average 2% of correct responses were discarded for each of the control subjects and 4% of data for both types of patients). The results (mean % errors and RTs) for each task (Animals and Objects) were then analysed with four separate repeated-measures analyses of variance.

Animals task

Error rates. In the analysis on the mean % errors data, View (canonical versus noncanonical) was

the within-subject factor and Group (LH, RH, controls) the between-subjects factor. This analysis revealed a reliable difference in error rate between the groups, $F(2, 27) = 3.8, p < .03$, power = .6. The control subjects committed fewer errors (mean % error = 5.6, $SE = 0.5$) than either the LH stroke group (mean % error = 12.8, $SE = 2.6$) or the RH stroke group (mean % error = 9.2, $SE = 1.1$). However, post hoc Fisher's LSD tests (crit. diff. = 4.9) showed that only the LH group differed reliably from the control group ($p < .006$), whereas the difference between the LH and RH groups approached significance ($p < .08$) and the RH patients did not reliably differ from the control subjects ($p < .25$). The main effect of View was also significant, $F(1, 27) = 39.5, p < .0001$, power = 1.0. All subjects found it more difficult to match labels to noncanonical views (mean % error = 12.6, $SE = 1.7$) than canonical views (mean % error = 5.1, $SE = 0.7$).

Importantly, this analysis of variance revealed a significant interaction between the factors of Group and View, $F(2, 27) = 7.2, p < .003$, power = .9. LH patients showed more difficulty, as we would expect, than RH patients and control subjects (see Figure 4) in identifying animals in noncanonical contorted poses (LH: mean % error = 19.4, $SE = 4.1$; RH: mean % error = 11.1, $SE = 1.6$; control subjects: mean % error = 7.2, $SE = 0.3$). A separate ANOVA on the mean % error rates for noncanonical views confirmed these effects, $F(2, 27) = 6.0, p < .006$, power = .85. Post hoc Fisher's LSD tests (crit. diff. = 7.4) showed that the LH group differed reliably from both the RH group ($p < .03$) and the control group ($p < .002$), whereas the RH patients did not reliably differ from the control subjects ($p < .29$). In contrast (see Figure 4), there was no difference between the three groups when they viewed canonical or typical poses of animals (control subjects: mean % error = 4.0, $SE = 0.4$; LH: mean % error = 6.1, $SE = 1.7$; RH: mean % error = 5.9, $SE = 1.0$). A separate ANOVA on the mean error rates for canonical views failed to reveal any difference, $F(2, 27) = 1.0, p < .40$, power = .2.

Response times. Similar analyses were performed on the response time data with View (canonical versus noncanonical) as the within-subject factor and

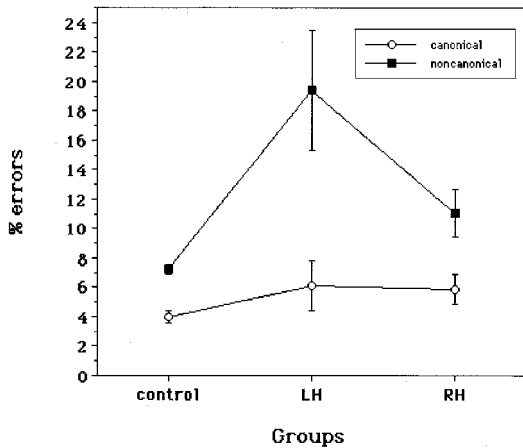


Figure 4. *Animals task: Means and standard errors of percent error rates to canonical and noncanonical views of nonrigid shapes for the left-hemisphere patients (LH), the right-hemisphere patients (RH), and the control subjects (Ns).*

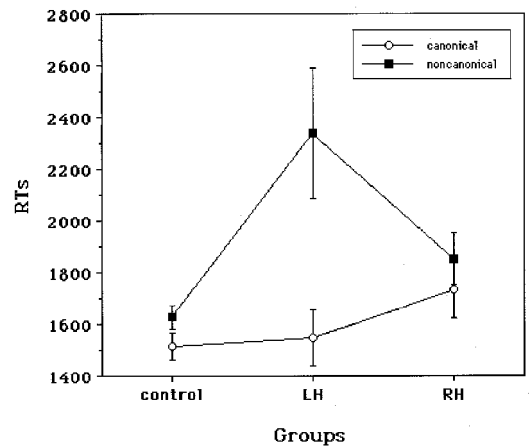


Figure 5. *Animals task: Means and standard errors of RTs to canonical and noncanonical views of nonrigid shapes for the left hemisphere patients (LH), the right hemisphere patients (RH), and the control subjects (Ns).*

Group (LH, RH, controls) as the between-subjects factor. The main effect of Group approached significance, $F(2, 27) = 2.9$, $p < .07$, power = .58. Consistent with their high error rate, LH patients were slower than normal subjects in matching names of animals to noncanonical poses (LH: mean RTs = 1943 ms, $SE = 162$; control subjects: mean RTs = 1572, $SE = 36$); also consistent with their low error rate, the RH patients (mean RTs = 1792 ms, $SE = 72$) were neither slower than the control subjects nor faster than the LH patients. Post hoc Fisher's LSD tests (crit. diff. = 3.2) confirmed that the LH group differed reliably from the control group ($p < .02$) whereas the RH patients did not reliably differ from the control subjects ($p < .17$) or the LH patients ($p < .33$). The main effect of View was also significant, $F(1, 27) = 7.9$, $p < .002$, power = 1.0. Subjects were overall slower in matching labels to noncanonical views (mean RTs = 1940 ms, $SE = 104$) than canonical views (mean RTs = 1597 ms, $SE = 55$).

Most importantly, the analysis of variance on RTs revealed a significant interaction between the factors of Group and View, $F(2, 27) = 7.9$, $p < .002$, power = .95. As we predicted, LH patients were slower than RH patients and control subjects in identifying animals in noncanonical, contorted, poses (LH: mean RTs = 2340 ms, $SE = 252$; RH:

mean RTs = 1851 ms, $SE = 99$; control subjects: mean RTs = 1628 ms, $SE = 45$). A separate ANOVA on the mean RTs for these noncanonical views confirmed these differences, $F(2, 27) = 5.3$, $p < .01$, power = .80. Post hoc Fisher's LSD tests (crit. diff. = 469 ms) revealed a reliably slower performance for the LH group versus both the RH group ($p < .04$) and the control group ($p < .004$), in contrast with no difference between the RH and the control subjects ($p < .33$). Moreover, there was no difference between the three groups when they viewed canonical or typical poses of animals (LH: mean RTs = 1546 ms, $SE = 109$; RH: mean RTs = 1732 ms, $SE = 106$; control subjects: mean RTs = 1515 ms, $SE = 53$). A separate ANOVA on the mean RTs for canonical views failed to reveal any difference, $F(2, 27) = 1.6$, $p < .22$, power = .30. Figure 5 illustrates these findings.

Objects task

Error rates. Identical analyses to those described for the Animals task were applied to the data from the Objects task. First, one repeated measures analysis of variance was performed on the mean % errors with View (canonical versus noncanonical) as the within-subject factor and Group (LH, RH, controls) as the between-subjects factor. There was a reliable difference in error rates between the groups,

$F(2, 27) = 4.9, p < .01$, power = .77. The control subjects committed fewer errors (mean % error = 4.9, $SE = 0.4$) than either the LH stroke group (mean % error = 7.6, $SE = 1.1$) or the RH stroke group (mean % error = 10.0, $SE = 1.5$). However, in contrast with the Animals task findings, post hoc Fisher's LSD tests (crit. diff. = 3.3) showed that only the RH group differed reliably from the control group ($p < .004$), whereas there was no difference between the RH and LH groups ($p < .15$) or between the latter group and the controls ($p < .11$). The main effect of View was also significant, $F(1, 27) = 53.4, p < .0001$, power = 1.0. All subjects found it more difficult to match labels to noncanonical views (mean % error = 12.6, $SE = 1.7$) than canonical views (mean % error = 5.1, $SE = 0.7$).

The analysis of variance revealed also a significant interaction between the factors of Group and View, $F(2, 27) = 5.9, p < .008$, power = .84. In contrast with the previous findings in the Animals task, the RH patients showed more difficulty than LH patients or the control subjects (see Figure 6) in matching labels to artefacts seen in noncanonical atypical views (LH: mean % error = 7.6, $SE = 1.1$; RH: mean % error = 10.0, $SE = 1.5$; control subjects: mean % error = 4.9, $SE = 0.4$). A separate ANOVA on the mean error rates for just the noncanonical views confirmed these effect, $F(2, 27)$

= 6.5, $p < .005$, power = .88, and post hoc Fisher's LSD tests (crit. diff. = 4.6), showed that the RH group differed reliably from the control group ($p < .001$), whereas group differences only approached significance for the comparisons of the LH group and the RH group ($p < .09$) or the LH and the control group ($p < .07$). There was clearly no difference between the three groups when they viewed canonical views of these objects (LH: mean % error = 4.9, $SE = 1.3$; RH: mean % error = 5.8, $SE = 0.9$; control subjects: mean % error = 3.8, $SE = 0.3$). A separate ANOVA on the mean error rates for canonical views failed to reveal any difference, $F(2, 27) = 1.1, p < .33$.

Response times. An analysis on the response time data with View (canonical versus noncanonical) as the within-subject factor and Group (LH, RH, controls) as the between-subjects factor showed a main effect of Group, $F(2, 27) = 4.7, p < .02$, power = .48. Post hoc Fisher's LSD tests (crit. diff. = 204 ms) showed that the control group differed reliably from both the LH group ($p < .02$) and the RH group ($p < .01$); but also that the LH and RH groups were far from showing a difference ($p < .86$). Thus, LH and RH patients were equally impaired in their performance speed when matching names of rigid objects to noncanonical poses (LH: mean RTs = 1441 ms, $SE = 76$; RH: mean RTs = 1459 ms, $SE = 62$; control subjects: mean RTs = 1186, $SE = 23$). The main effect of View was also significant, $F(1, 27) = 67.1, p < .0001$, power = 1.0. All subjects were on average slower in matching labels to noncanonical views (mean RTs = 1474 ms, $SE = 57$) than canonical views (mean RTs = 1251 ms, $SE = 34$).

We expected an interactive effect between the factors of Group and View and, indeed, the analysis confirmed its presence, $F(2, 27) = 6.4, p < .001$, power = .41. Both patient groups were equally impaired in their efficiency in matching labels to objects seen in noncanonical, unusual, perspectives (LH: mean RTs = 1586 ms, $SE = 114$; RH: mean RTs = 1607 ms, $SE = 87$; control subjects: mean RTs = 1229 ms, $SE = 35$). A separate ANOVA on the mean RTs for these noncanonical views confirmed these differences, $F(2, 27) = 6.2, p < .006$,

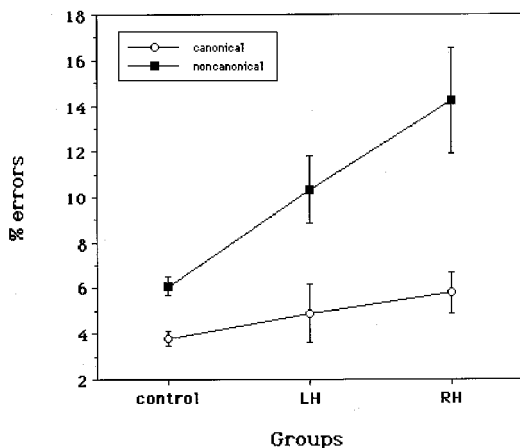


Figure 6. Objects task: Means and standard errors of percent error rates to canonical and noncanonical views of rigid shapes for the left-hemisphere patients (LH), the right-hemisphere patients (RH), and the control subjects (Ns).

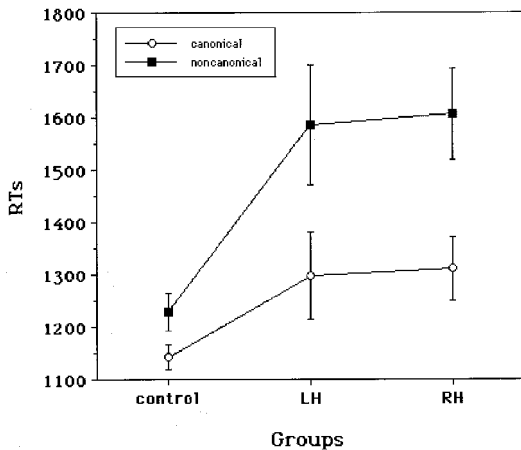


Figure 7. *Objects task: Means and standard errors of RTs to canonical and noncanonical views of rigid shapes for the left-hemisphere patients (LH), the right-hemisphere patients (RH), and the control subjects (Ns).*

power = .57, as well as post hoc Fisher's LSD tests (crit. diff. = 247 ms), revealed a reliably slower performance of both the LH and RH groups ($p < .006$ and $p < .004$, respectively) when compared to the control group ($p < .004$). Instead, there was no difference between the two groups of patients ($p < .86$). Also, there was no difference between the patients' groups, and between these and the control subjects, when they matched canonical views of these rigid objects (LH: mean RTs = 1297 ms, $SE = 83$; RH: mean RTs = 1311 ms, $SE = 61$; control subjects: mean RTs = 1143 ms, $SE = 24$). A separate ANOVA on the mean RTs for canonical views failed to reveal any difference, $F(2, 27) = 2.3$, $p < .12$, power = 0.28. Figure 7 illustrates these findings.

Discussion

We found a specific deficit in LH patients when animals in contorted poses were matched to their names. The deficit cannot be accounted for by a problem in encoding words or other lexical processing per se because the effect was dependent on view or shape transformations (i.e., with contorted poses) and there was no deficit in the same patients in matching labels to canonical views of either animals or objects. Instead, these findings are consistent with the hypothesis that the superior abilities

of the LH in encoding categorical spatial relations and/or parts play a role in the initial identification of a novel contorted pose of a flexible shape. Indeed, we surmise that LH lesions may disrupt the only perceptual strategy that is likely to succeed in these extremely challenging visual conditions.

This study may be the first to report the effects of unilateral brain damage on the perception of *nonrigid* or flexible objects. Previous research had examined perceptual deficits in neurological patients when identifying *rigid* objects, seen either in noncanonical or canonical views. Warrington and colleagues (e.g., Warrington & James, 1986; Warrington & Taylor, 1973, 1978) observed that patients with lesions to the RH (especially those with damage to the parietal lobe) had perceptual impairments in identifying *rigid* objects when these were seen in noncanonical views. Their results were originally interpreted in terms of Marr's theory (cf. Marr, 1982, p. 328); that is, RH damage causes a failure to derive the correct object-centred reference frame on foreshortened objects. Warrington and James (1986) later argued that some foreshortened views can hide several of the object's "features" (parts) that need to be mapped onto stored structural descriptions in order to achieve identification. However, this account seems inconsistent with evidence from damage to the brain of human and non-human primates. These studies implicate the ventral system, but not the dorsal, in visual shape representations (e.g., Maunsell & Newsome, 1987; Ungerleider & Mishkin, 1982); thus, it seems unlikely that damage to the parietal lobe could directly affect the description of features or the memory of objects or parts' representations as seen from specific views, since pattern recognition neurons that are specifically tuned to objects or parts are typically found in the temporal lobes (cf. Perrett, Oram, & Ashbridge, 1998). Therefore, it is more likely that dorsal (e.g., right parietal) damage interferes with procedures that operate in processes that require "visual problem solving" and that engage different types of visual top-down processing. Indeed, numerous studies suggest an important role of the parietal cortex in attention-related processes as well as in the control of eye fixations (e.g., Colby, Duhamel, & Goldberg, 1995; Corbetta, 1998;

Wojciulik & Kanwisher, 1999). The parietal role in attentional processing (both overt and covert) may explain the presence of parietal activations in human neuroimaging studies of shape processing (e.g., Kraut, Hart, Soher, & Gordon, 1997; Price, Moore, Humphreys, Frachowiak, & Friston, 1996) as well as some shape selectivity of parietal single cells, as seen in nonhuman primate studies (e.g., Sereno & Maunsell, 1998).

Interestingly, Warrington and Taylor (1973, 1978) reported a difference in the error rates of 35 LH patients and 39 RH patients when they named 20 common objects seen in gray-scale photo images. Each object was shown either in a canonical view (typically showing an object's side) or a non-canonical view (typically an end-on view). These photos showed rigid objects or artefacts (e.g., a bucket, a ladder, a typewriter), although one item included pictures of a kitten (see Warrington, 1982). In Warrington and Taylor's (1973) study, RH patients made more errors (25%) than LH patients (17%) or control subjects (2.5%). However, the patients' latencies in naming the pictures were not reported. Therefore, it remains unclear whether this group of LH patients, despite being more accurate than RH patients, would have shown impairment in their speed of response (as did the patients in the present study).

We found that RH patients were less accurate than LH patients in the recognition of non-canonical views of rigid objects. This result replicates Warrington and colleagues' findings. However, we also found that the two unilateral patient groups were equally inefficient (i.e., slower than control subjects) in matching names to pictures. Within our account, we expected a LH lesion to impair the top-down hypothesis testing (based on parts extraction and categorical relations) while sparing other matching strategies that are more dependent on RH functioning. These spared RH perceptual abilities alone may be sufficient for accurate recognition of rigid objects; e.g., either by retrieval of the global pattern of specific (noncanonical) views (cf. Kosslyn, 1994), mapping of the object's surface depth (cf. Marr, 1982), or mentally transforming an internal holistic model of the rigid shape (cf. Tarr & Pinker, 1989; Ullman,

1996). As mentioned earlier, independent evidence within cognitive neuroscience converges in showing a superior role of the RH both in surface depth perception and in coordinate mental transformations of shapes.

EXPERIMENT 2

A potential problem with the interpretation of the findings of the previous experiment is that the Animal and Object tasks did not differ solely in terms of shape properties and their spatial transformations (nonrigid versus rigid), but they also differed in terms of their object class (animals versus artefacts). Thus, the semantic domains of the stimuli could have confounded the observed dissociations. Specifically, the LH may support a domain-specific knowledge system for living (animate) things whereas the RH may support a domain-specific knowledge system for nonliving (inanimate) things.

Several neuropsychological studies have investigated the selective loss of knowledge about specific categories of objects (e.g., animals, artefacts, foods, fruits, vegetables, musical instruments, etc.; cf. Warrington & Shallice, 1984). In a study with a large number of brain-damaged patients ($N = 30$), Damasio and colleagues (Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996) found that impairments for both the category of animals and that of tools were associated with damage to the LH infero-temporal areas. Caramazza and Shelton (1998) reviewed the neuroanatomical evidence of category-specific deficit studies and concluded that the majority of patients showing deficits for living or animate things had sustained damage to the LH temporal lobe. There are, however, instances of patients (typically recovering from herpes simplex encephalitis) that implicate the RH temporal lobe for a selective deficit for living things (see Saffran & Schwartz, 1994). In contrast, there seems to be no evidence pointing to a RH specialisation for the semantic knowledge of artefacts. On the contrary, artefact recognition most predominantly engages a LH network (e.g., Damasio et al., 1996; Martin, Wiggs, Ungerleider, & Haxby, 1996; Perani et al.,

1995). Last, Gainotti and colleagues (Gainotti, Silveri, Daniele, & Giustolisi, 1995) concluded that patients who present category impairment on both verbal and nonverbal tasks almost always show bilateral brain lesions.

The available evidence from the (rapidly growing) literature on functional imaging of the human brain supports the observation that semantic and lexical processing for animals, plants, and artefacts can activate regions of temporal lobes. However, the results of these neuroimaging studies are ambiguous and often difficult to compare. In their PET study, Damasio and colleagues (1996) found that pictures of animals, artefacts, and people all activated (separate) areas within the temporal lobe of the LH. Perani and colleagues (1995), as well as Martin and colleagues (1996), found that naming pictures of animals and tools activated areas of the LH temporal lobe. Other studies involving naming of visual stimuli have shown similar findings (see Moore & Price, 1997; Moscovitch, Kapur, Köhler, & Houle, 1995; Price et al., 1996; Rosier et al., 1997; Sergent, Ohta, & MacDonald, 1992; Zelkovicz, Herbster, Nebes, Mintun, & Becker, 1998). In contrast, other neuroimaging studies (e.g., Gauthier, Anderson, Tarr, Skudlarski, & Gore, 1997; Kawashima et al., 2001; Leube, Erb, Grodd, Bartels, & Kircher, 2001) have found that the RH fusiform cortex was specifically activated in association with the naming of animals. In an object decision task, Gerlach, Law, Gade, and Paulson (1999) found that perceiving natural objects recruited parts of the RH temporal lobe; in a subsequent study (2000), they also used a categorisation task and found that whereas the RH was activated during object decision, the LH was activated during categorisation. Stewart, Meyer, Frith, and Rothwell (2001) sought to obtain converging evidence for the different roles of the cerebral hemispheres by delivering transcranial magnetic stimulation (TMS) to different parts of the brain. They delivered TMS that selectively interfered with processing in BA 37 in the LH or RH while subjects named words, pseudowords, colour patches, or Snodgrass and Vanderwart drawings. Stewart et al. found that TMS increased naming latency only for the line drawings of objects and only after LH

stimulation. The selectivity of the interference clearly indicates that the LH's role in object naming does not simply reflect phonological and lexical processes (cf. Levelt, Praamstra, Meyer, Helenius, & Salmelin, 1998), but also specific types of visual processing.

Regarding artefacts (e.g., tools) the evidence is more consistent, since there appears convergence from single-case studies and neuroimaging studies of normal subjects that (temporal) areas of the LH are specifically implicated (e.g., Damasio et al., 1996; Ilmberger, Rau, Noachtar, Arnold, & Winkler, 2002; Martin et al., 1996). Note, however, that such evidence runs contrary to the findings of this study, as well as those of previous studies on brain-damaged patients' identification of noncanonical perspectives (e.g., Warrington & Taylor, 1978). These overall contrasting results strongly suggest that other factors, beside "category," could contribute to the observed patterns of brain activation and the functional effects of lateralised lesions. Such factors may be many, for example: task demands and difficulty; whether retrieving semantic, nonvisual information or giving a lexical response is required or not; the level of taxonomy of the required identification or lexical access; and the subjects' expertise with the stimuli. We add to this list the perceptual attributes of the particular stimuli used (i.e., perspective and, for flexible objects, whether they appear contorted or not) as one factor determining which brain mechanisms will be functionally implicated in the task.

In sum, the evidence for the substrates for two semantic domains of animals and artefacts being split between the two hemispheres is not in itself very strong; and the LH lateralisation pattern for artefacts runs contrary to the evidence on brain-damaged patients' identification of noncanonical perspectives. Nevertheless, we cannot ignore such an alternative account and, consequently, we performed a second experiment aimed to tease apart whether the two hemispheres are differentially engaged (1) by the presentation of stimuli belonging to one semantic class or (2) by the type of spatial transformation required when processing the stimuli. In particular, if semantic domain is the most relevant variable and the previously observed LH

deficit for contorted views of animals reflected the repeated priming of the class “animals,” then presenting rigidly rotated, noncanonical views of animals in typical poses should yield, once again, a LH effect. Alternatively, semantic domain may not be the relevant factor behind these hemisphere-specific effects, which are due instead to the type of spatial transformations; then, presenting (rigid) rotations of animals’ shapes should yield a RH effect. The two accounts lead to opposite predictions and our account would also predict a reversal of the hemisphere-based effects if artefacts were viewed in contorted shapes. However, only the prediction on rigid rotations of animals was tested in the present experiment, whereas the prediction on contorted artefacts was not; nevertheless, only a few real-world artefacts are flexible and allow contortions (e.g., umbrellas, bicycles, some desk lamps and chairs), but all animals allow noncanonical coordinate transformation of the same rigid pose.

The following experiment makes use of a well-known method for revealing lateralisation of function in normal subjects; namely, the divided visual field technique (see Hellige, 1993; Springer & Deutsch, 1996). This method relies on showing that the cerebral hemispheres differ in their ease of carrying out different processes. That is, if the LH performs one process better than the RH, and the RH performs another process better than the LH, then the two processes must rely on distinct underlying mechanisms. If the same mechanism were used in both cases, either one hemisphere would perform both processes better or there would be no difference between the hemispheres. Specifically, visual stimuli appear tachistoscopically in one of the two lateral visual hemifields while participants maintain central fixation. As in Experiment 1, we used a picture-name verification task, in which each picture was followed by the visual presentation of a name for an animal (half of the time correct), and the participants decided whether the name was appropriate for that specific animal. Some of the pictures showed the animal from a canonical view (e.g., a horse standing in its typical four-legged position and viewed frontally from a slightly skewed angle); in contrast, some of the pictures showed the same animal in the same position but

seen in a noncanonical perspective (e.g., the horse viewed from the rear; see Figure 8 for examples). Crucially, all of these noncanonical perspectives represent a rigid rotation of a typical or conventional pose of each animal; as discussed earlier, the identification of these shapes should be most efficiently solved by perceptual mechanisms that we hypothesise to depend more prevalently on RH structures.

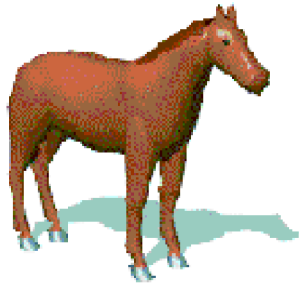
Method

Subjects. Ten right-handed students (four females and six males) at the University of Tromsø, Department of Psychology, volunteered as subjects. Handedness was assessed by self-report.

Stimuli and apparatus. Twenty-two colour-rendered digital drawings of animals were selected from the Viewpoint Premier models online database. All drawings were realistic depictions (polygonal meshes and NURBS models of animate and inanimate objects) in which the correct proportions, natural texture, and shading of the animals’ bodies were clearly represented. For this experiment, two views were selected for each of the 22 selected species, according to the following criteria: (1) One drawing depicted a specific view of the animal that was judged by the authors to be “conventional” (i.e., the body appeared in a natural standing position and, typically, as seen from either a side or $\frac{3}{4}$ “canonical perspective,” cf. Palmer, 1999; Palmer et al., 1981); (2) the other drawing depicted the animal in the same pose but viewed from another angle of perspective (rotated in depth) that was judged by the authors to be unconventional and noncanonical; i.e., a rear view of the animal.

Specifically, the set of images included an anteater, bat, bee, bull, camel, chicken, cockroach, dog, dolphin, eagle, elephant, elk, finch, fox, goat, horse, owl, penguin, pig, polar bear, reindeer, and shark. These animals’ names were also presented visually, in Norwegian and in Geneva font (size 24). In foil trials, names of animals from the same visual stimuli set were paired with an inappropriate picture (e.g., a picture of a “dog” was followed by the name

Canonical



Noncanonical



Figure 8. Examples of rigid rotations of animals' shapes used in Experiment 3. The left column shows canonical views and the right column noncanonical views of the same animals' shapes.

“horse”); each name appeared equally often as a distractor and a target.

Images were downloaded from the World Wide Web, resized by fitting each drawing into the frame of a 7×7 cm empty box and edited with Adobe Photoshop software. The boundary of the animal's image was no more than 5 mm from any side of the frame. The box with an animal inside could appear in one of two different positions on the central horizontal meridian of a PowerBook Macintosh screen, either 2.7 cm to the left or 2.7 cm to the right of central fixation. The distance of the screen from the observer was adjusted so that each image occupied approximately 5° of visual angle. The head of the animal was always toward the screen centre (i.e., rightward for left visual field trials and leftward for right visual field ones) in order to facilitate recognition (details of the head are typically smaller than those of other parts of the body and would therefore benefit from the higher resolution of retinal locations near to the fovea). Two versions of each of the lateralised stimuli were prepared, one in each visual field (which allowed counterbalancing of the lateralised presentations). All sequences of trials and storage of key presses were controlled by MacLab software (Costin, 1988).

Procedure. Subjects sat upright and placed their heads on a chinrest. There were no practice trials; subjects were told that they would see drawings and read names of animals, and their task was to determine whether the name was appropriate for that animal. Each trial had the following sequence of events: (1) a blank screen; the subjects would initiate a trial by pressing the space bar of the computer's keyboard; (2) a small fixation cross then appeared at the centre of the screen, which remained visible for 450 ms; the subjects were asked to gaze directly at the cross and maintain fixation until the end of the trial; (3) a lateralised visual stimulus (i.e., an animal in a box) appeared for 100 ms to the left or right of the fixation cross; (4) the written name of an animal appeared centred in the lower portion of the screen (so as to appear in the portion of the screen below that occupied by the animals' images) and over a uniform white background; (5) the subject indicated, as quickly and accurately as possible, whether

the name of the animal was appropriate by pressing with the index finger of each hand one of two keys marked “ja” and “nei” (corresponding to the A and Æ keys of the Norwegian keyboard). For half of the subjects the “ja” label corresponded to a left hand response whereas for the other subjects it corresponded to a right hand response. Following each key press, a blank screen would appear and the subject would initiate a new trial.

Results

We first obtained descriptive statistics for each subject. Means of % errors and response times (RTs) were calculated for each combination of the following factors: View (canonical versus noncanonical) and Hemisphere (LH versus RH). The data were pooled over type of match (correct versus incorrect) and subjects' groups (left hand versus right hand response = a correct match), since preliminary analyses showed that none of these factors interacted with any of the other factors. Times from trials on which errors occurred were excluded from computation of the RTs (about 1% of the trials), and trials with RTs longer than 3 SD s from each individual's mean RT for that condition were excluded from all the statistics (also about 1% of the trials).

Response times. A repeated-measures analysis of variance with View (canonical versus noncanonical) and Hemisphere (LH versus RH) as the within-participants variables was performed on RT as the dependent variable. Most importantly, this analysis revealed the predicted interaction between View and Hemisphere, $F(1, 9) = 8.04$, $p < .02$, power = .72. As expected, the subjects evaluated noncanonical views faster when images were presented initially to the RH (mean RT = 837 ms, $SD = 132$, versus LH mean RT = 912 ms, $SD = 148$); as confirmed by a separate t -test, $t(9) = 2.7$, $p < .03$. Instead, the subjects' matching of names to canonical views of animals did not reliably differ between the LH and the RH (RH mean RT = 753 ms, $SD = 71$; LH mean RT = 793 ms, $SD = 115$), $t(9) = 1.4$, n.s. Figure 9 illustrates these results. The main effect of View was also signifi-

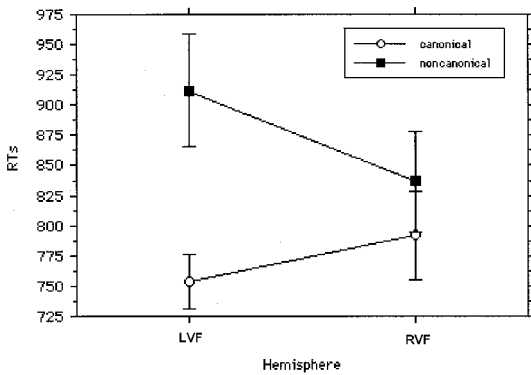


Figure 9. Divided-fields task: Means and standard errors of RTs to left visual field presentations (LVF) and right visual field presentations (RVF) for canonical and noncanonical views of a same animal's pose.

cant, $F(1, 9) = 8.2$, $p < .02$, power = .73. Subjects evaluated canonical views (mean RT = 772 ms, $SD = 95$) faster than the noncanonical views (mean RT = 874 ms, $SD = 142$). The main effect of Visual Field failed to reach significance, $F(1, 9) = 2.3$, $p = .12$, power = .33.

Error rates. A separate repeated-measures analysis of variance with View (canonical versus noncanonical) and Hemisphere (LH versus RH) as the within-participants variables was performed on the mean % error rates as the dependent variable. The main effect of View was significant, $F(1, 9) = 5.6$, $p < .04$, power = .56. Subjects made more errors in matching names to noncanonical views (mean % error = 4.4, $SD = 6.3$) than to canonical views (mean % error = 7.5, $SD = 7.9$). The main effect of Hemisphere approached significance, $F(1, 9) = 4.8$, $p < .06$, power = .49. Subjects tended to make more errors in the LH (mean % error = 6.7, $SD = 8.1$) than in the RH (mean % error = 5.2, $SD = 6.4$). Similarly, the interaction between View and Hemisphere approached significance, $F(1, 9) = 3.9$, $p < .07$, power = .42. Subjects tended to make more errors when noncanonical views were presented initially to the LH (mean % error = 10.1, $SD = 9.1$, versus RH mean % error = 4.8, $SD = 5.8$) or when canonical views were presented to either hemisphere (LH mean % error = 5.5, $SD = 7.2$; RH mean % error = 3.2, $SD = 5.3$).

Discussion

Names of animals seen in noncanonical, noncontorted views were better matched when the pictures were presented initially to the RH (i.e., after left visual field presentations), whereas no hemispheric difference was observed for canonical views of the same shapes. We hypothesised that noncanonical perspectives of nonrigid objects in a conventional pose would engage a RH viewer-centred perceptual memory subsystem as well as a RH coordinate spatial transformation subsystem. This prediction was also derived in our original account but, crucially, runs opposite to the prediction of Experiment 1, where nonrigid objects (animals) were shown in contorted poses. Thus, the findings of the second experiment are difficult to reconcile with the account that the observed hemisphere-specific effects are due to the visual stimuli belonging to a particular semantic domain, class, or category. We also note that the results of Experiment 1 showed equal performance of either LH or RH patient groups when seeing conventional or canonical views of either animals or objects and it was only when the shapes were spatially transformed that a differential effect of the lateralised lesions was observed.

A few other divided-fields studies (Humphrey & Jolicoeur, 1993; Sergent & Lorber, 1983; St. John, 1981) have previously attempted to evaluate hemisphere-specific advantages in normal subjects for processing different views of an object. No visual differences were found in these studies. However, null findings in divided visual field studies are common. The effects can be fragile and undetectable when the design exceeds an optimal narrow window of parameters. For example, St. John's study lateralised pictures of objects viewed in different perspectives (e.g., a shoe), but the stimuli presentations were longer than the optimal timing to guarantee central fixation. Also, the choice of the dependent variable seems crucial: Humphrey and Jolicoeur measured only the percentage of objects named correctly and no RTs were recorded. Partial information relayed from one hemisphere to another via the corpus callosum could result in accurate performance but more sensitive measure-

ments based on the efficiency (speed) of response should have been able to pick up the relative differences in performance (cf. Laeng & Caviness, 2001). In the present study, the hemisphere-based effects were detected by the RT measure, whereas accuracy merely approached statistical significance.

The RH advantage in identifying noncanonical views of rigidly rotated animal shapes allows us to document a double dissociation with another divided visual field study on normal subjects by Laeng et al. (1999), which showed drawings of animals in contorted poses (i.e., the same stimuli we used in Experiment 1). In that study, a LH advantage was found when subjects first encoded the animals' contorted poses and a RH advantage was found for identifications of the same contorted poses after they had become familiar. Moreover, correlation analyses between the subjects' visual-field asymmetries between (1) matching whole pictures to names, (2) matching body parts to the whole body, and (3) judging categorical spatial relations between separate objects revealed that the degree and polarity of lateralisation of categorical spatial encoding predicted the hemispheric advantage in the first time identification of the whole contorted shapes.

GENERAL DISCUSSION

A perceptual impairment was found specifically in LH patients when they matched names of animals to contorted poses of the animals' bodies. In contrast, RH patients were more inaccurate, relative to LH patients, when they matched names of artefacts with noncanonical views of such rigid objects. However, LH patients were as slow as RH patients in matching noncanonical views of rigid objects. In addition, the two patient groups showed no impairment (either in accuracy or in speed of response) in matching canonical or typical views of either rigid or nonrigid objects. Last, when patterns of advantages or ease of processing for the identification of nonrigid shapes (animals) were examined in normal subjects with a divided field task, it was found that the RH identified noncanonical perspectives of animals in conventional (rigid) poses best.

We conclude that lateralised damage can disrupt parallel perceptual strategies. LH damage would affect a top-down hypothesis-testing mechanism based on parts and relations (structural descriptions), which is most useful for the recognition of nonrigid objects (e.g., animals). When viewing novel or unusual configurations (contortions) of a flexible shape, this parts-based processing could provide an efficient (or even the only successful) recognition scheme. To specify this account further, we suggest that when initially viewing a contorted flexible object, a few visible parts of the object may be able to find a match with stored representations of parts in visual pattern memory. For example, in a contorted human shape (like the dancer's in Figure 1), a foot, a hand, or part of the arm may be clearly recognisable even when the pose alters the global shape. The information available from nonoccluded parts, as well as visible spatial relations among these parts, could provide clues as to the identity of the whole. If so, a strategy for gathering more visual information could be executed. For example, we would argue that when looking at Figure 1, a global shape subsystem would first attempt, unsuccessfully, to find a match. At the same time, a series of eye fixations would gather information about salient parts. One first eye fixation may be directed to portions of the outline where the contours suggest the presence of a natural part (e.g., the hand; see Figure 1). We assume that parts information is extracted automatically and in parallel, based on simple features like convexity (cf. Driver & Baylis, 1995; Wolfe & Bennett, 1997). Subsequently, the identified part/s could activate an internally stored structural description, which would act as a perceptual hypothesis (cf. Deco & Schürmann, 2000; Rybak, Guskova, Golovan, Podladchikova, & Shevstova, 1998). This stored information, which contains the complete set of parts and their arrangement into an abstract structure, in concert with the information that the eye fixations feed in about the orientation and size of the part/s, would then formulate a prediction relative to the location of other parts. This prediction, by taking also into account the current eye position, would command the shifts of the eyes onto a new location so as to focus central vision (and the atten-

tion window) on other candidate parts (e.g., the arm). Thus, predictions from the perceptual hypothesis can be translated cyclically into actions. This "top-down, hypothesis testing" guidance of series of fixations would allow, in turn, a refinement of the perceptual analysis and of further predictions about the location of parts. The cycle of successive fixations, analyses, and predictions may thus unfold in time until sufficient information is gathered to reach an object identification decision (Deco & Schürmann, 2000; Rybak et al., 1998).

A "top-down, hypothesis testing" mechanism could also assist in the recognition of rigid shapes, although it may not be essential for this. We found that LH lesions were more likely to affect the patients' efficiency in speed—instead of accuracy—for rigid shape recognition. In contrast, RH patients may benefit from the intact LH processing abilities and therefore be able to identify most rigid shapes seen in noncanonical views. Interestingly, both in our study as well as in Warrington and Taylor's (1973), the RH patients' accuracy rates for noncanonical views were significantly reduced but never completely abolished. For example, in their study, RH patients were correct in 83% of the noncanonical views trials and the 13 most impaired RH patients, mostly with parietal lesions, showed a mean correct naming rate of 75% of these "unconventional" views. As Warrington and James (1988) have already pointed out, the RH parietal lobe may support an added or "optional resource" to several other mechanisms of visual analysis.

In our account, information about both the global shape and the parts of an object is extracted automatically and in parallel, and once an object has been identified by one subsystem, processing is terminated, readying the system for the next stimulus. In visually familiar and unambiguous circumstances, global shape extraction and immediate matching to stored perceptual templates would be a more efficient strategy than one based on the recognition and description of parts (cf. Cave & Kosslyn, 1989). Hence, the two sorts of information (global and parts-based) are not used to the same extent in all circumstances. Crucially, if the object and its pose are familiar, the entire shape will be matched as a single representation, before the parts-and-

relations processing would reach the same conclusion.

Research on the effects of perspective or pose on object identification has focused on the performance of normal subjects (e.g., Biederman & Gerhardstein, 1993; Bülthoff & Edelman, 1992; Jolicoeur, 1990; Lawson, 1999; Rock & Di Vita, 1987; Tarr & Pinker, 1989). A few clinical studies have examined the effects of brain damage on the identification of objects seen in noncanonical views or other unusual viewing conditions (e.g., Bulla-Hellwig, Ettlinger, Dommasch, Ebel, & Skreczek, 1992; Humphreys & Riddoch, 1984; Lawson & Humphreys, 1999; Layman & Greene, 1988; Warrington & James, 1986, 1991; Warrington & Taylor, 1973, 1978). These indicated that damage to dorsal, especially parietal, areas is likely to result in impairments in recognising noncanonical views. Our observations appear consistent with those of Warrington and colleagues in that damage to parietal areas can result in object's identification impairments. We propose that rigid shapes (e.g., common artefacts) can be recognised by a variety of perceptual mechanisms (e.g., memory for specific views, transformations in coordinate space). We also propose that a conventional pose of a flexible familiar object could benefit from mechanisms that perform rigid transformations in coordinate space (e.g., mental rotation or interpolation of views) of a shape's internal model. All of these mechanisms have been hypothesised to depend on the processing of ventral and dorsal areas of the RH.

Recently, neuroimaging studies have specifically examined the perspective effects on the activation of brain subsystems. In a PET study, Kosslyn and colleagues (1994) found that subjects performing a picture-name matching task of canonical and noncanonical views of rigid objects showed massive activation of areas in the dorsal (spatial relations encoding) systems. Specifically, the inferior parietal lobe in the RH was active when objects were shown in noncanonical views. This brain imaging evidence converges with that on the effects of brain damage on noncanonical views of rigid objects, as reported in the present study as well as that gathered by Warrington and colleagues. In addition, Kosslyn

and colleagues found no selective activation in the LH parietal lobe when subjects saw noncanonical views of rigid objects in comparison to the activation found when judging canonical views of the same objects. This finding is also consistent with the findings of Warrington and Taylor (1973) and Warrington and James (1991) on the effects of LH lesions. Our study also appears consistent with such evidence in that the error rates of our LH patients for noncanonical views of artefacts were smaller compared to those of patients with RH lesions, although both groups were equally impaired in terms of their speed of response or efficiency. One possibility, entertained by Kosslyn and colleagues (1994), is that top-down processing mechanisms run virtually all the time, reflexively and in parallel (in "cascade"), even when their engagement is not essential and other mechanisms terminate the processing before they can contribute to the object's recognition.

In conclusion, properties of the visible shape appear to determine in a predictable way which strategy the visual system will use to identify an object and, in turn, which (lateralised) neural systems will be recruited and play a functional role in an object recognition task.

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