Object-based Neglect Varies with Egocentric Position

Hans-Otto Karnath[1,2], André Mandler[1], and Simon Clavagnier[3]

Abstract

■ Different reference frames have been identified to influence neglect behavior. In particular, neglect has been demonstrated to be related to the contralesional side of the subject's body (egocentric reference frames) as well as to the contralesional side of individual objects irrespective of their position to the patient (object-based reference frame). There has been discussion whether this distinction separates neglect into body- and object-based forms. The present experiment aimed to prove possible interactions between object-based and egocentric aspects in spatial neglect. Neglect patients' eye and head movements were recorded while they explored objects at five egocentric positions along the horizontal dimension of space. The patients showed both egocentric as well as object-based behavior. Most interestingly, data analysis revealed that object-based neglect varied with egocentric position. Although the neglect of the objects' left side was strong at contralesional egocentric positions, it ameliorated at more ipsilesional egocentric positions of the objects. The patients showed steep, ramp-shaped patterns of exploration for objects located on the far contralesional side and a broadening of these patterns as the locations of the objects shifted more to the ipsilesional side. The data fitted well with the saliency curves predicted by a model of space representation, which suggests that visual input is represented in two modes simultaneously: in veridical egocentric coordinates and in within-object coordinates. ■

INTRODUCTION

When we interact with our environment, we require information about the positions of things surrounding us. The brain uses different coordinate frames to code spatial locations of visual objects (Olson, 2003; Olson & Gettner, 1995, 1998; Duhamel, Bremmer, BenHamed, & Graf, 1997; Brotchie, Andersen, Snyder, & Goodman, 1995; Galletti, Battaglini, & Fattori, 1993; Duhamel, Colby, & Goldberg, 1992; Andersen, Essick, & Siegel, 1985). "Egocentric" coordinates determine the position of an object relative to the own body or parts thereof (trunk, head, and retina), whereas allocentric "object-based" coordinates code features of an object in coordinates relative to the object itself. Studies on human visual attention have revealed evidence for information processing in these different reference systems (Atchley & Kramer, 2001; Egly, Driver, & Rafal, 1994; Duncan, 1984; Posner, 1980). Egocentric and object-based mechanisms also seem to be involved in the disturbed spatial orienting behavior observed in stroke patients suffering from right hemisphere damage and spatial neglect. The characteristic failure of neglect patients to explore the side contralateral to the lesion has been described to occur not only with respect to egocentric reference frames but also relative to object-based coordinates (Savazzi, Mancini, Veronesi, & Posteraro, 2009; Marsh & Hillis, 2008; Hillis et al., 2005; Behrmann & Geng, 2002; Ota, Fujii, Suzuki, Fukatsu, & Yamadori, 2001; Behrmann & Tipper, 1994, 1999; Karnath, Niemeier, & Dichgans, 1998; Pavlovskaya, Glass, Soroker, Blum, & Groswasser, 1997; Tipper & Behrmann, 1996; Behrmann & Moscovitch, 1994; Driver, Baylis, Goodrich, & Rafal, 1994; Karnath, 1994; Arguin & Bub, 1993; Driver, Baylis, & Rafal, 1992; Young, Hellawell, & Welch, 1992; Driver & Halligan, 1991; Gainotti, Messerli, & Tissot, 1972).

It was speculated whether this obvious distinction between egocentric and object-based inattention separates neglect into body- and object-based forms (e.g., Marsh & Hillis, 2008; Hillis et al., 2005; Walker, 1995; Marshall & Halligan, 1993). In line with this notion, several anatomical studies carried out in neglect patients reported evidence for separate neural structures involved in egocentric versus object-based visual information processing (Medina et al., 2009; Grimsen, Hildebrandt, & Fahle, 2008; Rorden, Fruhmann Berger, & Karnath, 2006; Hillis et al., 2005; Binder, Marshall, Lazar, Benjamin, & Mohr, 1992). Functional neuroimaging in healthy subjects supported this view only in part, demonstrating that different frames of reference in spatial cognition show partly different but largely common areas of activity (Wilson, Woldorff, & Mangun, 2005; Committeri et al., 2004; Galati et al., 2000; Vallar et al., 1999; Honda, Wise, Weeks, Deiber, & Hallett, 1998; Fink, Dolan, Halligan, Marshall, & Frith, 1997). Alternative hypotheses have argued that object-based neglect may be explained in purely egocentric terms as so-called "relative egocentric neglect" (Driver & Pouget, 2000) or that object-based and egocentric behavior may constitute different manifestations of the same (disturbed) system acting in different situations (Karnath & Niemeier, 2002).

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Different computational models of spatial attention were suggested to explain how the same physical input is organized in different reference frames (Deneve & Pouget, 1998, 2003; Mozer, 1999, 2002; Niemeier & Karnath, 2002a; Pouget & Sejnowski, 1997, 2001). Among them, Niemeier and Karnath (2002a) proposed a representation concept coding visual input in two kinds of coordinates simultaneously, with no need for further transformation. This "integrated space-object map" (ISO-map) codes the position of an object in egocentric space along a head- and/or trunk-centered dimension and the object's within-object coordinates along an object-based dimension. In neglect patients, the salience functions were assumed to be altered in a particular way, namely, the bell-shaped pattern along the horizontal egocentric axis with the peak shifted to the ipsilesional right side and the ramp-shaped pattern along the horizontal object-based axis increasing monotonically from left to right. A central prediction of the model was, thus, a direct interaction between object-based and egocentric coordinates, namely, that the left–right asymmetry in neglect should improve with more ipsilesional positions of the objects. This latter prediction is most interesting as it does not belong to the a priori properties of the ISO-map model.

The present study aimed to compare the predictions with the actual visual exploratory behavior of neglect patients, showing the typical clinical behavior such as constant eye and head orientation toward the right (Fruhmann-Berger & Karnath, 2005) and ignoring of contralesionally located people or objects in their everyday behavior as well as their performance in traditional cancellation and copying tasks. In these patients, we were interested to verify a possible interaction between egocentric and object-based aspects. For this purpose, we presented prototypical objects, namely, line drawings of houses, at five egocentric positions along the horizontal dimension of space and recorded subjects' eye and head movements while exploring the objects.

METHODS

Subjects

We tested 10 neurological patients admitted to the Center of Neurology at Tübingen University. Three patients showed spatial neglect (NEG) because of a right hemisphere stroke. Four stroke patients also suffered from an acute right hemispheric lesion but did not show spatial neglect (RBD). Three further neurological patients had no brain damage (NBD). Apart from one RBD patient with a small skotoma in the lower left visual quadrant, neurological examination of all patients revealed no oculomotor and no visual field defects. All subjects gave their informed consent to participate in the study that was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Demographic and clinical data of all subjects are presented in Table 1.

Patients with spatial neglect had to show pathological behavior in at least two of the following three clinical tests: the "Letter Cancellation Task" (Weintraub & Mesulam, 1985), the "Bells test" (Gauthier, Dehaut, & Joanette, 1989), and a copying task (Johannsen & Karnath, 2004). All three tests were presented on a horizontally oriented 21×29.7 cm sheet of paper. In the Letter Cancellation Task, 60 target letters "A" are distributed among distractors. Patients were asked to cancel all of the targets. The Bells test requires identifying 35 bell symbols distributed on a field of other symbols. For both these tests, we calculated the Center of Cancellation (CoC) using the procedure and software by Rorden and Karnath (2010; www.mricro.com/cancel/). This value indicates the center of mass for all the detected items, such that identifying all the targets would generate a score of 0 whereas identifying only the rightmost item would provide a score of one. This measure is sensitive to both the number of omissions and the location of these omissions. CoC scores greater than 0.09 in the Letter Cancellation Task and the Bells test were taken to indicate neglect behavior (cf. Rorden & Karnath, 2010). In the copying task, patients were asked to copy a complex multi-object scene consisting of four figures (a fence, a car, a house, and a tree), two in each half of the test sheet. Omission of at least one of the contralateral features of each figure was scored as 1, and omission of each whole figure was scored as 2. One additional point was given when contralateral-located figures were drawn on the ipsilesional side of the paper sheet. The maximum score was 8. A score higher than 1 (i.e., >12.5% omissions) indicated spatial neglect (Johannsen & Karnath, 2004).

Table 1 demonstrates that the three neglect patients investigated in the present study all showed CoC and omission scores that were considerably above these formal criteria.

Apparatus

The patient sat upright in a (wheel)chair, which was positioned in a cubic frame. The patient's head was positioned in the center of the cubic frame (diameter = 105 cm) and could be freely moved. The trunk was immobilized on the chair by a belt and shoulder straps. Within the frame, a unitary, arc-shaped array of black letters (each 1.8° high) on a white ground was presented on a printed surface (Figure 1A). The letters covered a rectangular area of ±120° left and right of the body's midsagittal plane and of ±40° above and below the patient's eye level. The room was normally lightened. Gaze, eye-in-head, and head-on-trunk positions were measured using the magnetic field search technique (Robinson, 1963). Three orthogonal alternating magnetic fields were generated by three pairs of Helmholtz coils mounted on the outer surface of the cubic frame. The patient's gaze position was measured by a 2-D search coil (Skalar Medical, Delft, the Netherlands), which was embedded in a silicon rubber ring and adhered on the sclera of the left eye by suction. Head-on-trunk position

Table 1. Demographic and Clinical Data of All Subjects with and without Spatial Neglect

		Spatial Neglect	*No Neglect (Controls)*	
			RBD	*NBD*
Number		3	4	3
Sex		1f, 2m	2f, 2m	3m
Age (years)	mean (*SD*)	59.6 (16.5)	59.9 (8.1)	47.7 (9.2)
Etiology		3 infarct	4 infarct	
		1 hemorrhage		
Time since lesion (days)	mean (*SD*)	14.0 (3.5)	13.5 (16.5)	
Paresis of contralesional side	% present	100	100	
Visual field deficit	% present	0	25	
Letter cancellation (CoC)	mean (*SD*)	0.53 (0.28)	0.01 (0.04)	
Bells test (CoC)	mean (*SD*)	0.66 (0.30)	0.03 (0.05)	
Copying (% omitted)	mean (*SD*)	58.3 (28.9)	0.3 (0.5)	
Lesion location		NEG1: F, P, T, I	RBD1: Bg, I	
		NEG2: F, P, Bg	RBD2: Th, O	
		NEG3: F, P, T, Bg, I	RBD3: F	
			RBD4: Bg	

RBD, right brain damage without spatial neglect; NBD, nonbrain damage; f, female; m, male; CoC, Center of cancellation (cf. Rorden & Karnath, 2010); F, frontal; P, parietal; T, temporal; O, occipital; I, insula; Th, thalamus; Bg, basal ganglia.

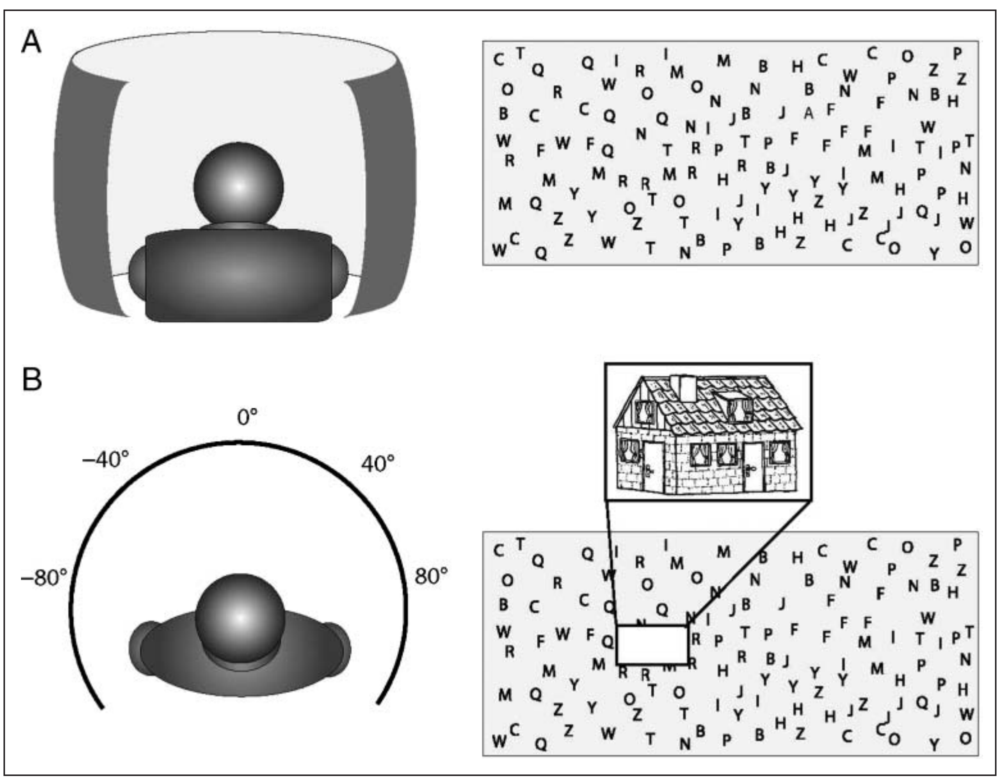


Figure 1. The two experimental conditions. (A) The subjects were presented a unitary, arc-shaped array of black letters covering a rectangular area of ±120° left and right of the body's midsagittal plane and ±40° above and below the patient's eye level. The subjects were asked to search for a single (nonexistent) target letter "A." (B) In each experimental trial, just one house was presented in a random order at one of five horizontal locations (−80°, −40°, 0°, +40°, and +80° with respect to the subject's trunk) with the center of the houses positioned at eye level. The task of the subject was to closely explore the house and to determine possible differences compared with previous stimuli.

was recorded with a further solenoid attached to the patient's forehead. The sampling rate was 100 Hz. Data were stored in a hard disk for offline analysis. The eye-in-head positions, which represent the difference between the corresponding gaze and head-on-trunk positions, were determined by multiplying the rotation matrices of gaze positions with the inverse rotation matrices of head-on-trunk positions. Gaze positions represent combined eye-in-head and head-on-trunk positions. Head-on-trunk and gaze coordinates 0°/0° were aligned with the patient's midsagittal body axis in the horizontal plane and the individual eye level in the sagittal plane. Eye-in-head coordinates were head-centered with coordinates 0°/0° aligned with the head's midsagittal axis at eye level. Positive values indicate locations at the right of these centers, and negative values indicate locations at the left.

Procedure

We studied the exploratory gaze movements of our subjects in two conditions. The first condition served as a baseline. In this condition, the subjects were instructed to search for a single black target letter "A" located "somewhere in the whole letter array" (Figure 1A). In fact, no target letter was presented during data registration. This design should avoid systematic effects of target detection on the distribution of eye movements not directly related to the process of visual search. All subjects were required to conduct two trials of this condition, each lasting 60 sec.

In the second condition, the subjects were instructed to explore black and white drawings of houses. The houses ($n = 5$, each 20° wide and 10° high) differed slightly in the number of elements (windows, doors, etc.). Each of these houses was mirrored along the vertical axis to avoid possible exploration biases along the horizontal dimension induced by the house architecture. In total, this resulted in 10 drawings of houses. Before data recording started, one house was presented to the subject, giving the instruction to "closely explore it because subsequently other houses will be presented on the arc-shaped array to be compared with it." To achieve a dense visual exploration per house, the (pseudo)task of the subject was to determine whether the subsequently presented houses were different or identical with the one presented before (in a one-back task), as well as to describe the architectural differences. In each experimental trial, one single house was presented onto the arc-shaped array of black letters (cf. Figure 1B). It was placed at one of five horizontal locations (−80°, −40°, 0°, +40°, and +80° with respect to the subject's trunk) in a random order, with the center of the houses positioned at eye level (Figure 1B). Different houses were presented four times (two houses and their mirror-reversed versions) at each of the five horizontal positions for 20 sec per trial. Thus, in total, 80-sec scanning time was obtained per position. The five horizontal stimulus locations were calibrated individually for each subject by presenting a rectangle that had the same spatial dimension as the houses (20° wide and 10° high). While calibration data were recorded, the subjects had to fixate the middle of each side composing the rectangle, indicated by a red laser pointer.

RESULTS

Figure 2 illustrates the mean percentage of exploration time for horizontal gaze positions during the first condition of the experiment, when the subjects were instructed to search for a single black target letter "A" located "somewhere in the whole letter array" (Figure 1A). Both control groups (RBD, NBD) showed flat, symmetrical distributions of exploratory movements, covering a broad part of the whole letter array of ±120° left and right of the body's midsagittal trunk plane, with a slight increase for the more central parts of the array (Figure 2). In both control groups, the mean gaze position was very close to the midsagittal trunk plane (RBD: 5.5°, $SD = 7.3$; NBD: 5.0°, $SD = 6.5$) with no statistical difference ($t(5) = -0.09$, $p = .933$). The following analyses were, thus, carried out by combining the data of RBD and NBD subjects into one control group (CON, $n = 7$).

In contrast to controls, the neglect patients ignored the left part of the letter array completely (Figure 2). Their mean gaze position was shifted +48.5° ($SD = 9.2$) to the right of the midsagittal trunk plane.

Figure 3 presents samples of typical scanpaths recorded in a patient with spatial neglect and in a patient without neglect while exploring an object stimulus at each of the five horizontal locations (in each experimental trial, only one stimulus was present at one of the five horizontal locations). Whereas the control subject explored the objects homogeneously, the neglect patient showed asymmetrical visual exploration movements ranging from entire neglect of the left side up to scanning of both sides with an asymmetrical distribution of exploration movements.

For comparison of the distribution of horizontal gaze positions during object exploration at the different egocentric positions, in Figure 4A, the centers of all house stimuli were aligned and coded 0° (for reasons of clarity, Figure 4A does not present gaze distributions obtained at stimulus positions −40° and +40°). The control group showed very similar distributions of gaze positions when exploring the houses at different egocentric locations. The distributions were flat and covered the whole object symmetrically (Figure 4A). This is further illustrated by the distribution of the two parameters extracted from the visual scanpaths, that is, the mean and the standard deviation of eye movement distribution (Figure 4B). For both parameters, we calculated a linear regression analysis over the five horizontal object positions. The control group did not show a significant correlation neither for

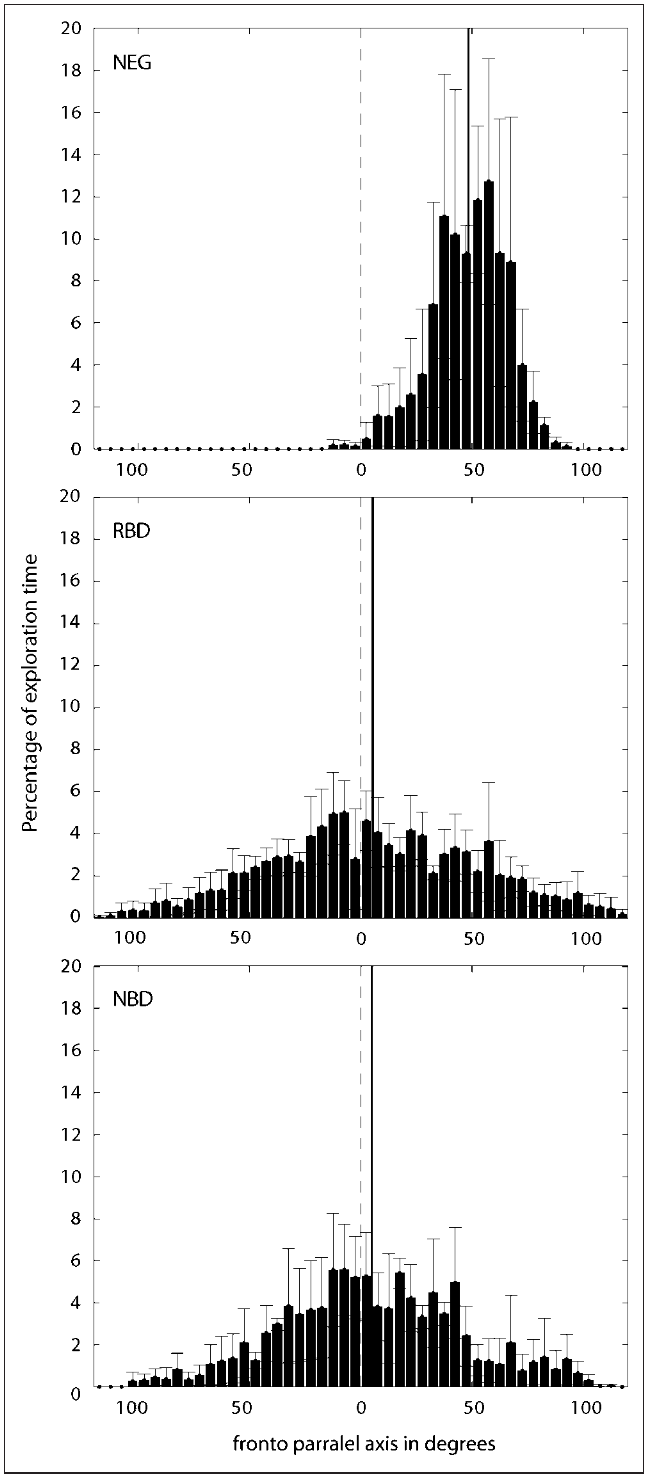


Figure 2. Mean percentage of gaze exploration time (and standard deviation) for horizontal positions recorded in the group of neglect patients (NEG) and the two control groups (RBD, NBD) when the subjects searched for a (nonexisting) target in the entire letter array (±120° horizontal and ±40° vertical extension). The vertical dashed line marks the midsagittal trunk plane (0°). Negative gaze positions indicate locations on the left side of this plane, and positive values indicate locations on its right side. The vertical filled line marks the mean gaze position of each group.

the mean value ($r = -.25, p = .143$) nor for the standard deviation ($r = .18, p = .312$).

In contrast, the three neglect patients showed a clearly asymmetrical distribution of gaze movements favoring the objects' right side. Beyond, the egocentric horizontal location of the object had a systematic effect on the grade of asymmetry. At the extreme left-sided object position (−80°), the neglect patients spent most of the scanning time on the extreme right side of the object. This object-based bias became less prominent as egocentric object positions located farther to the subject's egocentric right. At the extreme right-sided object position (+80°), the bias was markedly reduced in all three neglect patients. This trend along the horizontal plane was reflected by a regression analysis performed over the five horizontal object positions. We found a clear negative relationship for the mean value of horizontal gaze position ($r = -.65, p = .008$) and a positive relationship for the standard deviation ($r = .61, p = .014$).

To test the predictions of the ISO-map model (Niemeier & Karnath, 2002a), we compared the patients' ocular exploration behavior of the house stimuli presented at the different egocentric sites with the saliency curves at these locations, as predicted by the model. Figure 5 illustrates the predicted saliency curves in contrast to the recorded ocular exploration data of the neglect group. Different colors were used to illustrate the distribution of the patients' ocular exploration at the five stimulus locations. The ISO-map model suggests an imbalance of salience always in favor of the right object half (black lines in Figure 5). With more ipsilesional object positions, the gradient becomes less steep and the width of the salience distribution expands. In other words, the model predicts that the left–right asymmetry lessens with more ipsilesional positions of the objects. Overall, the patients' ocular exploration data followed the predictions of the model. We found the neglect patients' exploration behavior systematically changing along the different horizontal object locations (Figure 5). Whereas the distribution was strongly in favor for the ipsilesional side for objects on the contralesional side, this changed toward more balanced, squat distributions for objects situated more ipsilesionally. Only the distribution of exploratory eye movements on the leftmost position (−80°) was not observed as steeply biased as predicted by the model.

DISCUSSION

In the present study, we presented objects at five egocentric positions along the horizontal dimension of space in consecutively admitted patients with acute right hemisphere stroke. The patients with spatial neglect showed the typical clinical behavior such as ignoring of contralesionally located people or objects in their everyday behavior as well as their performance in traditional cancellation and copying tasks. The patients did not show

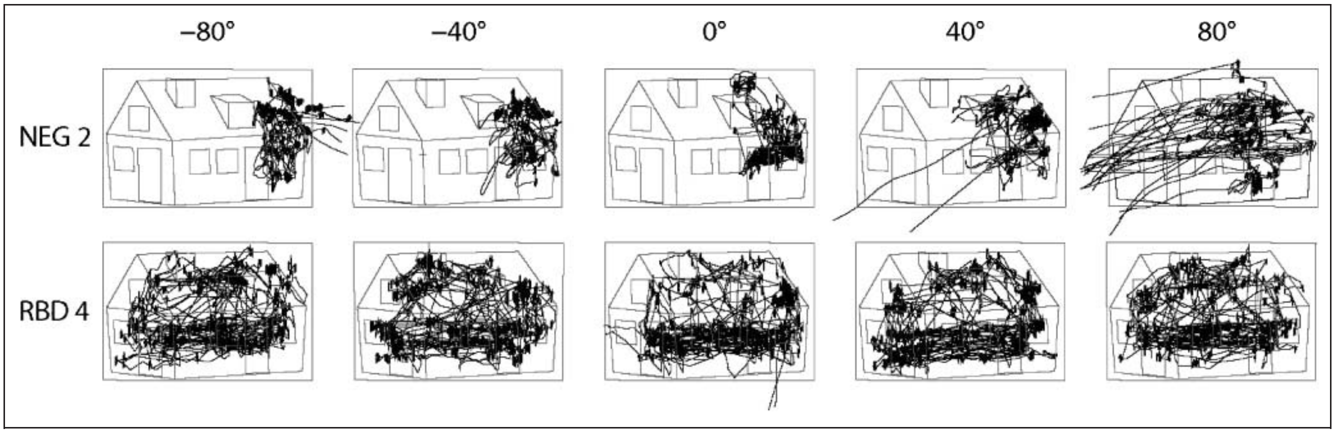


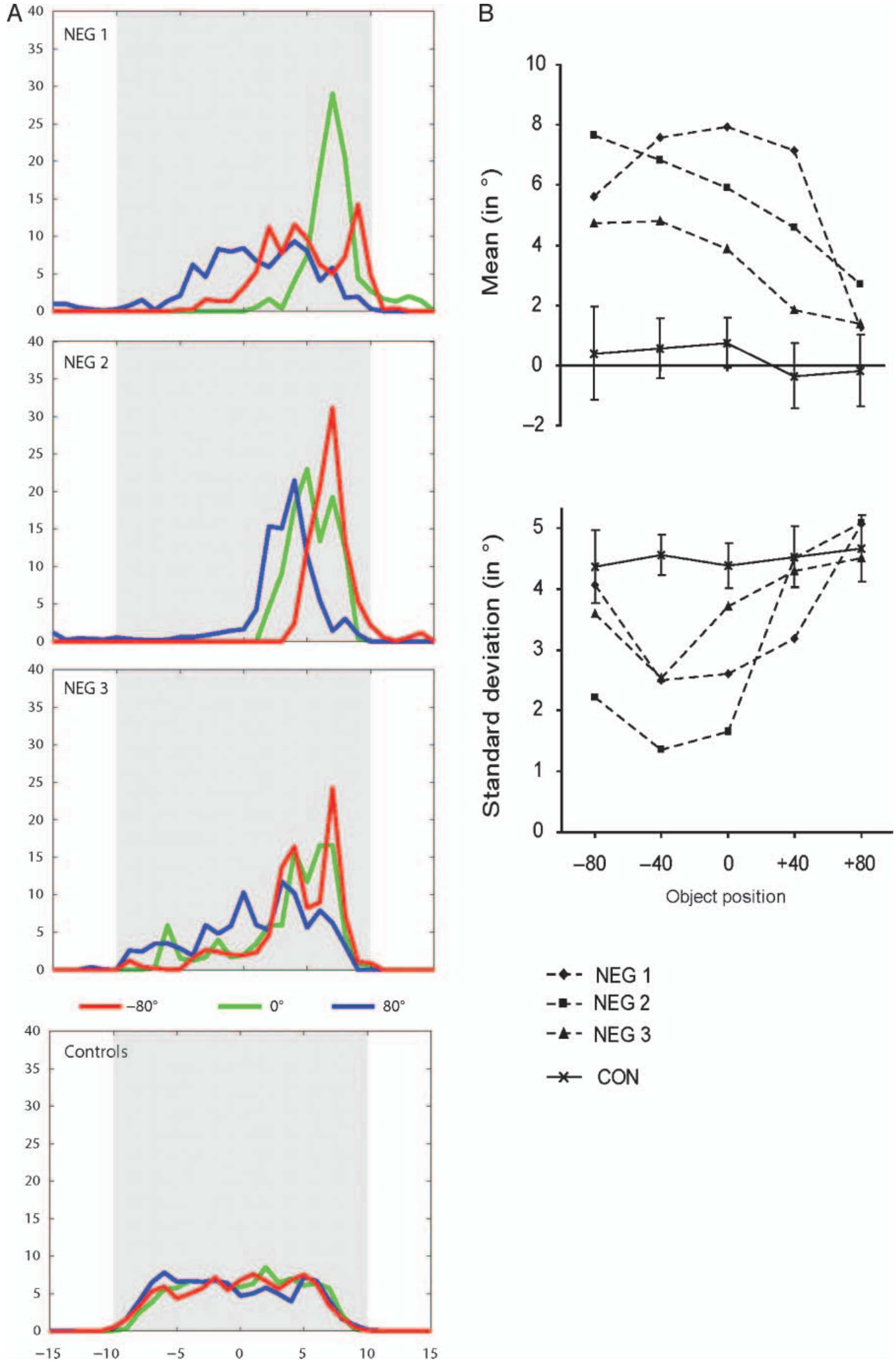
Figure 3. Typical scanpaths of an RBD patient with spatial neglect (NEG2, top) and an RBD patient without neglect (RBD4, bottom), scanning an object stimulus at each of the five horizontal locations. In each experimental trial, only one stimulus was present at one of the five locations.

purely egocentric nor purely object-based behavior in the present experiment. Rather, they showed a distribution of horizontal gaze positions relative to the object that changed along the different object locations. Whereas the neglect of the objects' left side was strong at contralesional egocentric positions, the neglect symptoms ameliorated at more ipsilesional egocentric positions of the objects. The exploration behavior, thus, revealed both "object-based" and "egocentric" aspects in the same neglect patients.

There are two key respects in which the experimental fixation distributions and theoretical saliency functions as predicted by the ISO-map model clearly agree, namely, the peak height drops and the distribution broadens as objects are shifted into ipsilesional egocentric space. On the basis of the idea of coding visual input of an object simultaneously in both egocentric and object-based dimensions, the ISO-map model predicts an imbalance of salience always in favor of the right object half, and this imbalance/gradient becomes less steep and the width of the salience distribution expands with more ipsilesional egocentric object positions (Niemeier & Karnath, 2002a). According to this prediction, the neglect patients exhibited steep, ramp-shaped patterns of exploration for objects located on the far contralesional side and a broadening of these patterns as the locations of the objects shifted more to the ipsilesional side. However, there are also several aspects in which the behavioral data do not entirely fit the model prediction. Fixation time distributions have very sharp peaks, which the saliency functions do not have. The model data predicts monotonically decreasing peak saliency when objects are displaced farther into ipsilesional egocentric space, whereas variation in the height of the peak of the fixation distribution does not appear to be monotonic (the peak is smaller at −80° and larger at −40° and 0°). Because the salience function has to operate through the oculomotor system to generate the fixation data, this could impose its own constraints, accounting for some discrepancies. On the other hand, these discrepancies might suggest that a different model or a modified ISO-map model could provide a better fit.

Beyond the ISO-map model, several alternative models were suggested to explain egocentric and object-based effects in spatial neglect. Pouget and Sejnowski (1997, 2001) proposed a network model generating egocentric coordinates on the basis of retinal position and eye position. In this network, lateralized stimuli are processed mainly by contralateral networks. With a target selection mechanism based on saliency, lesions of this model predicted neglect not only for the egocentric left but also for the left side of objects, the latter without an explicit object-based representation. The center-shifted saliency distribution giving rise to object-based neglect was assumed to be retinotopic in nature. A similar assumption underlies the retinotopic attentional gating mechanism suggested by Mozer (1999). However, to explain neglect behavior, these purely egocentric models have to assume a ramp-shaped salience curve across space to achieve that an imbalance of visual search always occurs—as in spatial neglect—for the left side. In contrast to this assumption,

Figure 4. Distribution of horizontal gaze positions during object exploration at the five egocentric positions. Vertical axes in percentage of exploration time. (A) The centers of all house stimuli were aligned and coded 0°. The gray area indicates the horizontal extension of the presented objects. The distribution of horizontal gaze positions observed at the different egocentric object positions are color coded (−80°, red; 0°, green; +80°, blue). For reasons of clarity, the figure does not present the distributions obtained at locations −40° and +40°. (B) Mean and standard deviation of the horizontal eye distribution obtained at each of the five horizontal object locations. The object's center in the horizontal plane was coded 0°. Positive values indicate locations at the right of this center, and negative values indicate locations at the left of it. NEG, neglect patient; CON, control group (n = 7).


A
NEG 1
NEG 2
NEG 3
Controls
−80°
0°
80°
B
Mean (in °)
Standard deviation (in °)
Object position
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NEG 2
NEG 3
CON

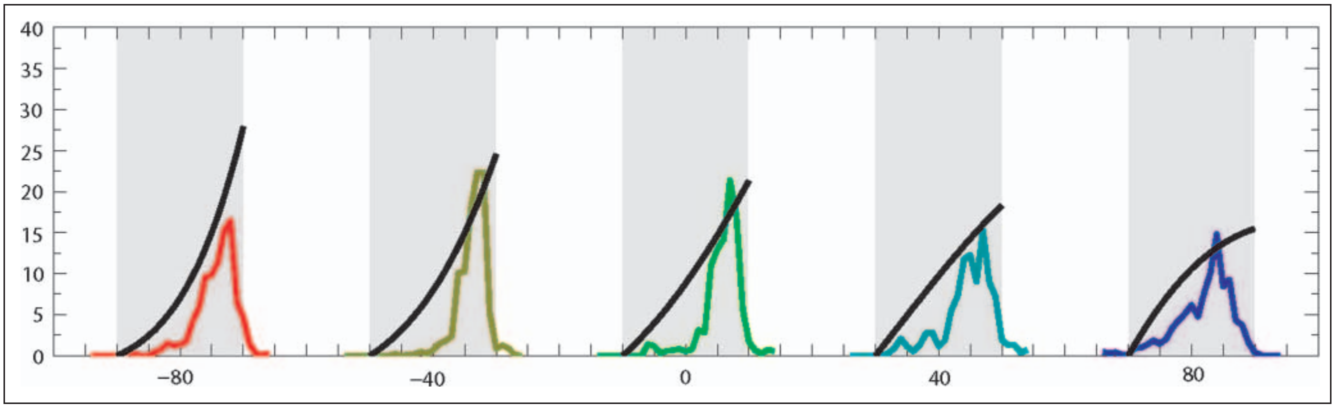

Figure 5. Comparison of the neglect patients' ocular exploration behavior with the predictions of the ISO-map model (Niemeier & Karnath, 2002a). The black lines illustrate the predicted saliency curves for objects situated at the five egocentric sites (−80°, −40°, 0°, +40°, and +80°). The gray area indicates the extension of the house stimuli presented at these locations. The neglect patients' average distribution of exploratory eye movements recorded at these five stimulus locations is illustrated in different colors matching to the color coding used in Figure 4A. Scaling is arbitrary but equal for all five curves (in percentage of exploration time).

several investigations of patients with neglect have revealed a symmetrical, bell-shaped distribution of spatial attention across egocentric space (Niemeier & Karnath, 2002b; Karnath et al., 1998; Hornak, 1992). To explain genuine object-based effects, Deneve and Pouget (1998; for a version with more detailed examples, see Deneve and Pouget, 2003) suggested a neuronal gain field model. The activity of these neurons resembled object-based response patterns that varied with retinotopic position. In contrast to the present finding, the model did not predict amelioration of neglect symptoms in more ipsilesional positions. The same is true for the module-based model by Deco and Rolls (2002). This model as well assumed the distribution of saliency on a given object to be constant, irrespective of its egocentric position. In a model based on a saliency function spreading along the horizontal dimension, Driver and Pouget (2000) were able to show that confining attention to a particular location may lead to an asymmetrical spread of attention at that location if a shift of global saliency function is assumed. Although their model is geared toward retinal position, it could be reformulated for any other body-related reference frame. Both this model and the ISO-map model generate discontinuous saliency functions for most objects and positions. Only if coupled with a mechanism translating this saliency function into observable behavior, the function becomes continuous. For the ISO-map model, this could be achieved by a winner-takes-all mechanism (cf. Niemeier & Karnath, 2002b), similar to the one put forward by Koch and Ullman (1985).

Our present findings support previous observations in spatial neglect. Niemeier and Karnath (2002b) recorded the visual exploration of neglect patients when their attention was directed to the whole surrounding space and compared it with a condition when their attention was drawn to two smaller arrays at two locations at the right of the midsagittal plane. The patients not only ignored the left side of egocentric space but also showed asymmetrical exploration of the two arrays. In a second study, the authors used the same setup but different conditions (Karnath & Niemeier, 2002). When the neglect patients in this latter experiment had to attend to the whole surrounding environment, their gaze positions were deviated toward the ipsilesional right with the center of exploration around +80° right of the midsagittal trunk plane. With respect to this maximum, they oriented gaze with decreasing frequencies toward left and right. Subsequently, the patients' attention was directed toward a circumscribed area positioned right within the patients' spontaneously attended part of space, namely, toward the segment between +40° and +80°. The exploratory behavior changed dramatically when this area became a specific ROI. The patients now completely neglected the left side of this segment. Thus, the same part of space, namely, the area from +40° to +60°, that had been attended spontaneously when the subjects' attention was directed to the whole surrounding space now was neglected when it became (by instruction) the "left side" of a circumscribed segment to which their attention was allocated. A similar observation has also been reported by Baylis, Baylis, and Gore (2004). The authors investigated three patients with spatial neglect on their ability to detect target letters at ipsilesional and contralesional locations on a monitor and at different locations within large shapes situated on the left and right side of the monitor. When patients were asked to detect targets within the entire field, they showed neglect for the contralesional side. In contrast, when they were asked to detect targets within a particular object, they showed object-based neglect. In these two conditions, the displays and the targets were identical, with the only difference being the task instruction. As in the experiment by Karnath and Niemeier (2002), their results demonstrated that the reference frame of spatial neglect may be altered because of the (external) definition of a task-relevant region in a scene. The same physical stimulus at the same location in a scene may, thus, be attended or, in another situation, neglected, depending on the current goal of the subject. The observations favor the view that the brain might combine egocentric and object-based coordinates in an integrated coordinate system.

The findings of the present study may lead one to assume that the behavior termed "object-based" neglect may be a behavior that is not specific for only a subgroup of neglect patients but might occur regularly in subjects suffering from spatial neglect. However, the recent report by Marsh and Hillis (2008) appears to contradict such assumption. The authors tested acute stroke patients for egocentric and object-based forms of neglect. They used a visual and a tactile variant of the test suggested by Ota et al. (2001), in which the patient is presented with a page of circles or triangles. Half of the stimuli had a gap on either the left or the right side. Egocentric neglect was demonstrated by a failure to mark the stimuli situated on the contralesional side of the sheet of paper, whereas allocentric object-based neglect was documented by a failure to detect contralesional gaps on both sides of the sheet. Nineteen stroke patients showed spatial neglect in the visual modality. Seventeen of these patients (89%) demonstrated egocentric visual neglect, and four patients (21%) met the criteria for object-based visual neglect. Only two patients (11%) showed both egocentric and object-based neglect.

Our present results do not argue against the possibility that stroke patients with spatial neglect indeed may exhibit neglect relative to only one frame of reference, that is, either an object-based or egocentric reference frame. In comparison with the 19 patients studied by Marsh and Hillis (2008), the present study investigated only a small sample of three neglect patients. However, the behavior of these patients was documented with high resolution by recording eye and head position using the search coil technique. It remains an issue of future research to study the pattern of eye and head positions that patients with spatial neglect generate when performing a task of the type created by Ota and colleagues (2001). Is it possible that a distribution of horizontal gaze positions comparable with the one observed in the present study underlies the patients' performance in such a paper-and-pencil task as well?

In conclusion, our present findings demonstrate that object-based neglect varies with egocentric position. Along the five egocentric object positions, the neglect of the objects' left side was strong at contralesional egocentric positions and ameliorated at more ipsilesional egocentric positions. This pattern of gaze positions during object exploration was well described, on the level of saliency of targets, as a multiplication of shifted bell curve on the egocentric part and a linear gradient on the object-based part, as predicted by the ISO-map model. The present data may, thus, indicate that visual input is coded in egocentric and object-based coordinates simultaneously and that egocentric and object-based neglect may constitute different manifestations of the same disturbed system.

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