Object Orientation Agnosia: A Failure to Find the Axis?

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Abstract

■ A dissociation between the ability to recognize misoriented objects and to determine their orientation has been reported in a small number of patients with vascular lesions. In this article, we describe a 57-year-old man with probable Alzheimer's disease who shows the same dissociation. Neuroimaging findings indicated marked hypometabolism in the posterior cortical regions, particularly the postero-superior parietal lobes. Clinically, the patient had good object recognition accompanied by severely impaired spatial abilities. The experimental investigations comprised a variety of tasks in which he identified misoriented objects, evaluated the orientation of single objects, or discriminated the orientation of simultaneously presented items. Results revealed that his object recognition was independent of orientation and was largely mediated by salient features. With respect to orientation judgements, the patient displayed a profound inability to judge the orientation of nonupright objects, but remarkably intact (though largely implicit) knowledge of the upright orientation. Strikingly, his orientation judgements were also more accurate for upside-down objects than for other orientations (i.e., 90°). We interpret these results as evidence that judgements about object orientation are facilitated when the orientation of the principal axis of the object matches that of an internal representation. We propose that the inability to determine other orientations may be due to the failure of an "axis-finding" mechanism implemented in the posterior parietal lobes, that translates between object-centered and eye-centered coordinates appropriate for guiding visual scanning. ■

INTRODUCTION

The ability to judge spatial attributes of an object, including the orientation, can be dissociated from the ability to recognize and name the object. The most striking evidence for this has come from studies of neurological patients that directly compared the patient's knowledge of object identity and orientation (Best, 1917, translated by Ferber & Karnath, in press; Karnath, Ferber, & Bulthoff, 2000; Turnbull, Laws, & McCarthy, 1995; Turnbull, Beschin, & Della Sala, 1997). These investigations revealed a profound disturbance in the judgement of orientation despite intact ability to identify misoriented objects. Difficulty judging the orientation of letters, shapes, and objects, or production of misoriented copies of geometric figures have been described in other patients (Davidoff & Warrington, 1999; Robertson, Treisman, Friedman-Hill, & Grabowecky, 1997; Solms, Kaplan-Solms, Saling, & Miller, 1988), but in these cases knowledge of object identity and object orientation were not systematically compared.

Turnbull and colleagues have so far offered the most detailed account of this phenomenon, which they termed "agnosia for object orientation" (Turnbull et al., 1995; Turnbull, Beschin, et al., 1997). They described three cases which showed a clear dissociation between preserved ability to identify objects presented in different orientations and inability to recognize whether the depicted orientation was the correct (upright) one. These patients also made orientation errors in spontaneous drawing and in copying. In addition, some of them had difficulty discriminating upright from upside-down drawings of identical objects, or mirror-images of the same objects. Turnbull and colleagues speculated that this orientation agnosia reflects the operation of an orientation-independent route to object recognition. This proposal is based, in part, on the two visual pathways theory put forward by Goodale and Milner (1992), which posits a ventral (occipito-temporal) visual system dedicated to object recognition and a dorsal (occipito-parietal) visual system dedicated to visuo-motor routines that guide actions. Milner and Goodale (1993) suggested that different forms of object representations are employed by the two visual pathways, with the ventral visuo-perceptual pathway employing object-centered representations suitable for recognizing objects under different circumstances, and the dorsal visuomotor pathway utilizing viewer-centered representations appropriate for the moment-to-moment interaction with objects. One prediction of this model, therefore, is that damage to the dorsal visual pathway would lead to an impairment in generating and using viewer-centered object representations that, it has been argued, are necessary for the discrimination of mirror-images or for determining the orientation of an object in

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egocentric coordinates. This prediction is supported by the fact that all three patients described by Turnbull et al. (1995) and Turnbull, Beschin, et al. (1997) had evidence of parietal lobe damage.

Although these patients are impaired at judging the orientation of nonupright drawings, there is evidence that their ability to recognize and use the upright orientation is somewhat preserved. For example, one patient was better able to match the orientation of objects when the model was upright (Turnbull et al., 1995), and another tended to copy misoriented drawings in an upright orientation (Turnbull, Beschin, et al., 1997). An even clearer demonstration of preserved knowledge of upright orientation comes from another recently described case (Karnath et al., 2000). This patient (KB) made no errors in her orientation judgements when the items were upright, but response accuracy dropped to chance levels when the items were presented in nonupright orientations. The authors concluded that KB was not agnosic for object orientation and, therefore, disagreed with Turnbull et al.'s interpretation that the disorder is caused by the failure of a neural system that codes orientation information. They accounted for KB's results by appealing to neurophysiological evidence that multiple view-dependent representations of an object are encoded in the ventral visual stream and that a larger number of cells are tuned to the most frequently encountered views of an object (Perrett, Oram, & Ashbridge, 1998). Therefore, Karnath et al. (2000) argued that upright orientations, by virtue of their stronger representation, would be more robust against neuronal damage. While this may offer a mechanism whereby knowledge of the upright orientation is preserved, it still does not explain why these patients are unable to use this knowledge to interpret other orientations. It is precisely this inability to interpret nonupright orientations, an effortless task for normal people, that needs to be explained before we can fully understand the nature of this disorder.

In this article, we present the case of EL, a new patient who shows a dissociation between his ability to identify misoriented objects and his ability to recognize their orientation. Unlike previously reported patients who had mostly vascular lesions, EL has a degenerative disorder, probably Alzheimer's disease, affecting primarily the posterior parietal lobes. To our knowledge, this is the first case of object orientation agnosia reported in a patient with a neurodegenerative condition and serves to establish this disorder as a functional entity independent of pathological process. It is also the first case in which the stability of the deficit was demonstrated over a sustained period of time (7 months). Based on EL's results on tests of knowledge of object orientation and orientation discrimination, as well as other evidence, we propose an explanation for this disorder related to a failure to locate an object's principal axis. We further speculate that this is due to a deficit in updating retinotopic representations while attempting to locate the axis of the input image.

RESULTS

EL's neuropsychological examination revealed relatively intact object recognition skills accompanied by severely impaired spatial abilities (see Methods section for details). The following experiments investigated whether EL's spatial difficulties extended to judgements about object orientation.

Experiment 1: Object Recognition Versus Knowledge of the Object's Canonical Orientation

Rationale and Task

In this experiment, EL's object recognition was contrasted with his knowledge of the same object's canonical orientation. Forty pictures of objects were presented individually on a total of four occasions, once in each of the cardinal orientations (0°, +90°, 180°, −90°). EL first named the item as it was presented, then judged whether the item was in its correct orientation. If he considered that an item was incorrectly oriented, he was asked to turn the picture around to what he thought was its upright orientation. EL's performance was compared to that of 7 age-matched control subjects.

Results and Discussion

Two of the control subjects made one error each in naming a misoriented item (roller skate), while all others scored 100%. They also performed very well on the orientation task, with only one subject making a single error. This subject accepted the picture of an iron resting on its end as correctly oriented, which could be regarded as a legitimate mistake given that irons are frequently positioned so.

EL correctly named 36/40 items in each of the upright and the 180° orientations and 32/40 items in each of the +90° and −90° orientations (Figure 1). There was no effect of orientation on naming ($\chi^2(3) = 3.13$, *ns*). In contrast to his relatively good recognition of objects seen in different orientations, EL showed a profound impairment in judging an object's orientation. As a preliminary analysis, his orientation judgements for all objects, irrespective of whether they were correctly identified, were compared with his orientation judgements for only those items that he could recognize. EL correctly judged the orientation of 78/160 (49%) items overall, and of 70/136 (51%) of the correctly identified items, providing further evidence that accurate recognition did not facilitate judgements about the object's canonical orientation ($\chi^2(1) = 0.45$, *ns*). For the remainder of this article, we focus on his orientation judgements for correctly named objects

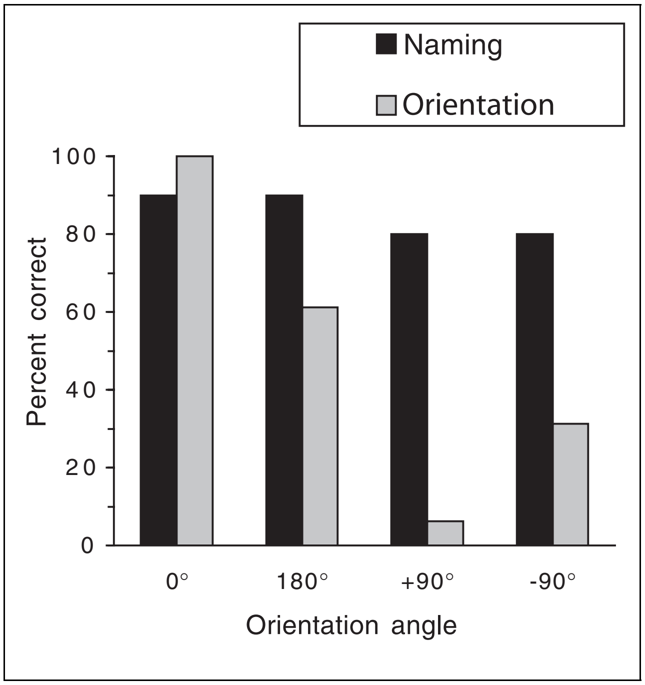

Figure 1. Percent correct responses for EL's naming and orientation judgements in Experiment 1. The orientation judgement was only analyzed for correctly named items.

only, as this provides the clearest dissociation between object recognition and knowledge of the object's orientation.

As shown in Figure 1, EL's orientation judgements were not equally impaired across orientations. First, there was a clear dissociation between his ability to judge orientation when the object was presented upright (36/36 correct) compared to other orientations (rotated 180°, 22/36 correct; rotated +90°, 2/32 correct; rotated −90°, 10/32 correct). Statistical analyses showed that his ability to judge the orientation of items rotated by 180° was significantly worse than for upright items [$\chi^2(1) = 14.98$, $p < .01$], but better than for items rotated by −90° [$\chi^2(1) = 4.92$, $p < .05$] and items rotated by +90° [$\chi^2(1) = 19.99$, $p < .01$]. In addition, he was less accurate when the items were rotated +90° than when they were rotated −90° [$\chi^2(1) = 5.06$, $p < .05$].

When EL indicated that an item was misoriented, he was able to show the correct orientation 24/38 times (63%). Of the remaining 14 items, he misoriented 5 by approximately 45°, 6 by ±90°, 2 by approximately 135°, and 1 by 180°.

These findings indicate that, in addition to relatively intact object recognition, EL's ability to recognize the upright orientation is also well preserved, in sharp contrast with his marked difficulty judging nonupright orientations. Furthermore, he shows a tendency for systematic errors when the items are rotated by 90°, indicating that this orientation is perhaps more difficult to discriminate from the upright than the 180° orientation. It might be interesting to note that his orientation judgements were more accurate when the item was rotated clockwise by 90° than when it was rotated counterclockwise. However, as other patients in the literature have shown the opposite pattern with respect to their judgements of +90° and −90° orientations (e.g., case NL, Turnbull, Beschin, et al., 1997), this finding must be interpreted with caution.

It could be argued that EL's seemingly preserved knowledge of the canonical upright is simply the result of a positive response bias operating in the absence of any knowledge of orientation. For instance, if the visual system cannot interpret orientation information at all, the default state might be to accept all orientations as potentially correct. While this seems to be the case when items are rotated by 90°, EL correctly rejected 61% of the items presented at 180°, indicating that in this case at least he was not responding "yes" by default. Moreover, when asked to show the correct orientation of pictures that he considered misoriented, he was much more likely to place the pictures in their canonical orientation than in any other orientation and his errors tended to be orientations close to 0° (up to 90°). Taken together, these results suggest that EL has access to an internal representation that contains information about the canonical orientation. However, he is unable to use that knowledge to determine when an object is in a different orientation, and this process appears to be particularly difficult when the item is rotated by 90°.

Experiment 2: Effects of Salient Features on Recognition and Orientation Judgements

Rationale and Task

The results of Experiment 1 raise the possibility that EL's good recognition of misoriented drawings could be mediated by certain orientation-invariant properties of objects. Indeed, a number of aspects of his performance on other tests of object processing indicated a tendency to rely on features for object recognition. For example, he was significantly impaired at matching objects across different viewpoints when salient features were obscured, while at the same time performing normally with foreshortened views of objects, which rotate the principal axis of the object but maximize the visibility of defining features. In addition, his recognition of silhouettes on the Visual Object and Space Perception Battery (VOSP, Warrington & James, 1991) was much worse than his recognition of other line drawings, although that result is somewhat confounded by the rotation in depth of items in that test. In this experiment we directly compared EL's ability to (1) identify line drawings versus silhouettes of the same objects, presented in different orientations in the picture plane and (2) judge the orientation of these stimuli. This experiment followed the same general procedure as Experiment 1, using a subset of those items. It was conducted 7 months after Experiment 1, and thus it also serves as a measure of the stability of EL's deficits.

Results and Discussion

EL's performance was compared to that of the same 7 control subjects who participated in Experiment 1. Two of the control subjects made a single error each when naming misoriented silhouettes, while the other 5 subjects scored 100%. All control subjects scored 100% on the orientation judgement test.

As shown in Figure 2A, EL's recognition of line drawings was very good in all orientations. Because of the smaller number of items, performances on the +90° and −90° conditions were combined to give a single score for 90° orientation. EL failed to name 2 items when presented upside down (dog and chair, calling the latter "stool"), but he correctly recognized all items in the 0° and 90° conditions. In contrast, his recognition of silhouettes was strongly influenced by their orientation [$\chi^2(2) = 12.31$, $p < .01$]. He scored 19/20 when the silhouettes were upright, but only 11/20 in the 180° condition, and 9/20 in the 90° condition. Statistical analysis confirmed that recognition of the upright silhouettes was significantly better than that of silhouettes rotated by 180° [$\chi^2(1) = 6.53$, $p < .05$] or silhouettes rotated by 90° [$\chi^2(1) = 9.64$, $p < .01$].

With respect to orientation judgements for correctly named items, EL showed the same pattern of performance as in Experiment 1, indicating that this deficit was stable over a 7-month period (see Figure 2B). Unlike his performance on the recognition part of the test, his orientation judgements did not differ between drawings and silhouettes. When the items were upright, he scored 100% with both types of stimuli. When the items were rotated by 180°, he correctly judged the orientation of 9/18 drawings and 5/11 silhouettes [$\chi^2(1) = 0.02$, *ns*]. When the items were rotated by 90°, he correctly judged the orientation of 5/20 drawings and 1/9 silhouettes ($\chi^2(1) = 0.13$, *ns*). The statistical analyses showed that his orientation judgements were significantly better for upright items than for items rotated by 180° [$\chi^2(1) = 10.48$ and 9.77, for drawings and silhouettes, respectively, *ps* $< .01$] and also significantly better than for items rotated by 90° [$\chi^2(1) = 20.91$ and 19.49, for drawings and silhouettes, respectively, *ps* $< .01$]. The difference between orientation judgements for items rotated by 180° versus items rotated by 90° was not statistically reliable for either the drawings [$\chi^2(1) = 1.6$, *ns*] or the silhouettes [$\chi^2(1) = 1.38$, *ns*], due to the small number of items available for analysis. However, the general trend was the same as that of Experiment 1, with better performance for items rotated by 180°.

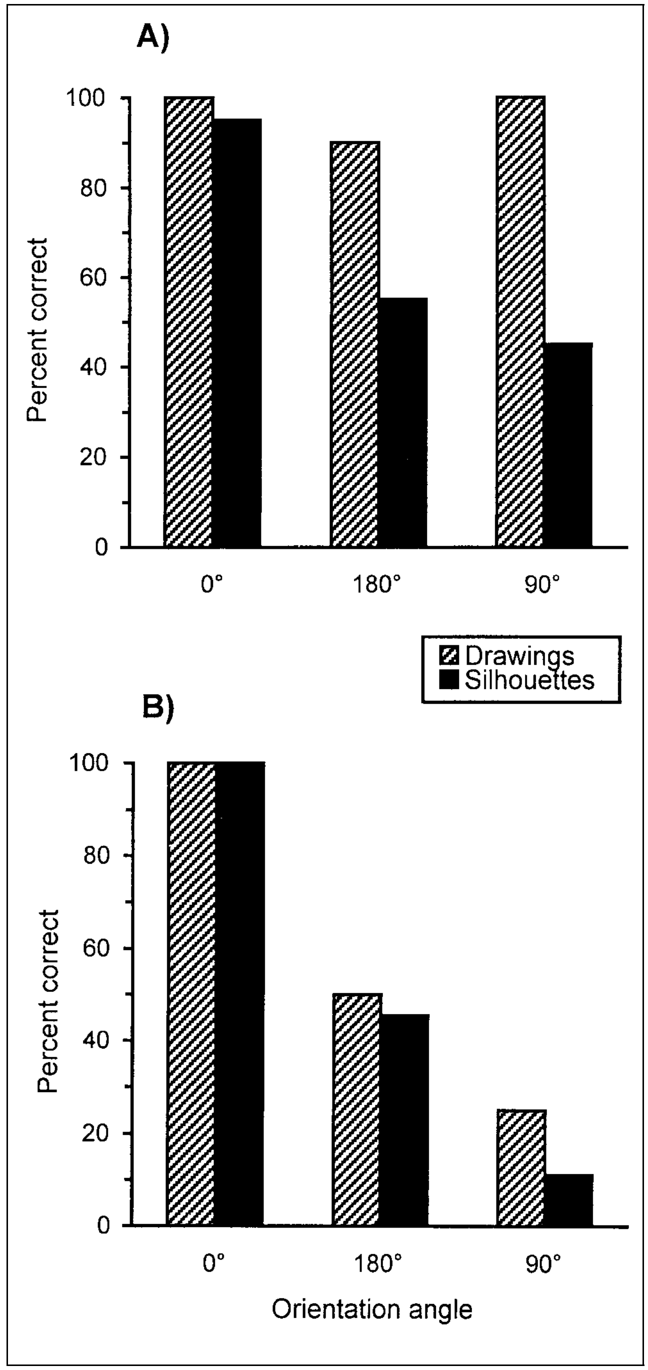

Figure 2. (A) Percent correct responses for naming line drawings and silhouettes of the same objects, in different orientations, in Experiment 2. (B) Percent correct responses for the orientation judgement task in Experiment 2. The orientation judgement task was only administered for the correctly named drawings and silhouettes.

When asked to reorient items that he considered misoriented, EL was correct with 12/16 (75%) drawings, and with 3/7 (43%) silhouettes. His errors consisted of positioning 2 of the drawings at 45° and 2 at 90° and 4 of the silhouettes at 90°. Therefore, as in Experiment 1, he showed poor discrimination between upright and orientations up to 90°.

In sum, these results provide further evidence for separate mechanisms for object recognition and judgement of object orientation. Specifically, it appears that the presence of salient features facilitates EL's identification of misoriented objects, while the fact that he has no difficulty recognizing upright silhouettes suggests that the familiar contour of the object at this orientation is enough to enable successful recognition. In contrast, the presence or absence of features has no effect on EL's orientation judgements. With both types of items, he was perfectly able to recognize the upright orientation as correct, but showed a profound inability to interpret other orientations. Moreover, the pattern of systematic errors in the case of 90° orientations seen in Experiment 1 was replicated in this experiment.

Experiment 3: Orientation Discrimination

Rationale and Tasks

Experiment 1 suggests that EL finds the 90° orientation less discriminable from the upright than the 180° orientation. Experiment 3 was designed to investigate this issue in a series of orientation discrimination tasks. EL was presented with pairs of identical objects and was asked to decide whether they were in the same or different orientations. Experiments 3a and 3b tested the discrimination of upright versus upside-down items, and upright versus 90°-rotated items, respectively. The results suggested that EL's orientation judgements were facilitated when the items' orientations differed by 180° in the picture plane. Experiments 3c and 3d investigated whether this facilitation generalized to other instances in which the objects differed by 180°, by testing EL's ability to discriminate between two objects when both were rotated by 90° (clockwise vs. counterclockwise), or between mirror images, which can be thought of as a 180° rotation in depth. To establish whether EL was able to make other types of judgements for items rotated by ±90°, we administered a control task (Experiment 3e) in which EL made same/different judgements regarding the identity of two objects rotated by ±90°. Finally, Experiment 3f tested EL's ability to discriminate between arrows that differed in orientation by 180°. We chose this task because arrows do not have a canonical orientation, but nonetheless have an obvious axis of elongation and an obvious direction.

Results and Discussion

As summarized in Table 1, EL performed at chance on most tests of orientation discrimination (Experiments 3b, 3c, 3d, and 3f). This poor performance may not seem surprising given that EL has a marked simultanagnosia. However, two findings indicate that EL's simultanagnosia could not be responsible for his poor performance on these experiments. First, in Experiment 3e he could successfully discriminate the identity of 2 misoriented objects, performing significantly better than when required to discriminate the orientation of equivalently misoriented objects in Experiment 3c ($\chi^2(1) = 11.40$, $p < .01$). This clearly shows that he is able (though not perfectly so) to perceive 2 items and compare them in some way. Second, and most interestingly, in Experiment 3a EL could discriminate the orientation of upright from upside-down objects with 80% accuracy. In the context of his simultanagnosia, this is close to ceiling performance (see results of Experiment 3e and Table 2). Therefore, inasmuch as he is able to perceive 2 stimuli, he seems to have relatively little difficulty discriminating between an upright and an upside-down object. His discrimination of upright versus upside-down items was significantly better than his discrimination of upright versus 90°-rotated objects [$\chi^2(1) = 4.62$, $p < .05$]. It was also better than his discrimination of 2 objects rotated by +90° or −90° [$\chi^2(1) = 6.65$, $p < .01$] or his discrimination of mirror images ($\chi^2(1) = 4.62$, $p < .05$).

Table 1. Performance on Tests of Orientation and Identity Discrimination in Experiment 3

Experiment	*EL's Score*	*Normal Controls (n = 7) Mean (SD)*
Object orientation discrimination		
(3a) 0° vs. 180°	32/40 (80%)	39.86 (0.38)
(3b) 0° vs. 90°	22/40 (55%)	40
(3c) +90° vs. −90°	20/40 (50%)	40
(3d) Mirror-image	22/40 (55%)	40
Object identity discrimination		
(3e) +90° vs. −90°	35/40 (88%)	40
Arrow direction discrimination		
(3f) vertical arrows	10/20 (50%)	20
horizontal arrows	13/20 (65%)	20

These findings confirm our prediction that EL is able to determine object orientation better when the item is rotated by 180° than when it is rotated by 90°. This superior performance is not due to a general facilitation in discriminating the orientation of objects that differ by 180°, because it only occurs when the orientation of the top–bottom axis is preserved (as in the case of upright and upside-down objects). When the top–bottom axis of objects is misaligned (e.g., when the items are rotated by +90° vs. −90°), EL remains unable to interpret their orientation. This is also true for items, such as arrows,

Table 2. EL's Performance on Tests of Object Recognition and Spatial Function

Test	*EL's Score*	*Norms Mean (SD)*
BORB		
Test 6: Naming overlapping figures		
Single letters	36/36 (100%)	
Paired letters	71/72 (99%)	
Overlapping letters	57/72 (79%)	
Single drawings of objects	33/40 (83%)	
Paired drawings of objects	29/40 (73%)	
Overlapping drawings of objects	20/40 (50%)	
Test 10: Object decision (B Easy)	26/32	30.5 (1.4)
Test 11: Item match	29/32	30.0 (2.2)
Test 14: Naming	62/76	70.3 (3.2)
Object Matching (Humphreys & Riddoch, 1984)		
Minimal features match	7/20 (35%)	19.7 (0.38)
Foreshortened views match	18/20 (90%)	19.3 (0.92)
VOSP		
Silhouettes	7/30	22.2 (4.0)
Object decision	12/20	17.7 (1.9)
Progressive silhouettes	14	10.8 (2.5)
Dot counting	1/10	9.9 (0.2)
Position discrimination	10/20	19.6 (0.9)
Number location	0/10	9.4 (1.1)
Judgement of line orientation		
(2-alternative forced-choice)	5/10 (50%)	
Pyramids and Palm Trees (Howard & Patterson, 1992)		
3-word version	47/52 (90%)	min score = 48
Semantic Memory Battery (Hodges, Salmon, & Butters, 1992)		
Picture sorting (living/nonliving)	43/48 (90%)	48 (0.02)
Naming to definition	19/24 (79%)	22.5 (1.4)
PALPA (Kay, Lesser, & Coltheart, 1992)		
Spoken word–picture matching	38/40 (95%)	39.3 (1.07)

Norms as published in the manual or primary reference for each test. BORB = Birmingham Object Recognition Battery; VOSP = Visual Object and Space Perception Battery; PALPA = Psycholinguistic Assessment of Language Processing in Aphasia.

that do not have an intrinsic top–bottom axis or canonical orientation.

Experiment 4: Discrimination of Vertical and Horizontal Gratings

Rationale and Task

It is possible that EL's poor performance with items rotated by ±90° was due to an inability to interpret the horizontal dimension of space. This unusual problem was recently described in a patient with a similar dementing illness, who demonstrated a selective inability to draw horizontal lines or process items along the horizontal dimension of space (Grossi, Fragassi, Giani, & Trojano, 1998). Therefore, EL might have a similar problem, which renders him unable to process object orientation when the top–bottom axis of the object is horizontally aligned. To examine this possibility, we administered a final experiment in which EL was asked to indicate whether displays of line gratings were vertical or horizontal.

Results

EL scored 19/20 on this test. His only error was, in fact, with a vertical grating. This indicates that, despite his general cognitive decline, EL was still able to interpret vertical and horizontal orientations of lines almost 1 year after Experiment 3 was conducted. Therefore, his impaired discrimination of upright and 90°-rotated objects is unlikely to be caused simply by a general deficit in processing horizontally aligned axes.

DISCUSSION

Is Object Identity Processed Independently from Object Orientation?

Experiment 1 demonstrated that EL was unable to determine the orientation of rotated objects, while showing very good recognition of the same objects. This is consistent with the hypothesis that object identity and object orientation are processed separately (Best, 1917 translated by Ferber & Karnath, in press; Turnbull, 1997; Turnbull et al., 1995; Turnbull, Beschin, et al., 1997). The results of Experiment 2 provide an explicit mechanism for orientation-independent object recognition based on the identification of salient features of objects, irrespective of their position (cf. Warrington & James, 1986; Humphreys & Riddoch, 1984).

Turnbull, Carey, & McCarthy (1997) have proposed an anatomical distinction between an orientation-dependent route to object recognition implemented in the dorsal visual stream, and an orientation-independent route implemented in the ventral visual stream. While there is continuing debate about whether neurons in the ventral stream code information about object orientation (Rollenhagen & Olson, 2000; Perrett et al., 1998), there is good evidence that regions in the dorsal visual pathway, particularly areas of the posterior parietal cortex, do code visual information in a variety of viewer-centered reference frames (Colby, 1999; Goodale & Milner, 1992; Stein, 1992). For example, neurons in one region of the intraparietal sulcus, the lateral intraparietal area (LIP), code information in eye-centered coordinates, and are important for continuously updating retinal representations in order to map the location of objects relative to the observer (Duhamel, Colby, & Goldberg, 1992). Neighboring regions in the intraparietal sulcus code information in arm-centered coordinates, for the purposes of reaching and grasping (Sakata & Taira, 1994; Sakata, Taira, Kusunoki, Murata, & Tanaka, 1997; Colby & Duhamel, 1991). Of particular interest to the present study is the recent discovery of orientation-selective neurons in the caudal part of the intraparietal sulcus of the macaque monkey (Sakata et al., 1997, 1998). Some of these neurons respond preferentially to the orientation of the longitudinal axis of a long, thin, object, while others are sensitive to the orientation of a flat surface of an object in three dimensions. Similarly, a recent functional imaging experiment revealed activation in the right intraparietal sulcus of healthy humans during an axis-orientation comparison task (Faillenot, Decety, & Jeannerod, 1999). Thus, convergent evidence from monkey and human studies points to the existence of a number of different viewer-centered space representations in the parietal cortex, including a specific mechanism that processes axis orientation. Therefore, it is reasonable to assume that orientation and mirror-image discriminations rely, at least in part, on the posterior parietal cortex.

Although the widespread degenerative changes that occur in Alzheimer's disease make it difficult to draw any firm conclusions about the location of EL's lesion, we note that his PET scan indicates predominantly parietal lobe hypometabolism. Metabolism in the postero-superior parietal regions was grossly abnormal, with relatively spared metabolism in the temporal lobes. Relatively preserved object recognition and semantic ability also suggest largely intact occipito-temporal function. Thus, his profile provides tentative support for the distinction between a ventral route to object recognition which is not orientation-dependent but which probably also codes the usual upright orientation of objects, and a more dorsally located neural mechanism for processing the orientation of objects for other purposes. It is also worth noting that EL's hypometabolism was more pronounced in the right parietal lobe and, as such, is consistent with evidence from a split-brain patient (Funnell, Corballis, & Gazzaniga, 1999) and with recent imaging findings that orientation discrimination and transformation are subserved specifically by the right intraparietal sulcus in humans (Harris et al., 2000; Faillenot et al., 1999).

The Importance of Being Upright (or Upside Down)

As noted earlier, an important finding of this study is that EL has preserved recognition of the upright orientation of objects. Other cases with this disorder also show preserved knowledge of the canonical upright to varying degrees, as reviewed in the Introduction. These findings suggest that stored object representations do contain information about the usual upright orientation of objects.

In a series of studies, Perrett and his colleagues showed that multiple view-dependent representations of an object are encoded in the ventral visual stream and that a larger number of cells are tuned to the most frequently encountered views of an object (Ashbridge, Perrett, Oram, & Jellema, 2000; Perrett et al., 1998). Therefore, a numerical bias in cells responding to the upright orientation might be one mechanism by which canonical orientation is encoded as part of an object representation (Karnath et al., 2000). When an upright object is encountered, there is a strong match between the orientation information contained in the input image and that contained in the stored representation, leading to correct recognition of this orientation.

The argument that EL, and other patients, have intact knowledge of the canonical orientation raises an obvious question: Why are they unable to use this knowledge to determine when an object is in a different, nonupright, orientation? This is particularly striking given that EL was not required to identify the actual orientation, but simply state whether the item was upright or not. The fact that he cannot perform this apparently easy and logical step indicates that his recognition of upright is largely implicit and, therefore, he is unable to use this knowledge in a flexible way. A possible explanation for this phenomenon might be that, although he is able to recognize the upright orientation by virtue of neuronal response patterns in the ventral stream, he has sustained damage to a mechanism that allows normal people to detect when an object is misoriented. The evidence reviewed in the previous section suggests that this mechanism is largely dependent on the integrity of the right parietal lobe.

An alternative possibility which should be considered is that EL's good performance with upright objects resulted from a positive response bias, rather than representing preserved knowledge of the canonical upright. Indeed, there is some evidence of such a response bias since EL gave 75% ''yes'' responses in Experiment 1, when in fact this response was only true for 25% of the items. However, this response bias was not uniform across all conditions, being most evident when objects were rotated by 90°, and much less so when the objects were inverted. If EL's perfect performance in identifying the orientation of upright items were due to a positive response bias, then his performance on the inverted items must be in spite of this bias, indicating some recognition of the orientation of those objects. In other words, EL seems able to glean some information about orientation, but only when objects are either upright or upside down. This conclusion is supported by the results of Experiment 3, where he was only able to successfully discriminate these two orientations.

EL's ability to discern an upside-down orientation somewhat more successfully than a 90° orientation is not unique. For example, patient KB had an almost identical pattern of results to EL: She scored 71% correct with inverted items but she erroneously judged 89% of the items rotated by ±90° to be upright (Karnath et al., 2000). Although the authors did not explore this finding in detail, in light of EL's results we suggest that KB also had more difficulty recognizing that an item rotated by 90° was misoriented than making the same judgement in the case of an upside-down item. Further support for this suggestion comes from KB's efforts at orienting wooden letters, where she apparently made some errors by placing the letters at 90° or mirror reversed, but never upside down. Similar evidence is provided by patient NL who tended to copy misoriented drawings in an (incorrect) upright orientation, but only did so for models presented at 90° from the upright (Turnbull, Beschin, et al., 1997, Figure 5). He copied upside-down items correctly in an upside-down orientation. This better preserved ability to judge upside-down orientations is not entirely surprising since there is evidence from normal subjects that upside-down orientation tends to be determined more quickly than a 90°-rotated orientation (De Caro, 1998; Braine, Plastow, & Greene, 1987).

On balance, we believe that the most parsimonious account of EL's pattern of results is that, in the context of severely impaired ability to judge nonupright orientations, his performance is facilitated when the top–bottom axis of the object is vertically aligned. This facilitation is based, at least to some extent, on information about the upright contained in an internal object representation possibly stored in the ventral visual stream. However, EL seems unable to use this internalized knowledge in order to detect a misalignment of the principal axis of the object. In the final section, we consider how this failure might occur and speculate on the role that spatial transformation routines implemented in the parietal lobe might play in this process.

Object Orientation Agnosia: A Failure to Find the Axis?

We have reviewed evidence that EL's recognition of misoriented objects occurs mostly on the basis of salient features, and largely in the absence of bottom–up information about the object's orientation. We believe that these salient features activate the stored representation of the object, which also contains information about the upright orientation. This information could be conceptualized as a set of predictions about the spatial configuration of the object features in an object-centered reference frame. These predictions would, on the one hand, serve to confirm the identity of the object, and, on the other hand, provide top–down information about the usual location of features and the position of the principal axis in image (retinal) coordinates. Here we use the term ''axis'' to refer to a virtual line defined by the geometric relations between salient points of the stimulus, such as the top and bottom endpoints (Marr, 1982).

Following this assumption, when EL is presented with an upright item the orientation of the axis is perfectly predicted by the information contained in the stored representation. Therefore, he readily locates the object's axis and successfully recognizes its orientation. When the stimulus is upside down, the axis is still in the predicted location and, consequently, EL has little difficulty finding it. However, in this case, the direction of the axis (and the relative position of the features) are wrong, helping EL to deduce that the object is misoriented. The critical case is when the stimulus is rotated by 90°, since its principal axis is no longer in the expected position. In this case, locating the axis would require initiating a new search at a different location than that predicted by the internal representation. We propose that an inability to engage such an ''axis-finding'' mechanism (Tarr & Pinker, 1991) is at the root of EL's difficulty with object orientation. With respect to the operational process that underlies this axis-finding mechanism, we suggest that it may rely on spatial transformation routines implemented in the posterior parietal lobe, that translate between object-centered and eye-centered coordinates appropriate for guiding visual scanning (Stein, 1992).

Previous research has shown that normal subjects use highly specific ''scanpaths,'' defined as repetitive sequences of fixations and saccades, when viewing a particular visual pattern (Noton & Stark, 1971). Scanpaths recorded while subjects view familiar patterns are similar to those recorded during the initial encoding of the pattern (Noton & Stark, 1971). Moreover, the sequence of eye movements produced during visual imagery of a scene is highly correlated with the sequence of eye movements recorded while subjects studied the scene (Brandt & Stark, 1997). Taken together, these findings suggest that stored object representations include information that guides visual scanning. The spatial configuration of object features is encoded as a pattern of eye movements and this eye movement sequence is invoked during subsequent viewing of the object under different conditions. With respect to orientation judgements, we suggest that when an item is upright or upside down, the stored eye movement routine easily locates the axis, resulting in successful recognition of that orientation. In contrast, when an object is rotated by 90°, the eye movement routine fails to locate the axis. In this case, finding the axis would require an active search for both of its endpoints while updating the retinotopic map with every saccade. If this search could not be initiated, or if the retinotopic map were not adequately updated during the search, it would be impossible to compute the geometric relation between the two endpoints, and thus identify the orientation of the axis.

Primate neurophysiological studies have demonstrated that area LIP of the intraparietal sulcus combines visual and eye movement information to maintain a stable, eye-centered representation of space (Colby, 1999). Neurons in this area can fire in anticipation of eye movements, or in response to the memory trace of a visual stimulus, indicating that they are involved in remapping an internal representation to keep it in agreement with the new visual information that will arrive following an eye movement (Colby, Duhamel, & Goldberg, 1995; Duhamel, Colby, et al., 1992). Furthermore, studies of patients indicate that remapping an eye-centered representation can be impaired as a result of parietal lobe damage (Heide, Blakenburg, Zimmermann, & Komf, 1995; Duhamel, Goldberg, FitzGibbon, Sirigu, & Grafman, 1992). In these studies, subjects were required to look sequentially at two different targets displayed for a very brief period. Because both stimuli disappeared by the time the eye movements were made, the second saccade had to be executed purely based on the memory of the target's location. In order to plan the second saccade correctly, the system must remap the memory trace of the second target from the coordinates of the initial eye position to the coordinates of the new eye position. Patients with parietal lobe lesions were unable to compensate for the first saccade when this was directed in the contralesional visual field, indicating an inability to remap the location of the second target. It is interesting to note that EL, as well as KB, the patient described by Karnath et al. (2000) had documented damage to the posterior parietal cortex, and that both exhibited considerable gaze apraxia on neurological testing (see Methods section). Therefore, we suggest that the difficulty in finding the axis of a misoriented object could be explained by a failure to update a retinotopic map in eye-centered coordinates, as a consequence of parietal cortex dysfunction.

CONCLUSIONS

In this paper, we have described a patient with object orientation agnosia in the context of a degenerative disease that primarily affected his parietal lobes. Like other patients with this disorder, he demonstrates a striking dissociation between an intact ability to recognize misoriented objects and a profound impairment in determining these objects' orientation. EL has preserved (implicit) knowledge of the object's canonical orientation and this knowledge seems to facilitate his judgements of orientation when the top–bottom axis of the test stimulus is aligned with the upright, but not in other cases. We believe that this deficit is best accounted for by a failure to update retinotopic maps during visual scanning in order to locate a misaligned axis.

The findings of this study have clear implications for theories of object recognition. One of the most influential of these postulates that recognition requires the construction of an object-centered representation that, itself, is based on a viewpoint-dependent representation derived from the input image (Marr, 1982). EL's results run counter to the idea that a viewpoint-dependent representation must precede the formation of an object-centered representation and recognition. In this regard, they complement the findings of a recent study, which showed that normal subjects determine object identity before they determine object orientation (De Caro, 1998). Thus, these results are more consistent with Corballis' (1988) proposal that recognition can occur before the object is assigned an internal reference frame that is subsequently used to determine the object's orientation.

METHODS

Subjects

EL is a 57-year-old man with 9 years of education and no family history of dementia. He presented in February 1998 with a history of progressive cognitive deterioration over approximately 5 years. His main complaints were of visuospatial problems, accompanied by increasing word-finding difficulties, forgetfulness, and deterioration in his writing skills. He described difficulties carrying out familiar manual tasks, such as assembling a fishing rod or using his tools. More recently, he had developed a dressing apraxia, characterized by a difficulty in orienting his clothes correctly. His wife noted that he was unable to find objects even when they were on the table in front of him and would often reach incorrectly towards a target. Over a period of 2 to 3 years he became unable to drive because of poor ability to judge the relative location of other cars on the road, and increasing topographical disorientation in unfamiliar environments.

Neurological examination revealed a left homonymous hemianopia and an inability to locate objects in space in the right visual field. There was some degree of optic ataxia and he had difficulty initiating eye movements to the left, although a full range of eye movements was demonstrated. An MRI scan carried out in April 1999 showed mild cerebral atrophy and some scattered changes in the periventricular white matter. A PET scan in March 1999 showed marked glucose hypometabolism in the posterior brain regions. Metabolism in the postero-superior parietal lobes was grossly abnormal, with relatively greater involvement of the right parietal lobe. The area of hypometabolism extended into the occipital cortex and the mid-dorsolateral frontal lobes, sparing the primary motor cortex. The temporal lobes were relatively less involved than the parietal lobes, but again there was somewhat greater hypometabolism in the right temporal lobe than the left. There was also relative hypometabolism in the right thalamus. Metabolism in the mesial frontal lobes and orbitofrontal regions was largely normal. On the basis of the history, neurological examination, and imaging findings, EL received a provisional diagnosis of posterior cortical atrophy (biparietal variant, Hof, Vogt, Bouras, & Morrison, 1997; Mackenzie Ross et al., 1996) in the context of Alzheimer's disease. Results of a neuropsychological assessment carried out in March 1998 also indicate widely compromised cognitive function, consistent with a diagnosis of probable Alzheimer's disease.

A number of the tests administered during routine neuropsychological assessment indicated that, in contrast to his very severe visuospatial problems, EL's visual object recognition was generally well preserved. For example, on the Boston Naming Test he was able to describe or mime the use of most objects, despite being unable to produce many of the names. His visuospatial processing and object recognition skills were examined in more detail across a number of testing sessions between April and October 1998 (see Table 2).

On the VOSP (Warrington & James, 1991), EL was unable to count dots and to match or discriminate spatial locations. He performed at chance on a two-alternative forced-choice test of line orientation, in which the distractor item was misoriented by at least 40° relative to the target.

In contrast, performance on subtests of the Birmingham Object Recognition Battery (BORB, Riddoch & Humphreys, 1993) revealed that EL could name single letters and single objects well (see Table 2). When the items were presented in pairs, his performance was somewhat worse for the objects but not for the letters. With overlapping items, his performance declined further. Thus, with respect to the objects in particular, when two drawings overlapped, he was able to perceive only one of them, suggesting a marked simultanagnosia. It is interesting that EL was always able to recognize one of the overlapping figures, indicating a disorder of visual attention rather than an inability to extract a recognizable contour from a degraded visual array. On a test of matching objects in prototypical and unusual views (Humphreys & Riddoch, 1984), he could match the objects when salient features were visible and the principal axis foreshortened, but not when distinctive features were occluded. He had difficulty recognizing silhouettes of objects and animals from the VOSP, particularly when the image was rotated further in depth. Taken together, these results suggest that EL is highly reliant on distinctive features in order to recognize objects. EL's results on tests of semantic knowledge, including word–picture matching, semantic associations, picture sorting, and naming to verbal definition, were generally quite good, with only mild impairment on some tests (see Table 2).

EL's performance on the experimental tasks was compared to that of 7 healthy age-matched control subjects (mean age = 56 years, *SD* = 4.7).

Stimulus Materials

Experiments 1 and 2

For Experiment 1, 40 pictures with an unambiguous canonical orientation were selected from the Snodgrass and Vanderwart (1980) corpus and printed on 8 × 8 cm square cards. We used the 32 items employed by Turnbull et al. (1995) and Turnbull, Beschin, et al. (1997) and added eight others in an attempt to expand the range of semantic categories from which the stimuli were drawn. The full set was: airplane, anchor*, apple*, baby carriage, basket, bicycle*, bus, camel, cat*, chair*, clock, dog*, duck*, elephant*, frying pan, garbage can*, goat, gun, hanger, harp, helicopter, iron, kangaroo*, kettle*, lamp*, mushroom*, penguin*, piano*, pineapple*, record player, roller skate, shirt*, shoe, stove, telephone*, television, toaster, tree*, vase*, watering can. The items had an average familiarity rating of 3.46 and an average complexity rating of 3.24 (Snodgrass & Vanderwart, 1980).

A subset of these drawings (n = 20, denoted by *) were used in Experiment 2. This shorter set had an average familiarity rating of 3.48 and an average visual complexity rating of 3.18 (Snodgrass & Vanderwart, 1980). A set of black silhouettes of these items was also created and presented in the same manner.

Experiment 3

The stimuli used for Experiments 3a to 3e were 10 drawings from the Snodgrass and Vanderwart set (bear, camel, cat, chair, kangaroo, kettle, motorcycle, piano, rooster, shoe). All items were asymmetric along both horizontal and vertical axes and had an unambiguous canonical orientation. In Experiment 3f, the stimuli were horizontal arrows (pointing left or right) and vertical arrows (pointing up or down).

Experiment 4

Vertical and horizontal black line gratings (line thickness = 4 mm) were presented as a circular display (7 cm diameter) printed in the middle of a white page.

Procedure

Experiments 1 and 2

Experiment 1 was conducted in October 1998. EL was tested on 4 different occasions, separated by at least 4 days. During individual testing sessions, each of the 40 items was presented in one of the 4 cardinal orientations (0°, +90°, 180°, −90°), with 10 items appearing in each orientation in random order. Across the 4 testing sessions, each item was presented in all 4 orientations, yielding a total of 160 trials. EL first named the item as it was presented, then he was asked to judge whether the item was in its correct orientation ("as would normally be encountered in real life" or "the right way up"). There was no time limit. Correct responses (acceptance of the canonical orientation and correct rejection of other orientations) were recorded on each trial. If EL considered that an item was incorrectly oriented, he was then asked to turn the picture around to what he thought was its upright orientation. The normal control subjects were administered the test only once, with 10 items presented in each of the four orientations.

Experiment 2 followed the same procedure, with the following exceptions. First, the number of items in the +90° and −90° orientations was halved. Thus, each item was presented to EL in one of three orientations: 0°, 180°, and either +90° or −90°, yielding a total of 60 trials. Second, unlike in Experiment 1, this time EL saw each item in all three orientations, in random order, during the same testing session. The line drawings and the silhouettes were administered on different occasions, 2 weeks apart. The normal controls were administered a short version of the silhouette task, comprising the 20 items randomly distributed among the three orientations (0°, 90°, 180°). For EL, this Experiment was conducted in June 1999, 7 months after Experiment 1. For all control subjects, this task was administered before the line drawings test of Experiment 1.

Experiment 3

This experiment was conducted over several sessions during November 1998. All tests followed a similar procedure, based on that by Turnbull and colleagues (Turnbull & McCarthy, 1996; Turnbull, Beschin, et al., 1997). In Experiments 3a–d, pairs of identical objects (e.g., two bears), in either identical or different orientations, were printed on a page. Each item was presented four times during each experiment (twice in the same orientation, twice in different orientations), in random order, for a total of 40 trials requiring equal numbers of "same" and "different" responses. EL was asked to make a same/different judgement regarding the orientation of the two objects and had unlimited time to consider each item. Experiment 3a examined EL's ability to discriminate an upright object from one rotated through 180° in the picture plane. Thus, the objects were either in the same orientation (both upright or both upside down) or in different orientations (one upright and one upside down). In Experiment 3b, the objects were either upright or rotated by ±90°. Thus, pairs of identical objects could either be in the same orientation (both upright, and both at either +90° or −90°) or in different orientations (one upright and one rotated by ±90°). In Experiment 3c, both objects were rotated by ±90° from their canonical orientation, either in the same direction (e.g., both +90°) or in different directions (one rotated +90°, the other −90°). In Experiment 3d, the objects were always upright and were either in identical orientations (both facing left or both facing right) or were mirror images (facing each other or facing away). In Experiment 3e, EL was shown pairs of identical pictures (e.g., two pianos) or different pictures (e.g., a piano and a camel) and simply had to decide whether the two pictures represented the same object. Both objects were rotated by ±90° from the upright. Experiment 3e used drawings of arrows instead of objects. Twenty pairs of vertical arrows and 20 pairs of horizontal arrows were presented side by side on a page. Half the pairs pointed in the same direction (up, down, left, or right), and half the pairs pointed in opposite directions.

Two of the tests (Experiments 3a and 3d) were administered twice, once with the items printed side by side and once with the items printed one above the other, in order to check whether a poor performance could be related to EL's left visual field loss. The two arrangements yielded equivalent performances, though EL did slightly better with the side-by-side items. Therefore, for the remainder of the tests, items were presented only side by side and results are only reported for this arrangement.

Experiment 4

EL was presented with individual line gratings and was asked to decide whether they were vertical or horizontal. He indicated the orientation of the lines through a verbal response and by gesturing with his hand along a horizontal or vertical plane. Because EL's verbal responses had become somewhat unreliable by the time this test was administered (October 1999), responses were only accepted as correct if they were also accompanied by the correct gesture.

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