

## NOTE

# COORDINATE FRAMES FOR NAMING MISORIENTED CHIMERIC: A CASE STUDY OF VISUO-SPATIAL NEGLECT

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## ABSTRACT

A persistent line of inquiry for the students of visuo-spatial neglect has involved the perceptual frame of reference respect to which the neglected region of space is defined. On standard testing conditions viewer-centered and object-centered systems of coordinates are confounded. In order to disambiguate these two reference frames FB, a patient with severe left visual neglect consequent upon a right parieto-temporal haemorrhage, was asked to identify chimeric figures presented at different orientations. FB continued to recognize poorly the left side of chimeric figures even when the display was rotated 90° clockwise or anticlockwise so that the 'left' of the chimeric fell on the patient's egocentric up or down, respectively. The result suggests that, at least under the present testing conditions, unilateral neglect is tied to the principal (top-bottom) axis of the object. Object-centered vs. (viewer-centered) representational accounts of this finding are discussed.

## INTRODUCTION

Any account of visuo-spatial neglect must specify the frame of reference or coordinate system respect to which the side of space showing neglect is defined. A reference frame can be viewed as an orthogonal grating used to assign directions (top, bottom, right or left) in space or to mental representation (Palmer, 1985). Thus, 'left' in left neglect may be interpretable in terms of a variety of different spatial coordinates: retinal, head- or body-centered, gravitational and also in relation to coordinates intrinsic to the depicted object. Other than for neglect, this question has obvious implications for the current debate on space-based and object-based models of visual attention (Egley, Driver and Rafal, 1994; Vecera and Farah, 1994).

Recent investigations have examined the contribute of viewer-centered (*egocentric*) and environment-centered (*allocentric*) coordinates to visual neglect. An egocentric frame specifies positions relative to the viewer's midline, whereas an allocentric reference system codes information with respect to the gravitational vertical. For example, Calvanio, Petrone and Levine (1987) had patients report items arranged on spatial arrays, either while seated upright or while reclining on one side. In the latter condition the subjects' midline axis and the environmental vertical were out of alignment (roughly orthogonal), so that it became possible to examine in which frame unilateral neglect operated. The results revealed that neglect patients ignore information appearing on the left of their bodies, but also omit stimuli on the left of the display regardless of the posture they adopted. This finding led Calvanio et al. (1987) to propose that neglect affects both egocentric and allocentric representations of space. Similar experimental evidence has been also provided by other laboratories (Ladavas, 1987; Farah, Brunn, Wong et al., 1990). Viewer- and environment-centered coordinates do not exhaust, however, the range of reference frames within which visual information is described (Hinton, 1981; Feldman, 1985). Indeed, some studies reveal that, under some experimental circumstances, neglect can be based upon object-centered coordinates in which

measurements are referred to the principal axis of the perceptual object. Driver and Halligan (1991) provided the most striking evidence for object-centered neglect. They asked a right-hemisphere patient with left neglect, PP, to judge whether two vertically elongated shapes, presented one above the other, were same or different. Stimuli were displayed either upright or rotated 45°. PP omitted details on the left of the objects' principal axis even when the shapes were tilted so that their left details fell on the patient's egocentric right.

Further evidence supporting neglect in object-centered coordinates has been reported by Young, Hellawell and Welch (1992). Their patient failed in recognizing the left side of chimeric faces made by joining left and right halves of famous faces. When stimuli were rotated 90° to the right (or left), the patient continued to perform poorly on left-sided chimerics, defined in object-centered code, even though they actually appeared in the top half (or bottom half) of egocentric space. This result indicates that visuo-spatial neglect can operate within a reference frame defined by coordinates intrinsic to the object.

In the reading domain object-based neglect has been documented by Caramazza and Hillis (1990a, 1990b). They described a patient with damage to the left hemisphere who misread only the right half of words (e.g. humid → human). Interestingly, her problems in identifying the end letters were unaffected by the vertical or mirror-reversed orientation of the words. Caramazza and Hillis proposed that this patient had an impairment at the level in which a word-centered grapheme representation is processed.

However, other studies failed to confirm the existence of object-centered neglect. For instance, in a pioneering study Farah et al. (1990) asked 10 left neglect patients to perform a task which involved two distinct steps: first to identify drawings of familiar items and then to read letters randomly scattered over the space delimited by the outline of the drawings. To examine in which frame of reference neglect manifests itself, the authors compared the letter naming performance, when both viewer and stimulus display were upright, to that observed when the viewer or the stimulus were rotated 90°. Their findings showed that neglect arises within both viewer-centered and environment-centered coordinates, but refuted the hypothesis that an object-based frame is used to code the location of the neglected region of space.

Behrmann and Moscovitch (1994) adopted a paradigm similar to that described in Farah et al.'s study, except that, instead of reading letters, neglect patients had to report the colors drawn around the boundaries of line drawings. A significant object-centered neglect was observed only when stimuli were drawings of asymmetrical letters (e.g. letters with an intrinsic handedness, such as the letter B), not when drawings of common objects or symmetrical letters were used.

Both Farah et al. (1990) and Behrmann and Moscovitch (1994) investigated object-centered neglect with a visual search task. Since the nature of the visual representation required by the task may be crucial in bringing out space-based vs. object-based attentional selection (Vecera and Farah, 1994), we employed the chimeric figures recognition task, previously adopted by Young, Hellawell and Welch (1992), which may be more suited to engage an object-based representation than the visual search task of previous studies. Young et al.'s observation about object-centered coding in visual neglect was based on a small set of faces which are stimuli with a high level of intra-class similarity. There is ample evidence that the processing mechanisms leading to the visual recognition of faces differ from those used for object recognition (see Bruce and Humphreys, 1994, for a review). For example, object recognition seems to involve a parts-based representation, whilst faces are more likely to be encoded holistically (Tanaka and Farah, 1993). It remains therefore possible that the object-centered effect reported by Young et al. (1992) is tied to the nature of stimuli (Behrmann and Moscovitch, 1994). Recall that negative studies of object-centered neglect employed drawings of familiar objects. The goal of the present research is to assess the generality of Young et al.'s finding with line drawings of objects belonging to diverse categories.

Object-centered coordinates were decoupled from viewer-centered coordinates through a rotation of the stimulus display while the patient remained upright. The task required to identify chimeric figures presented in the upright or tilted conditions. Our assumption was that if neglect mechanisms affect an object-centered representation of space, movements of the object should move the location of the neglected area. Thus, neglect of the left side of the chimeric figures, which is expected when the stimulus is upright, should become neglect

of the upper side when figures are rotated 90° clockwise, but should change to neglect of the lower side when figures are rotated 90° anticlockwise.

### CASE REPORT

FB was a 65-year-old right-handed man with high-school education, who had recently retired from an administrative job. He was admitted at the Modena University Hospital on 13 May 1994 with complaints of intense right-sided headache and tendency to bump into things on his left-hand side, which had abruptly appeared on that morning. On neurological examination, the patient was found alert and cooperative, well oriented in time and space. A complete left homonymous hemianopia was revealed on testing to confrontation; clinical inspection showed that head and eye movements to visual targets were full and symmetric. Tactile stimuli were perceived well when given singly, but a marked extinction on the left was observed with double simultaneous stimulation (DSS). Sensory findings also included grossly defective appreciation of posture in the left arm and leg and auditory extinction. Left arm strength was only slightly diminished. No dysphasia, dysarthria or dyspraxia were observed. Analysis of the CT scan (performed on 13 May 1994), using the method described in Damasio and Damasio (1989), revealed a large area of high density involving the right angular gyrus (area 39) and the posterior sector of the middle temporal gyrus (area 37). The supramarginal gyrus (area 40) was partially damaged. The lesion was attributed to a haemorrhage in the vascular territory of the right middle cerebral artery (Figure 1).

Examination of higher cognitive functions started two weeks after admission; at this time the visual field defect had recovered, leaving in its wake a left visual extinction on DSS. FB obtained a verbal IQ of 115 on the WAIS-R. Language comprehension and production were normal. The ability to imitate with the right hand gestures made by the experimenter was normal. His digit span was five and no error was scored on simple arithmetics. A florid neglect could be elicited by various behavioral tests which included line and figure cancellation, line bisection, figure copying/drawing by memory and text reading. Thus, on the Bell Cancellation Test (Gauthier, Dehaut and Joannette, 1989), FB failed to cross any of 17 left-sided targets and omitted 4/18 on the right side. Horizontal lines (6 lines for each of 5 lengths), presented individually across the centre of an A4 paper, were bisected significantly to the right of the true center. On drawing a daisy from memory, petals on the left side were completely omitted; a bicycle was drawn (from memory) with its left wheel smaller than the right wheel; the spokes on the left of each wheel were left out. In oral reading of text, the patient omitted the first 4-7 words on each line, with no apparent insight that the resulting content often lacked of coherence. Neglect was not restricted to the visual modality. FB showed a similar pattern of left omissions during blindfolded tactile search of tokens scattered on the desktop in front of him: he scored 8/10 on the right side and 0/10 on the left side. On the contrary, there was no evidence of personal neglect (tested following Bisiach, Vallar, Perani et al., 1986).

### MATERIALS AND METHODS

#### *Stimuli*

The stimuli consisted of chimeric figures and whole figures. We selected from the Snodgrass and Vanderwart (1980) collection of drawings several figures of animals ( $n=19$ ) and common objects ( $n=21$ ) that have a canonical upright orientation (for the list of figures used see Appendix). All but 1 drawing (butterfly) depicted an asymmetric view of the items. They were cut along the vertical midline into right and left halves and showed to 3 normal subjects who were asked to choose the half side of each object containing essential defining features. These more informative half-drawings were then employed to assemble a set of 20 chimeric figures by juxtaposing 20 right halves and 20 non-matching left halves. The mirror-imaged versions of the same chimerics were also used so that the features of each half-

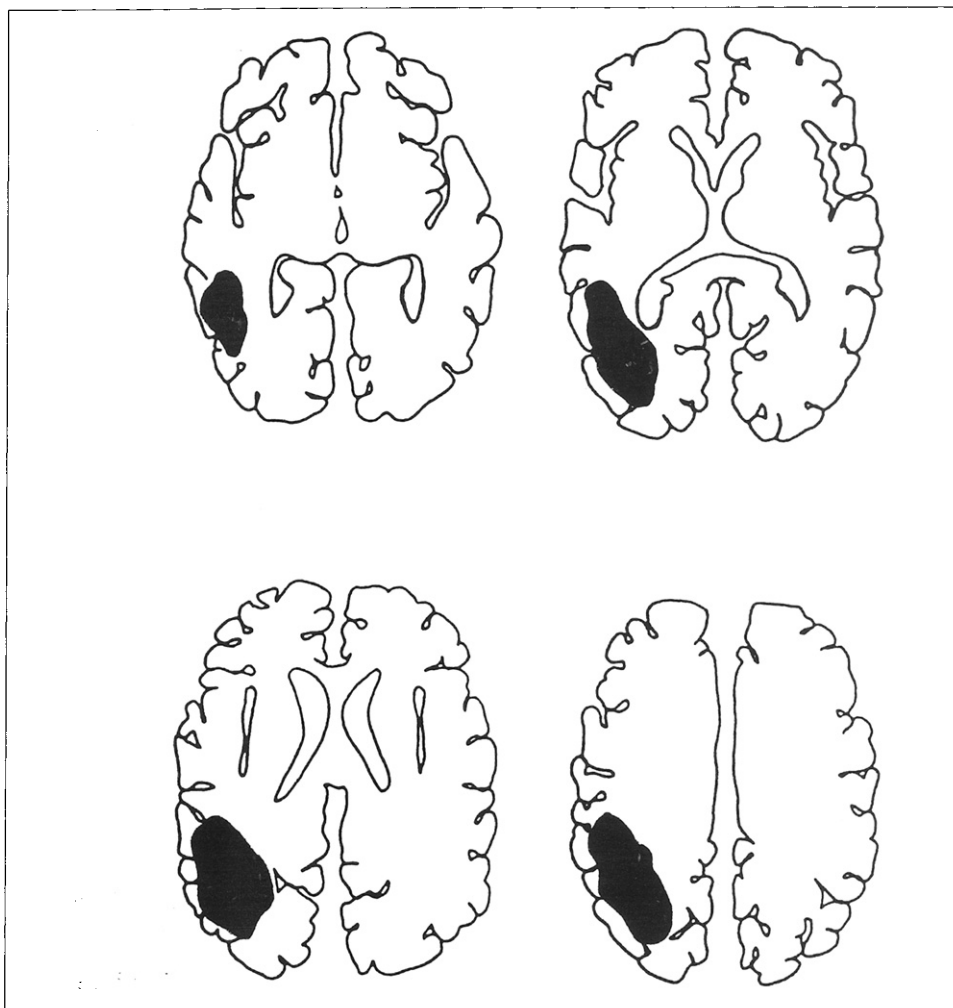


Fig. 1 - Reconstructed computerized scan of FB's brain damage. The figure shows the lesion (indicated as a shaded area) plotted onto standardized transverse sections following to the method described in Damasio and Damasio (1989).

drawing were equally present on either side of the chimerics. A total of 40 chimeric figures was employed. For the whole figures, we took the same 40 drawings from which the chimerics were generated. For 20 of them the more informative half (used in the chimerics) was printed on the left side, and for the other 20 on the right side. The purpose of using whole figures was to assess the integrity of FB's object processing abilities. Chimeric and whole figures ranged in size from  $4.5 \times 3$  cm to  $9 \times 7$  cm and were printed across the centre of a white, vertically oriented, A4 page ( $27.9 \times 21$  cm), one figure per sheet. The experiment was carried out 22 days after the stroke, in two sessions separate by a day; in the first session half of the stimuli were used (10 normal chimerics accompanied by 10 reversed versions and the corresponding 20 whole figures), whereas in the second session all 80 figures served as stimuli, yielding 120 stimuli in total.

#### Procedure

Each experimental session proceeded as follows: FB was seated in front of a table, in a quiet room, two experimenters were present. Each stimulus sheet was individually displayed

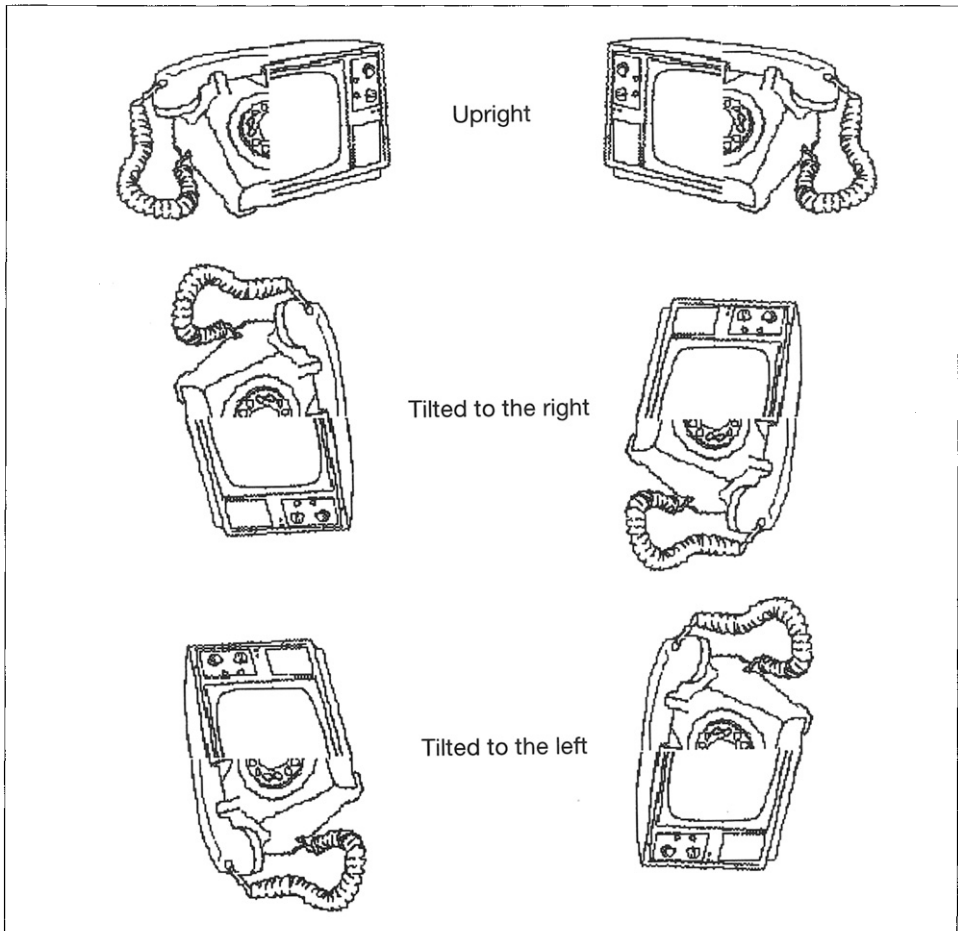


Fig. 2 – Example of chimeric figures used for each pair of stimuli in different orientation conditions.

in front of the patient and always centered on the midsagittal plane of his head and trunk. Viewing distance was approximately 45 cm. FB's task was simply to name the stimuli; he was informed that some drawings could depict anomalous objects or animals. The patient was allowed to examine the stimuli for as long as he liked, and any time he failed to report both halves of the chimerics, he received the prompt: "Do you see anything else?". No other feedback was provided. Responses and any other patient's comments were written down by one experimenter for later analysis. Stimuli were displayed under 3 different conditions (Figure 2): (1) *Upright*, viewer and stimulus upright, (2) *Tilted to the Right*, viewer upright and stimulus rotated in the frontal plane from the environmental vertical to 90° clockwise, and (3) *Tilted to the Left*, viewer upright and stimulus rotated 90° anticlockwise. Conditions were given in separate blocks. The upright condition was presented first in both experimental sessions; the tilted to the right condition was second in the first session and third in the second session. Within each condition, chimeric and whole figures were presented in random sequences. Breaks of at least 5 minutes were inserted between blocks. FB was requested to maintain an upright head posture while inspecting the stimulus displays. The second experimenter observed the patient closely to ensure that he was complying with the instruction. Eye movements were not restricted.

TABLE I  
*Number (and Percentage) of Correct Naming for the Left and Right Side of the Chimeric Figures in each Orientation Condition*

Orientation	Left side	Right side
Upright	4/60 (7%)	59/60 (98%)
Tilted to the right	22/60 (37%)	48/60 (80%)
Tilted to the left	20/60 (33%)	51/60 (85%)

## RESULTS

FB's naming performance on 60 whole figures was flawless, irrespective of their orientation. The results for the chimeric figures are presented in Table I; correct naming scores (and percentages) for the left and right side of the chimerics (defined in an object-centered frame of reference) are provided for each orientation condition.

FB's performance was scored correct only if he identified the stimulus (e.g. "It is a horse") and not if he simply recognized the category to which the stimulus belonged ("It is an animal").

We distinguished between 3 kinds of errors. *Omissions*, if the stimulus went completely unnoticed. *Non-recognition* errors, if FB failed to report the name of the stimulus, but remarked that something was present. *Category* responses (infrequent), if only the category of the stimulus, and not the specific exemplar, was identified.

In the Upright condition, when all frames were aligned, very few stimuli were reported on the left side, while practically all of those lying on the right side of the chimerics were reported (chi-square [1] = 101,  $p < 0.0001$ ), a finding that confirms the severity of FB's neglect for contralesional stimuli. More interestingly, FB's detected significantly less left-sided than

TABLE II  
*Number (and Percentage) of Left-sided Errors in Each Orientation Condition*

Orientation	Left side		
	Omission	Non-recognition	Category
Upright	51/56 (91%)	3/56 (5%)	2/56 (3%)
Tilted to the right	34/38 (90%)	4/38 (10%)	0/38 (0%)
Tilted to the left	33/40 (82%)	6/40 (15%)	1/40 (3%)

right-sided stimuli, as defined by the chimeric's principal (top-bottom) axis, also in the Tilted to the Right condition (chi-square [1] = 23.1,  $p < 0.0001$ ) and Tilted to the Left condition (chi-square [1] = 33.1,  $p < 0.0001$ ). To assess whether FB's rightward bias in naming chimeric figures was affected by the orientation of the stimuli, a log-linear analysis (Grizzle, Starmer and Koch, 1969) was carried out on the correct rates in the three conditions. It revealed a significant effect of condition (chi-square [2] = 15.6845,  $p < 0.001$ ). Post-hoc Scheffé-type method of multiple comparisons showed that in the tilted conditions the left-right differences (expressed as cross-product ratios) were not different from each other but were reliably smaller than that of the Upright condition. Thus, FB's ability to recognize the left component of chimerics partly ameliorated when it did not fall in left space defined by FB's sagittal midline.

FB correctly named both component halves of chimerics 4 (7%) times in the Upright condition, 10 (17%) times in the Tilted to the Right condition, and 12 (20%) times in the Tilted to the Left condition (chi-square [2] = 4.6, n.s.). On these occasions, he always reported the left side of the chimeric figure first.

Number (and percentage) of left-sided errors for each stimulus condition are summarized in Table II. Overall, the great majority of them were omissions (88%), followed by non-recognition errors (13%) and category errors (2%). The distribution of error types did not

differ statistically across orientation conditions. Right-sided errors were only non-recognition responses, and were more likely to occur in the tilted conditions (chi-square [2] = 10.04,  $p < 0.006$ ; see Table II).

## DISCUSSION

We report a patient with left neglect who showed a remarkable inability to pick up information located on the left of the principal (top-bottom) axis of the displayed objects. Strikingly, he continued to do so even when chimeric figures were tilted  $90^\circ$  to the right or left, so that the sides that would have been left in upright chimerics now fell on the upper or lower part, respectively, of the patient's egocentric space. This result suggests that, under some experimental situations, unilateral neglect can arise from a failure to represent or direct attention to locations in space defined with respect to a reference frame that is embedded in the object. If the crucial factor were a viewer-centered frame of reference, no difference between reporting the left and right sides of chimerics would be expected in the tilted conditions, since parts of both stimuli were in FB's right (egocentric) space.

The study confirms the generality of what Young et al. (1992) found, and is in keeping with previous investigations which focused on object-centered visuospatial neglect (Driver and Halligan, 1991; Caramazza and Hillis, 1990a, 1990b; Behrmann and Tipper, 1994; Behrmann and Moscovitch, 1994, Experiment 2 and 3). However, the reported effect contradicts the conclusion of Farah et al. (1990) that neglect mechanisms operate solely in terms of gravitational or viewer defined coordinates. Several reasons may account for the discrepancy between our own findings and those of Farah et al. (1990). For one thing, it can be argued that the identification of familiar objects that Farah et al. required with the aim to impose an object-centered frame for allocating attention, had scarce relevance to the letter search performed afterwards, all the more so, as the letter naming task occurred at a different ("smaller") spatial scale. The attentional shift toward local elements (letters) might have obscured the effect of the (large) object. This especially matters to neglect patients: Halligan and Marshall (1993, 1994), for example, reported that RB, a patient with left neglect, could mark without difficulty the four corners of a page where target lines were displayed, but failed to cancel left-sided lines immediately after (see more recently Marshall and Halligan, 1995).

An alternative explanation for the absence of an object-centered effect in Farah et al.'s study involves the type of representation needed to perform their task. On the basis of experiments with neglect patients, Humphreys and Riddoch (1994) suggested that visual attention operates independently on (at least) two forms of spatial representations: one describing stimuli in terms of constituent parts of a single object (a within-object representation), and one coding stimuli in terms of individual objects in a scene (a between-objects representation). On this account, the visual search paradigm used by Farah et al. may have demanded a "between-objects" type of representation, in which stimuli are more likely defined by a system of coordinates extrinsic to the display (viewer- or environment-centered). By contrast, the identification of chimeric figures may be more efficiently performed by selecting from an object-based representation in which object features are spatially referred to an intrinsic object axis.

The results of the present study also challenge Behrmann and Moscovitch's (1994) claim that object-based neglect emerges only with stimuli having a canonical handedness (e.g., asymmetric letters of the alphabet), but not with line drawings of familiar objects and animals, as those employed here. Our data suggest that under suitable experimental conditions, the presence of object-coded neglect is warranted, irrespective of the nature of the stimuli employed.

It must also be noted, however, that even if FB's performance revealed a consistent, object-coded pattern of errors, the magnitude of neglect was sensitive to the object orientation, as suggested by the decrease in severity of neglect when stimuli were displayed rotated of  $90^\circ$ . A similar pattern of performance has been documented in other studies on object-centered neglect (see Driver and Halligan, 1991, and Behrmann and Moscovitch, 1994). For example, PP (Driver and Halligan, Experiment 1) correctly detected 1/32 differences on the left and

25/32 on the right, when stimuli were upright, whereas, when stimuli were rotated, she scored 9/32 on the left and 18/32 on the right. One way to account for this effect is by proposing that FB's neglect occurred simultaneously with respect to two frames of references (e.g., viewer- and object-centered), each interacting upon the other. The patient's performance depended upon the relation between the orientation of the two frames. Specifically, performance was worst when the top-bottom axis of the object corresponded to the retinal vertical axis (a viewer-centered frame of reference), as in the upright condition.

The relationship between the intrinsic, viewpoint-independent frame of reference of an object and the current viewer-centered frame could be readily described within Hinton and Parsons' (1981) model of recognition of disoriented shapes. Further, it would be consistent with the idea that neglect may involve, independently (but simultaneously), multiple levels of visual processing in which space is coded in different coordinate frames (Bisiach, Capitani and Porta, 1985; Caramazza and Hillis, 1990b, Behrmann and Moscovitch, 1994).

A second possibility to explain the improvement of (left) neglect when chimerics were tilted, involves the increased difficulty to recognize objects presented at orientations far from upright (Rock, 1973; Jolicoeur, 1985). Our suggestion is that FB initially favoured the right side of the chimeric figures, whether tilted or upright, thus producing a rightward bias in object-centered space. However, occasional failure to recognize the right chimeric sub-figure (more frequent in the tilted than in the upright condition), prompted a (voluntary) shift of attention to the left side of the stimulus, with the result that neglect ameliorated (see also Seron, Coyette and Bruyer, 1989; Young et al., 1992; Humphreys and Riddoch, 1993). In keeping with this explanation right-sided errors were always of the non recognition type, whereas omissions prevailed on the left side.

Describing an object with respect to its own, intrinsic system of coordinates will ensure perceptual constancy despite the fact that the object can be seen from a variety of viewing angles, distances, illumination conditions and backgrounds (see Humphreys and Quinlan, 1987). The critical step in this process is to derive the major internal axis of the pictured object, such as the axis of elongation and/or symmetry, if one exists (Marr and Nishihara, 1978; Marr, 1982), or the top-bottom axis (Tarr and Pinker, 1991); this is thought to act as internal spatial coordinate referent used to locate object parts. The findings obtained in this study indicate that FB's visual neglect arises after the object principal axis has been assigned (e.g., upon detecting the top and bottom positions [Rock, 1973; Corballis, 1988]) and left-right directions have been coded. Such a case of object-centered neglect is fully consistent with what Driver, Baylis, Goodrich et al. (1994) have termed 'axis-based neglect', in which the distribution of attention over the viewed object reflects the combination of object-based and egocentric factors. They suggested that whereas object perception requires the assignment of an intrinsic frame of reference to the object (Marr and Nishihara, 1978), the handedness of the frame (such as the side of the object that will be labeled as 'left' and thus neglected) is determined within the viewer-centered reference frame.

Several vision researchers (Jolicoeur, 1985; see Jolicoeur, 1992, for discussion on this issue) have suggested that if an object is presented in some orientation other than its canonical one, the observer might compensate by an act of mental rotation (Shepard and Cooper, 1982). Recognition would occur only when such normalization process is complete. Thus, FB may have first mentally rotated the chimeric object to its upright canonical orientation (so that the right and left sides of the chimeric would align with the right and left side of the patient) and then matched this transformed stimulus against object representations stored in long-term memory. The alignment could be computed following a scheme akin to that proposed by Huttenlocher and Ullman (1987). It is not implausible, for example, that FB could initially use the top (or bottom) of a stimulus to determine which way to rotate the object in order to align it with a stored representation. Furthermore, experimental evidence suggests that long-term image representations of objects used in recognition are primarily viewer-centered (see Pinker, 1986; McMullen and Jolicoeur, 1990; Palmer, Rosch and Chase, 1981). By this account, FB's neglect may have involved the left side of this internal, 'normalized' representation of the stimulus, and not the 'raw' stimulus as directly presented to the patient's eyes. As pointed out by Bisiach, Bulgarelli, Sterzi et al. (1983), unilateral neglect entails 'represented' and not 'objective' (or perceived) stimuli. In other words, the mechanisms underlying unilateral neglect intervene at higher level of visual processing (a *late selection*



for inattention' [Bisiach and Berti, 1994]), when a more abstract description of the stimulus is computed. The observation, however, that the left-right gradient for chimeric figures varied with stimulus orientation would appear to imply that FB's neglect does not operate at a single, late stage of visual processing. It might be speculated that the overall performance of our patient was affected by two kinds of neglect, one related to the current view of the object and the other to the imagined, transformed object, both anchored to a viewer-centered frame of reference. Indeed, there is fresh evidence that visual and 'imaginal' neglect are distinct and dissociable disorders (Guariglia, Padovani, Pantano et al., 1993; Anderson, 1993). Thus, on the assumption that the input stimulus is transformed into a (upright) canonical format, the 'object-centered' effect reported here (but the same holds for other examples in the literature) could be conceptualized as a particular instance of ego-centered representational neglect (Bisiach, 1993).

Summing up, FB made more errors in recognizing the left than the right half of chimeric objects, irrespective of stimulus orientation. This confirms the hypothesis that neglect can be object-centered in the sense of being spatially referenced to the principal axis of the displayed object. A possible boundary condition on this claim, is that neglect involves a viewer-centered, abstract description of the stimulus accessed after that a normalizing process of mental rotation has taken place.

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#### APPENDIX

*List of the items selected from the Snodgrass and Vanderwart (1980) set of line drawings to generate the chimeric stimuli*

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airplane	artichoke
bicycle	bird
bus	butterfly
camel	car
cat	church
cow	cup
dog	duck
elephant	fish
foot	fox
frying pan	gun
horse	house
kangaroo	kettle
motorcycle	mouse
peacock	pipe
pocketbook	pig
rabbit	rooster
shoe	snail
telephone	television
tiger	truck
trumpet	watering can

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