CORTEX FORUM

OF FRAMES AND MIRRORS: REFLECTIONS ON NEGLECT. A REPLY TO MCCARTHY (2002)

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Vision, like physics, requires a reference frame within which the position and motion of an object can be defined (Tadin et al., 2002). The brain initially receives information in retinocentric coordinates but successive neural computations can develop and integrate such information so as to transform the nature of the visual reference frame into another representation (e.g., head-centred, body-centred, object-centred). The main reason for the brain to perform such transformations of reference frame could be to achieve a more efficient representation. An example from astronomy illustrates the argument: a planet's position can be determined either in a heliocentric or geocentric reference frame but astronomers have found the former representation to be more efficient than the latter.

The study of the syndrome of spatial neglect appears to provide a unique opportunity for the understanding of the nature of the reference frames used by the brain. These patients show a remarkable anomaly in their interactions with surrounding space, as well as with their own body. They show remarkable omissions in recognition, gross mistakes in spatial judgments, and impaired navigational abilities often incompatible with everyday functionality. To a first approximation, these patients can be described as unresponsive to stimuli in the contralesional part of space. Some issues arise immediately from this description. If the lesion (typically located within the right hemisphere of the patient) and the neglected object each represent two locations in space, both of these locations could be described in relation to one another in different ways, depending on the specific frame of reference used. Thus, investigating whether neglect patients ignore either contralesional stimuli, stimuli on the left side of their retinae or of their body midline, one side of each object, stimuli within or outside reach, etc., might allow us to understand which frames of reference are relevant for human vision. Impairments in neurological patients that can best be described within a specified spatial frame support the idea that such a spatial frame is actually used by the brain. In this commentary we review work on reference frames in neglect, focussing particularly on some recent studies that have used mirrors to disentangle frames of reference, and discuss some of the issues raised by McCarthy (2002) in her commentary on Laeng et al. (2002b).

Object-Based vs. Object-Centred Neglect

There are two meanings of 'object' neglect that have emerged in the recent literature and that should be distinguished from one another as well as from a third type of neglect that has been called ‘space-based’. We shall follow the distinctions made in the literature between these two types of object neglect by calling one type ‘object-based’ and the other ‘object-centred’ (Gibson and Egeth, 1994; Umiltà et al., 1995; Tipper and Behrmann, 1996; Peterson et al., 1998). Neglect that can be properly called ‘object-based’ refers to a disorder in the mechanism that controls the attentional selection for objects or shapes. Such object-based neglect differs from space-based neglect because the latter type is thought to select a region of space (which may or may not contain objects). Such a space-based mechanism has also been envisioned as a spotlight that selects space regardless of boundaries between objects (for example, a spotlight might illuminate only the upper part of an actor on stage). In contrast, there is no metaphor for object-based selection (unless we imagine an ‘intelligent’ spotlight that adapts the shape of its lens every time it illuminates a border and envelopes the region subtended by the border’s concavity so as to select a single object). This mechanism can only be truly described in cognitive terms (Driver and Baylis, 1998, p. 310): “Attention automatically spreads across the figural shape to which the dividing edge is assigned by bottom-up segmentation processes”. A deficit in this mechanism can be illustrated by the behaviour of Gainotti et al.’s (1972) patients in a copying task. Several of their patients copied many of the elements in the model drawing, not only on the right but also on the left side of the sheet, leaving unfinished the left half of various elements (e.g., a house, a tree). Because the majority of Gainotti and colleagues’ patients showing this problem had right hemisphere damage and the side of objects that was truncated was defined from the patient’s viewpoint, it can be concluded that a) this type of neglect is object-based since objects in any position on a plane, including the rightmost located objects from the patient’s viewpoint, can be affected; in contrast this type of neglect cannot be defined as b) spaced-based, since this would amount to neglecting whole objects located in one half of extrapersonal space; in addition, this form of neglect cannot be defined either as c) object-centred, because the side of objects that is truncated is the left side in terms of the patient’s viewpoint and not of the objects’ intrinsic frames (which would be instead the righthand side of the house’s front). Since Gainotti and colleagues’ study many others have now shown that patients can neglect half of an object even when it is wholly presented within the patient’s right hemispace (e.g., Driver and Halligan, 1991; Driver et al., 1994; Humphreys and Heinke, 1998)[1].

In contrast to object-based neglect, ‘object-centred’ neglect refers to the fact that many material bodies that occupy space can be parsed into components (parts) that require separate spatial definitions. Crucial to this sense of object-centred representations and neglect is the fact that some shapes possess intrinsic handedness. For example, animal bodies have handedness (except, maybe, amoebae). Consider the human body: it possesses a front and back and right and left sides, which can be defined independently of any viewer or orientation in

[1] However, Driver and Pouget (2000) have pointed out that neglect for the retinally left side of an object within either visual field might not be regarded as “object neglect”, since this could still be explained by a graded deficit account for leftward position within egocentric (viewer-centred) coordinates (Pouget and Sejnowski, 1997).

relation to the poles or surface of the Earth. As the philosopher Kant conjectured (Kant, 1768, 1783), a left and a right hand are different in absolute terms (e.g. 'the glove of one hand cannot be used for the other'). So, in the neuropsychological domain, an object-centred deficit in neglect refers to a deficit in selecting a shape's spatial region (e.g., the left) that is 'intrinsically' defined, irrespective of the viewer's position or perspective. Caramazza and Hillis (1990a, b) described this type of neglect for graphemic representations: their patient NG made errors in reading the endings of words even when the words were presented in a mirror. Hillis and Caramazza (1995) concluded that, given the presence of concurrent deficits of such neglect patients in non-lexical tasks, their disorders in reading and spelling would be the result of a common underlying deficit in an object-centred spatial framework for object recognition (as originally proposed by Marr, 1982). Behrmann and Tipper (1999) have shown that neglect patients continue to neglect the left side of an object also when it has been rotated and this side consequently appears to the right of the patient's field of vision. Humphreys and Riddoch (1994, 1995), and Behrmann and Tipper (1999) also showed that both spatial and object-centred neglect could be observed simultaneously. In our study (Laeng et al., 2002b) previously published in Cortex and reviewed in the same issue by Marie McCarthy (2002), we reported the simultaneous presence in a single stroke patient, AE, of neglect in various frames of reference. Two frames can be defined as viewer-centred ones, a) for objects to the left side of the patient's extrapersonal space and b) for objects far from the patient, i.e., outside the patient's peripersonal space; the third frame c) can be defined as object-centred, because the neglect affects objects held in the experimenter's left hand regardless of viewpoint (i.e., neglect for objects located on a frame defined by the human body supporting the objects).

Specifically, the patient's neglect was assessed in a colour-naming task, where the objects were small cubes with primary colours. Unsurprisingly, AE took longer to name cubes in the left hemispace: this is consistent with his diagnosis of unilateral neglect. In the simplest condition the cubes were placed on a table in front of the patient. However in some conditions the cubes were placed far from the patient, and it was shown that, consistent with Cowey et al. (1994, 1999) findings, AE had worse left-sided neglect for far locations. In some other conditions, the experimenter held the cubes in the palms of her hands, and either faced the patient or had her back to him. This manipulation allowed us to determine whether AE's neglect also had an allocentric component by seeing if the orientation of the experimenter's body, irrelevant to the task, influenced performance. This turned out to be the case: response times were slowest when the experimenter's back was turned, i.e. when the experimenter's left side coincided with the left side of AE's egocentric space. More generally, both in left and right hemispaces, the cube on the experimenter's left side was named more slowly: for the lefthand side this meant slower performance when the experimenter's back was turned, and for the righthand side this meant slower performance when the experimenter <u>faced</u> the participant. In line with the conclusions of previous investigators of similar phenomena in neglect patients (e.g., Tipper and Behrman, 1996; Behrman and Tipper, 1999), we suggested that

AE's neglect illustrated how the deficit could occur simultaneously in different reference frames, depending on the structure of the objects attended to, and the contingencies of the task.

Is Object-Centred Neglect Nothing More Than Object-Based Neglect?

McCarthy's (2002) commentary on our study with AE suggests an alternative view. Her proposal is that what we described as "object-centred" neglect did not necessarily reflect AE's use of a reference frame where the left hand of the experimenter is defined as such. That is, AE's neglect could still reflect the interaction of multiple reference frames, including an object-based one, but these would all be viewer-centred or dependent on egocentric coordinates. Importantly, in McCarthy's view, AE's increased naming latencies for stimuli located in the experimenter's left hand would arise because of an automatic process of (mental) rotation, normalization or alignment, of the perceived object (i.e., the experimenter's body) to the canonical position (i.e., a frontal view). So, on McCarthy's interpretation, when AE viewed the experimenter's back and the cube was in her left hand this would be attended to only after normalization processes had repositioned the hand on the good side of AE's mind's eye or visual buffer (and we know that neglect patients can neglect the left side of mental images: Bisiach et al., 1979). Such a mental transformation would not be needed when the object was in the experimenter's left hand and she was facing him. Hence latencies should be longer in the former condition than in the latter one.

The above considerations are stimulating but, in our view, unconvincing. First of all, it is unclear why an automatic process of mental rotation, normalization or alignment of the experimenter's body to the canonical position (i.e., frontal) should occur at all in a task that did not require identification of the object (body) supporting the other objects (cubes). Moreover, because the cubes were always supported by the same object, shown across rotations in depth that are both natural for the human body and well known to viewers, it seems to us that the situation did not pose the recognition challenge that would seem to be required in order to engage normalisation processes and perceptual strategies (cf. Laeng et al., 1999, 2002c). Instead, in our view, the cubes task required directing attention to specific parts of the human body frame, i.e. using spatial information provided by the human body's structural description. In other words, since the cubes task requires attending to each hand supporting a cube, this would consistently engage the structural description of the human body which would provide the spatial frame onto which the locations of the cubes would be defined.

Nevertheless, if we assume that a process of mental rotation took place, there were inconsistencies between McCarthy's interpretation and some of the observed interactive effects of the experimenter's orientation and of the hemispace in which the left and right hands were located. Specifically, two of the predictions derivable from the 'normalisation account' were clearly incorrect: A) the normalisation account would predict that AE should be slowest in reporting the colour of the object in the experimenter's right hand when she has

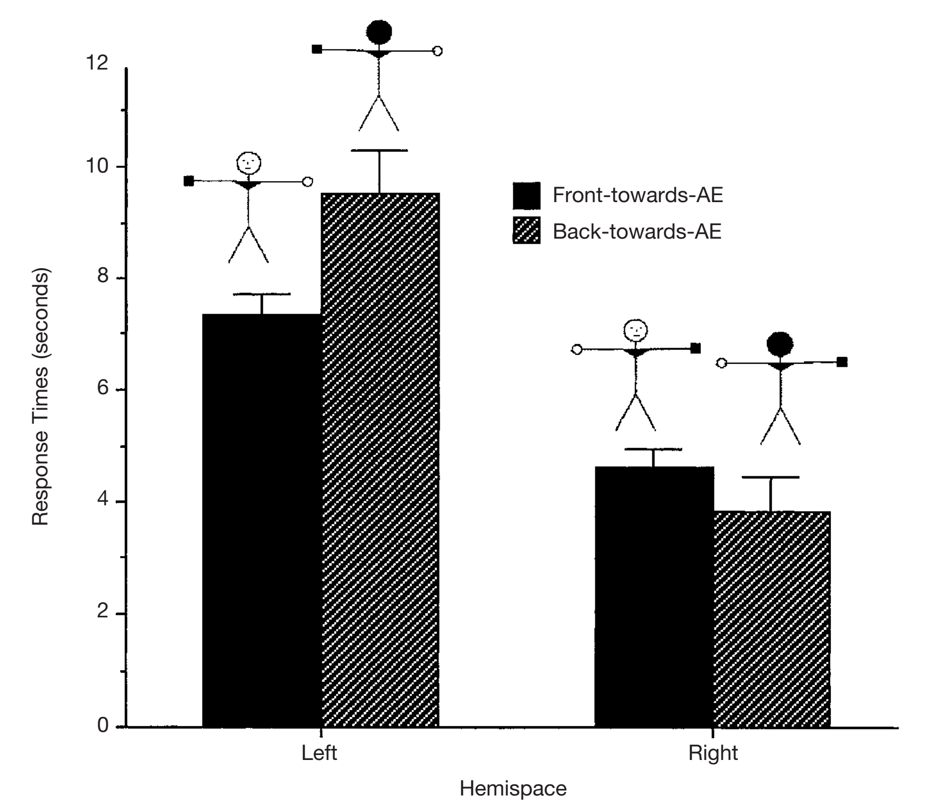

Fig. 1 – *Mean RTs and SEs for 'front-towards-patient' and 'back-towards-patient' presentations in the 'left' and 'right' hemispaces. Stickmen over each column represent the orientation of the experimenter (smiley face = frontal; black circle = back) and of the hand holding the reported cube (filled square).*

turned her back to him, since in this condition the mental transformation to the human body's canonical position would increase AE's latency and moreover, once the normalisation was completed, the right hand, seen in the transformed image, would now be in the neglected hemispace. In fact, AE was fastest in this condition (Figure 1). B) The normalisation account would also predict that AE should be fastest when the experimenter was facing him holding the cube in her left hand, since in this condition there would be no need for mental transformations and the cube is already visible in the right hemispace. In fact, latencies in the latter condition, B, were significantly slower than in the former, A (Figure 1). Note that reversing the order of processing of mental rotation and image scrutiny, so that rotation follows instead of precede attentional scanning, would not help to predict AE's behaviour either. In this case, the condition where the reported object was in the experimenter's left hand and she was facing him should have been the fastest. Instead, we observed that this condition was slower than the condition where the cube was in the experimenter's right hand and she turned her back to him (Figure 1); i.e., in a condition that should require normalization versus another that does not and where the cube is already on the 'good' side. Hence, we conclude that the normalization account is unable to explain the present results.

McCarthy's account is similar to that of Cubelli and Speri (2001) and Mapelli et al. (1996). In Cubelli and Speri's study of neglect patients, figures were presented upright as well as in various plane rotations including a complete 180º inversion (i.e., upside-down). None of the patients showed a tendency to neglect the right part of inverted stimuli (i.e., their intrinsically defined left side) as predicted by an object-centred account. These researchers made the rather strong claim that all previous evidence of object-centred neglect for non-orthographic stimuli could be based on normalisation processes of rotated stimuli to their canonical position. However, Cubelli and Speri's (2001) mental rotation account appears to encounter the same difficulty in explaining AE's behaviours as well as those of Behrmann and Tipper's patients (1994, 1999). Mapelli and colleagues' account (1996) suggested that reports of 'object-centred' neglect for orthographic stimuli (i.e., patient NG's neglect dyslexia for the right ending of words; cf. Caramazza and Hillis, 1990a, 1990b) could be accounted by the patient's letter-by-letter reading. Such serial letter processing would recode the temporal sequence of letters into the canonical visuospatial representation of a word (i.e. positioning the letters from left to right). Thus, the 'read-out' of such a visuospatial representation would consistently result in neglect for the same portion of the word, regardless of the orientation of the word in its original presentation (e.g., vertical or mirror-reversed). Maguire et al. (2002) also doubt that demonstrations of unilateral neglect relative to the intrinsic left side of objects truly constitute evidence for an object-centred frame; Maguire and colleagues propose that apparent object-centred neglect may arise from the combined effects of mental rotation and within-object information asymmetries. Maguire et al.'s (2002) account also has problems in interpreting all evidence for object-centred processing, given that the stimuli used in our study as well as in Behrmann and Tipper's did not present within-object asymmetries of shape (i.e., the human body and cubes, barbells).

But let's return to one of the issues raised by McCarthy (2002); that is, how to reconcile the findings in favour of the object-centred frame of reference in unilateral neglect with the findings on the use of mental rotation processes in object identification? Indeed, one solid finding of studies on object identification in normals is that recognition is dependent on view. Several classes of objects show increases in naming latencies for rotated stimuli. For example, the ability to identify human faces is strongly view-dependent (Troje and Bülthoff, 1996; Hill et al., 1997; O'Toole et al., 1998). Subjects recognize the front view of their own face better than another view; whereas for identifying other people's faces the 3/4 view is superior (Troje and Kersten, 1999; Laeng and Rouw, 2001). This suggests that the visual system is unable to construct a viewpoint-independent representation for a highly familiar object as one's own face. Also other classes of objects show increases in naming latencies for rotated stimuli (e.g., Palmer et al., 1981; Jolicoeur, 1985, 1988, 1990; Lawson et al., 1994; Newell and Findlay, 1997; Vannucci and Viggiano, 2000). These findings have led several investigators to propose that normalisation processes (e.g., mental rotation, alignment; cf. Tarr and Pinker, 1989; Ullman, 1989) take place when an object is seen in a non-canonical (i.e., unusual) view[2].

One way to account for the discrepancies in the findings of attentional (neglect) studies and pattern recognition studies could be based on the specific demands of the tasks used. The strongest evidence for object-centred processing would seem to come from studies that required the control of spatial attention (e.g., in visually tracking one object) both in neglect patients (e.g., Peterson et al., 1998; Behrmann and Tipper, 1999) and in normal subjects (e.g., Kahneman et al., 1992; Umiltà et al., 1995; Danziger et al., 2001). Object identification may not always require the processing of spatial relations within an object or among its parts but in some circumstances (e.g., when viewing unusual contortions of flexible objects; cf. Laeng et al., 1999; Laeng et al., 2002c), the parts-and-relations representation of an object (i.e., its structural description) might play an important role. In addition, orthographic representations may require a representation of the order of the graphemes (i.e. of the spatial relations between the letters; cf. Caramazza and Hillis, 1990). Finally, normalisation procedures of the global pattern representation might also play an important role in object identification in some but not all circumstances (e.g., when viewing unusual and unexpected rotations of objects, Jolicoeur, 1985, 1988, 1990).

To return to the specific case of the cubes task, we surmise that the patient had no doubt on as to what the object supporting the cubes was (i.e., a human body). Nevertheless, we believe that the task would engage a parts-and-relations representation of the human body because the task required the individuation of specific body parts and directing attention to these (and not because this was a difficult or unusual pose to be identified). In general, it would seem that any object may serve as a referent for the spatial coding of other objects (Danziger et al., 2001), but the human body is a spatially complex object, with an intrinsically defined spatial frame, and able to physically support other objects. Thus, if Laeng et al.'s (2002b) task truly engaged a structural description of the human body and its parts' locations, then we would expect that objects supported by the body would also be coded according to such a spatial frame.

Mirror Neglect, Mirror Agnosia

In Laeng et al.'s (2002b) study there were also three conditions where AE observed the cubes via a mirror: one where AE observed the cubes, which were in front of and close to him, via a distant mirror; and two where the experimenter stood behind him, one facing him and the other facing away. These mirror conditions were aimed at revealing the simultaneous presence of neglect for 'far' versus 'near' space in AE, given that external objects seen in a mirror can be 'near' the patient's body, although the patient actually looked at a

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[2] Increased latencies for some specific views can also be interpreted by appealing to mechanisms other than normalisation (e.g., the rate of accumulation of activity from neurons selective for particular view; Perrett et al., 1998) or the way object-centred representations are accessed (e.g., Biederman and Gerhardstein, 1993; Bar, 2001).

'far' location (i.e. the surface of the mirror). Several reports have appeared in the literature to the effect that neglect can also occur for peripersonal or for extrapersonal space (e.g., Pizzamiglio et al., 1989; Halligan and Marshall, 1991; Guariglia and Antonucci, 1992; Cowey et al., 1994, 1999; Bisiach et al., 1995; Berti and Frassinetti, 2000; cf. McCourt and Garlinghouse, 2000, for a dissociation between viewing distance and elevation in pseudoneglect). Maravita et al. (2000) used a mirror to specifically explore the question whether objects adjacent to the viewer's body but seen in a distant mirror are recoded as stimuli in peripersonal space. In our study, when the cubes were physically located near AE's body (i.e., within 'grasping' or peripersonal space) but seen in the mirror that had to be explored with long-distance scanning eye movements, latencies were longer, confirming that AE's problem was with exploring far space and that, even if AE recoded the stimuli within peripersonal space, this did not diminish his neglect. We suggested that action-based reference frames and mechanisms of attention (cf. Vindras and Viviani, 1998; Ward, 1999; Gourtzelidis et al., 2001; Coello et al., 2003) that rely either on a topological distinction based on hand movements (i.e., 'reachable' versus 'unreachable' space) or on the direction of eye movements (cf. Rizzolatti and Gallese, 1988; Vuilleumier and Schwartz, 2001) could have been affected in AE, concomitantly to the mechanisms of attention that code an object's position in the lateral (i.e., left/right) viewer-centred and object-centred coordinate frames. Finally, consistent with the above finding of neglect in allocentrically left space, AE's worst performance was found when the experimenter's reflected image would be seen facing AE, her left side reflected on the portion of the mirror in AE's left hemispace. Thus AE neglected the left side of the actual person not of her reflection. Beis and colleagues (2001; in press) have observed similar left hemispace-based neglect in patients reaching and grasping for coloured cubes seen in a frontal mirror.

We may add a note on the fact that people with intact brains typically use mirrors well, which means that the rules of catoptric interactions may have been internalised. As Umberto Eco points out (Eco, 1985), humankind has had several thousand years to learn to "read" mirrors and reflections. That is, we know how to use mirrors because when one looks into a mirror one immediately knows that there is no-one else in the mirror and that left and right are relative to the one looking, and not the (virtual) one looking back at the viewer. Thus, we are also 'catoptric animals' (Eco, 1985), possessing the double aptitude to be able to look at objects both in the perceptual reality and the virtual reality of mirrors. Mirrors are our visual prosthesis since they can extend our perspective (for example, to 'fill in' the 'blind spot' behind our head). Note, however, how skilled we are in interpreting mirror images: when seeing a car approach in the rear view mirror we do not brake but, appropriately, do the opposite and accelerate (Ramachandran et al., 1997). Similarly, men shaving in a mirror typically do not engage in spastic-like movements and mutilate their faces. Thus, we know what a mirror image is and we can act accordingly. Consider also the following scenario: if, in a mirror, you saw someone approaching you holding a knife in his right hand, which way would you turn to stop the blow? Which arm would you raise to parry it?

Finally, as McCarthy (2002) points out, mirrors can provide a useful paradigm for the clinical assessment of neglect. Prior to Laeng et al.'s (2002b) study, several researchers used mirrors in the attempt to dissociate different frames of reference in the investigation of neglect. Tegnér and Levander (1991) used a mirror to demonstrate directional hypokinesia (i.e., an impairment in the initiation of movement towards contralateral space; Reuter-Lorenz and Posner, 1990) in unilateral neglect. They positioned a 90° mirror to decouple the direction of visual attention (scanning) and of arm movement in a cancellation task (see also Bisiach et al., 1995; Làdavas et al., 1997; Husain et al., 2000). In addition, Ramachandran et al. (1997) described a peculiar phenomenon (that they labelled 'mirror agnosia') in some neglect patients asked to reach for an object only seen in a mirror. When they made objects in the contralateral field visible in the ipsilateral field via the mirror, the patients could indeed report seeing the objects but when asked to reach out and grasp them, the patients reached towards the mirror, only to be repeatedly frustrated by banging their hand against it. They acted, in other words, as if the frame of reference established by the reflection of the mirror did not exist or as if the objects were behind the mirror. Reminiscent of Alice in Carroll's (1872) "Through the looking glass", patients even claimed that the objects were really inside the mirror. Binkofski et al. (1999) have proposed that mirror agnosia may reflect a dissociation of allocentric and egocentric reference frames (see also Turnbull, 1997).

Can't See, or Won't See, Left?

McCarthy (2002) points out that the potential contribution of a hemianopia to a patient's neglect are often overlooked: it would be incorrect to assume that a visual field defect can have no influence on a patient's neglect, just because there are many patients with neglect with no visual field defect and there are many others with the opposite pattern. While the general point is well taken, it is likely that the relationship between a visual deficit and neglect is quite complex (e.g., Barton and Black, 1998; Smania et al., 1998; Doricchi and Angelelli, 1999; Doricchi et al., 2002; Tant et al., 2002; Harvey et al., in press).

To illustrate this, we draw attention to some other results with patient AE. His left-sided neglect, which was severe on classical clinical tests, was accompanied by a left-sided homonymous hemianopia. Laeng et al. (2002a) showed, not unexpectedly, that on a task where he had to decide whether or not a small diamond target was presented he made few errors to targets presented on the right hand side of the screen, but detected only about 60% of left-sided targets. His response times showed that right-sided targets were detected more quickly than left-sided ones, and that correctly pressing the 'No target' button took even longer. The surprising result was that the shortest response times were for trials where he incorrectly pressed 'No' to a left-sided target. It appears then that AE, despite his dense left-sided hemianopia, processed stimuli presented on the contralateral side faster than on the ipsilateral side. It is unclear how AE's vision could process left-sided stimuli that, typically, fell in the hemianopic field: Laeng et al. (2002a) concluded that it was due to faulty coordination between preattentive and attentional processing. Whatever turns out to be the correct account, it seems unlikely that AE's detection of visual stimuli in the blind field was a form of 'blindsight'. AE's RTs to left-sided field were rather slow (more than 1 sec. on average) and, crucially, they increased systematically with further displacement towards the left side. These findings are not consistent with the idea that his fast neglect responses merely depend on stimuli falling within the scotoma; rather, they are consistent with another, straightforward, account of AE's vision: the patient moved his eyes towards the left in order to include the display within his spared field of vision; hence, the items just to the left of the midline would be detected more quickly than items further to the left, because they are closer to the spared field of vision.

In conclusion, the work on mirrors reviewed here shows that the idea that patients with neglect ignore the left side of space needs qualifying with regard to which frame of reference the left side is defined. Thus, a central task of any complete account of neglect, and of human attention more generally, will be to explain how multiple frames of reference can interact.

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References

BAR M. Viewpoint dependency in visual object recognition does not necessarily imply viewer-centered representations. *Journal of Cognitive Neuroscience, 13:* 739-799, 2001.

BARTON JJS and BLACK SE. Line bisection in hemianopia. *Journal of Neurology, Neurosurgery and Psychiatry, 64:* 660-662, 1998.

BEHRMANN M and TIPPER SP. Object-based attentional mechanisms: Evidence from patients with unilateral neglect. In C Umiltà and M Moscovitch (Eds), *Attention and Performance XV*. Cambridge: MIT Press, 1994, pp. 351-375.

BEHRMANN M and TIPPER SP. Attention accesses multiple reference frames: Evidence from visual neglect. *Journal of Experimental Psychology: Human Perception and Performance, 25:* 83-101, 1999.

BEIS JM, ANDRÉ JM, BARRE A and PAYSANT J. Mirror images and unilateral spatial neglect. *Neuropsychologia, 39:* 1444-1450, 2001.

BEIS JM, ANDRÉ JM, PAYSANT J, LE CHAPELAIN L, BRET D and THISSE MO. Troubles du traitement des informations spéculaires chez des patients cérébrolésés droits présentant une héminégligence gauche. *Revue Neurologique*, in press.

BERTI A and FRASSINETTI F. When far becomes near: Remapping of space by tool use. *Journal of Cognitive Neuroscience, 12:* 415-420, 2000.

BIEDERMAN I and GERHARDSTEIN PC. Recognizing depth-rotated objects: Evidence and conditions for three-dimensional invariance. *Journal of Experimental Psychology: Human Perception and Performance, 19:* 1162-1182, 1993.

BINKOFSKI G, BUCCINO G, DOHLE C, SEITZ R and FREUND H. Mirror agnosia and mirror ataxia constitute different parietal lobe disorders. *Annals of Neurology, 46:* 51-61, 1999.

BISIACH E, LUZZATTI C and PERANI D. Unilateral neglect, representational schema and consciousness. *Brain, 102:* 609-618, 1979.

BISIACH E, PERANI D, VALLAR G and BERTI A. Unilateral neglect: Personal and extrapersonal. *Neuropsychologia, 24:* 759-767, 1995.

BISIACH E, TEGNÉR R, LEVANDER M, LÀDAVAS E, RUSCONI ML, MIJOVIC D and HJALTASON H. Through a looking glass. A new technique to demonstrate directional hypokinesia in unilateral neglect. *Cerebral Cortex, 5:* 439-447, 1995.

CARAMAZZA A and HILLIS AE. Spatial representations of words in the brain implied by studies of a unilateral neglect patient. *Nature, 346:* 267-269, 1990a.

CARAMAZZA A and HILLIS AE. Levels of representations, co-ordinate frames, and unilateral neglect. *Cognitive Neuropsychology, 7:* 391-445, 1990b.

CARROLL L. *Through the Looking-Glass, and What Alice Found There*. London: Macmillan and Co, 1872.

COELLO Y, RICHAUD S, MAGNE P and ROSSETTI Y. Vision for spatial perception and vision for action: A dissociation between the left-right and near-far dimensions. *Neuropsychologia, 41:* 622-633, 2003.
COWEY A, SMALL M and ELLIS S. Left visuo-spatial neglect can be worse in far than in near space. *Neuropsychologia, 32:* 1059-1066, 1994.
COWEY A, SMALL M, and ELLIS S. No abrupt change in visual hemineglect from near to far space. *Neuropsychologia, 37:* 1-6, 1999.
CUBELLI R and SPERI V. Naming rotated pictures and the riddle of object-centred neglect. *Cortex, 37:* 159-174, 2001.
DANZIGER S, KINGSTONE A and WARD R. Environmentally defined frames of reference: Their time course and sensitivity to spatial cues and attention. *Journal of Experimental Psychology: Human Perception and Performance, 27:* 494-503, 2001.
DORICCHI F and ANGELELLI P. Misrepresentation of horizontal space in left unilateral neglect: Role of hemianopia. *Neurology, 52:* 1845-1852, 1999.
DORICCHI F, ONIDA A and GUARIGLIA P. Horizontal space misrepresentation in unilateral brain damage II: Eye-head centered modulation of visual misrepresentation in hemianopia without neglect. *Neuropsychologia, 40:* 1118-1128, 2002.
DRIVER J and BAYLIS GC. Attention and visual object segmentation. In R Parasuraman (Ed), *The Attentive Brain*. Cambridge: MIT Press, 1998, Ch. 14, pp. 299-326.
DRIVER J, BAYLIS GC, GOODRICH SJ and RAFAL RD. Axis-based neglect of visual shapes. *Neuropsychologia, 32:* 1353-1365, 1994.
DRIVER J and HALLIGAN PW. Can visual neglect operate in object-centred co-ordinates? An affirmative single-case study. *Cognitive Neuropsychology, 8:* 475-496, 1991.
DRIVER J and POUGET A. Object-centred visual neglect, or relative egocentric neglect? *Journal of Cognitive Neuroscience, 12:* 542-545, 2000.
ECO U. Sugli specchi. In U Eco (Ed), *Sugli specchi e altri saggi*. Milano: Bompiani, 1985, Ch. 1, pp. 3-16.
GAINOTTI G, MESSERLI P and TISSOT R. Quantitative analysis of unilateral spatial neglect in relation to lateralization of cerebral lesions. *Journal of Neurology, Neurosurgery and Psychiatry, 35:* 545-550, 1972.
GIBSON BS and EGETH H. Inhibition of return to object-based and environmental-based locations. *Perception and Psychophysics, 55:* 323-339, 1994.
GOURTZELIDIS P, SMYRNIS N, EVDOKIMIDIS I and BALOGH A. Systematic errors of planar arm movements provide evidence for space categorisation and interaction of multiple frames of reference. *Experimental Brain Research, 139:* 59-69, 2001.
GUARIGLIA C and ANTONUCCI G. Personal and extrapersonal space: A case of neglect dissociation. *Neuropsychologia, 30:* 1001-1009, 1992.
HALLIGAN PW and MARSHALL JC. Left neglect for near but not far space in man. *Nature, 11:* 498-500, 1991.
HARVEY M., GILCHRIST ID, OLK B and MUIR K. Eye-movement patterns do not mediate size distortions effects in hemispatial neglect: Looking without seeing. *Neuropsychologia*, in press.
HILL H, SCHYNS PG and AKAMATSU S. Information and viewpoint dependence in face recognition. *Cognition, 62:* 201-222, 1997.
HILLIS AE and CARAMAZZA A. Spatially specific deficits in processing graphemic representations in reading and writing. *Brain and Language, 48:* 263-308, 1995.
HUMPHREYS GW and HEINKE D. Spatial representation and selection in the brain: Neuropsychological and computational constraints. *Visual Cognition, 5:* 9-47, 1998.
HUMPHREYS GW and RIDDOCH MJ. Attention to within-object and between-object spatial representation: Multiple sites for visual selection. *Cognitive Neuropsychology, 11:* 207-242, 1994.
HUMPHREYS GW and RIDDOCH MJ. Separate coding of space within and between perceptual objects: Evidence from unilateral visual neglect. *Cognitive Neuropsychology, 12:* 283-311, 1995.
HUSAIN M, MATTINGLEY JB, RORDEN C, KENNARD C and DRIVER J. Distinguishing sensory and motor biases in parietal and frontal neglect. *Brain, 123:* 1643-1659, 2000.
JOLICOEUR P. The time to name disoriented natural objects. *Memory and Cognition, 13:* 289-303, 1985.
JOLICOEUR P. Mental rotation and the identification of natural objects. *Canadian Journal of Psychology, 42:* 461-478, 1988.
JOLICOEUR P. Identification of disoriented objects: A dual-systems theory. *Mind and Language, 5:* 387-410, 1990.
KAHNEMAN D, TREISMAN A, and GIBBS BJ. The reviewing of object files: Object-specific integration and information. *Cognitive Psychology, 24:* 175-219, 1992.
KANT I. Concerning the ultimate ground of the differentiation of directions in space. In D Walford and R Meerbote (Eds), *The Cambridge Edition of the Works of Immanuel Kant: Theoretical Philosophy, 1755–1770*. Cambridge: Cambridge University Press, pp. 365–372 (Translation from the 1768 German edition).
KANT I. Mirror images. In Smart JJC (Ed), *Problems of Space and Time*. New York: MacMillan, 1964,

pp. 124-125 (Translation from Prolegomena zu einer jeden künftigen Metaphysik, 1783).
LÀDAVAS E, BERTI A, RUOZZI E and BARBONI F. Neglect as a deficit determined by an imbalance between multiple spatial representations. *Experimental Brain Research, 116:* 493-500, 1997.
LÀDAVAS E, PETRONIO A and UMILTÀ C. The deployment of visual attention in the intact hemifield of hemineglect patients. *Cortex, 26:* 307-317, 1990.
LAENG B, BRENNEN T and ESPESETH T. Fast responses to neglected targets in visual search reflect pre-attentive processes: An exploration of response times in visual neglect. *Neuropsychologia, 40:* 1622-1636, 2002a.
LAENG B, BRENNEN T, JOHANNESSEN K, HOLMEN K and ELVESTAD R. Multiple reference frames in neglect? An investigation of the object-centred frame and the dissociation between 'near' and 'far' from the body by use of a mirror. *Cortex, 38:* 511-528, 2002b.
LAENG B, CARLESIMO GA, CALTAGIRONE C, CAPASSO R and MICELI G. Rigid and non-rigid objects in canonical and non-canonical views: Hemisphere-specific effects on object identification. *Cognitive Neuropsychology, 19:* 697-720, 2002c.
LAENG B and ROUW R. Canonical views of faces and the cerebral hemispheres. *Laterality, 6:* 193-224, 2001.
LAENG B, SHAH J and KOSSLYN SM. Identifying objects in conventional and contorted poses: Contributions of hemisphere-specific mechanisms. *Cognition, 70:* 53-85, 1999.
LAWSON R, HUMPHREYS GW and WATSON DG. Object recognition under sequential viewing conditions: Evidence for viewpoint-specific recognition procedures. *Perception, 23:* 595-614, 1994.
MAGUIRE AM, BATES TC, BOYCOTT NL and CORBALLIS MC. Effects of object asymmetry on visual attention. *Brain and Cognition, 48:* 457-462, 2002.
MAPELLI D, UMILTÀ C, NICOLETTI R, FANINI A and CAPEZZANI L. Prelexical spatial representations. *Cognitive Neuropsychology, 13:* 229-255, 1996.
MARAVITA A, SPENCE C, CLARKE K, HUSAIN M and DRIVER J. Vision and touch through the looking glass in a case of crossmodal extinction. *NeuroReport, 11:* 3521-3526, 2000.
MARR D. *Vision: A computational investigation into the human representation and processing of visual information*. New York: Freeman, 1982.
MCCARTHY M. Fractionating the neglected space: The relevance of reference frames for defining left and right in spatial neglect. *Cortex, 38:* 465-477, 2002.
MCCOURT ME and GARLINGHOUSE M. Asymmetries of visuospatial attention are modulated by viewing distance and visual field elevation: Pseudoneglect in peripersonal and extrapersonal space. *Cortex, 36:* 715-731, 2000.
NEWELL FN and FINDLAY JM. The effect of depth rotation on object identification. *Perception, 26:* 1231-1257, 1997.
O'TOOLE AJ, EDELMAN S and BÜLTHOFF HH. Stimulus-specific effects in face recognition over changes in viewpoint. *Vision Research, 38:* 2351-2363, 1998.
PALMER S, ROSCH E and CHASE P. Canonical perspective and the perception of objects. In J Long and A Baddeley (Eds), *Attention and Performance IX*. Hillsdale: Erlbaum, 1981, pp. 131-151.
PERRETT DI, ORAM MW and ASHBRIDGE E. Evidence accumulation in cell populations responsive to faces: An account of generalisation of recognition without mental transformation. In MJ Tarr and HH Bülthoff (Eds), *Object Recognition in Man, Monkey and Machine*. Cambridge: MIT Press, 1998, pp. 111-145.
PETERSON MA, GERHARDSTEIN PC, MENNEMEIER M and RAPCSAK SZ. Object-centered attentional biases and object recognition contributions to scene segmentation in left- and right-hemisphere-damaged patients. *Psychobiology, 26:* 357-370, 1998.
PIZZAMIGLIO L, CAPPA S, VALLAR G, ZOCCOLOTTI P, BOTTINI G, CIURLI P and GUARIGLIA C. Visual neglect for far and near extra-personal space in humans. *Cortex, 25:* 471-477, 1989.
POUGET A and SEJNOWSKI TJ. A new view of hemineglect based on the response properties of parietal neurons. *Philosophical Transactions of the Royal Society: Series B, 352:* 1449-1459, 1997.
RAMACHANDRAN VS, ALTSCHULER EL and HILLYER S. Mirror agnosia. *Proceedings of the Royal Society of London: Biological Sciences, 264:* 645-647, 1997.
REUTER-LORENZ PA and POSNER MI. Components of neglect from right-hemisphere damage. An analyisis of line bisection. *Neuropsychologia, 28:* 327-333, 1990.
RIZZOLATTI G and GALLESE V. Mechanisms and theories of spatial neglect. In Boller F and Grafman J (Eds), *Handbook of Neuropsychology*, Vol. 1. Amsterdam: Elsevier, 1988, pp. 223-249.
SMANIA N, MARTINI MC, GAMBINA G, TOMELLERI G, PALAMARA A, NATALE E and MARZI CA. The spatial distribution of visual attention in hemineglect and extinction patients. *Brain, 121:* 1759-1770, 1998.
TADIN D, LAPPIN JS, BLAKE R and GROSSMAN ED. What constitutes an efficient referent frame for vision? *Nature neuroscience, 5:* 1010-1015, 2002.
TANT MLM, KUKS JBM, KOOIJMAN AC, CORNELISSEN FW and BROUWER WH. Grey scales uncover similar attentional effects in homonymous hemianopia and visual hemi-neglect. *Neuropsychologia, 40:* 1474-1481, 2002.

TARR MJ and PINKER S. Mental rotation and orientation-dependence in shape recognition. *Cognitive Psychology, 21:* 233-282, 1989.
TEGNÉR R and LEVANDER M. Through a looking glass. A new technique to demonstrate directional hypokinesia in unilateral neglect. *Brain, 114:* 1943-1951, 1991.
TIPPER S P and BEHRMANN M. Object-centred not scene-based visual neglect. *Journal of Experimental Psychology: Human Perception and Performance, 22:* 1261-1278, 1996.
TROJE NF and BÜLTHOFF HB. Face recognition under varying pose: The role of texture and shape. *Vision Research, 36:* 1761-1771, 1996.
TROJE NF and KERSTEN D. Viewpoint-dependent recognition of familiar faces. *Perception, 28:* 483-487, 1999.
TURNBULL OH. Neglect: mirror, mirror, on the wall- is the left side there at all? *Current Biology, 7:* 709-711, 1997.
ULLMAN S. Aligning pictorial descriptions. An approach to object recognition. *Cognition, 32:* 193-254, 1989.
UMILTÀ C, CASTIELLO U, FONTANA M and VESTRI A. Object-centred orienting of attention. *Visual Cognition, 2:* 165-181, 1995.
VANNUCCI M and VIGGIANO MP. Category effects on the processing of plane-rotated objects. *Perception, 29:* 287-302, 2000.
VINDRAS P and VIVIANI P. Frames of reference and control parameters in visuomanual pointing. *Journal of Experimental Psychology: Human Perception and Performance, 24:* 569-591, 1998.
VUILLEUMIER P and SCHWARTZ S. Modulation of visual perception by eye gaze direction in patients with spatial neglect and extinction. *NeuroReport, 12:* 2101-2104, 2001.
WARD R. Interactions between perception and action systems: A model for selective selection. In GW Humphreys, J Duncan and A Treisman (Eds), *Attention, Space and Action*. New York: Oxford University Press, 1999, Ch. 18, pp. 311-332.

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