

NOTE

EVIDENCE FOR AN INDEPENDENT STIMULUS-CENTERED SPATIAL REFERENCE FRAME FROM A CASE OF VISUAL HEMINEGLECT*

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INTRODUCTION

The computational literature suggests that several different reference frames relative to which the location of objects is specified may be required for proper visual function (Feldman, 1985; Marr, 1982; Marr and Nishihara, 1978; Monk, 1985). Most conceptualizations will concur with the following description: A viewer-centered spatial representation is one that defines the location of objects relative to the subject himself, and which therefore changes with every movement of the observer. In contrast, an environment-centered representation specifies the location of objects relative to one another — e.g. x is above y — and thus is not affected by movements of the observer. Finally, an object-centered representation is a volumetric internal model of an object and is independent of its location relative to either the viewer or the other stimuli in the environment.

The study of patients with visual hemineglect appears as quite appropriate to investigate the levels of spatial representation which are used by human vision. In general, patients with visual hemineglect behave as if the contralesional part of the stimulation does not exist, in that they fail to attend to it (De Renzi, 1982; Freidland and Weinstein, 1977; Hécaen and Angelergues, 1963; Heilman, 1985; Kinsbourne, 1987; Roy, Reuter-Lorenz, Roy et al., 1987). This syndrome has been attributed alternatively to either a defective attention system preventing the orientation of attention to the part of a spatial representation that corresponds to contralesional space (Heilman, 1985; Kinsbourne, 1970; 1987; Mesulam, 1983; Morrow and Ratcliff, 1988; Riddoch and Humphreys, 1987; Roy et al., 1987) or to a damaged spatial representation (Bisiach and Berti, 1987; Bisiach, Capitani, Luzzatti et al., 1981; Ogden, 1985). At present, these two views appear equally viable since disorders of attentional or representational mechanisms are both plausible causes for the failure to attend to contralesional items. Whichever the case may be, experiments with neglect cases may be profitable in the study of spatial representations since these appear to be implicated, directly or indirectly, in the occurrence of neglect symptoms.

In previous reports, authors have been able to dissociate the effects of the target location within subject-centered and environment-centered reference frames by having the subjects view the displays that were presented with their head either upright or tilted to one side (Calvanio, Petrone and Levine, 1987; Farah, Brunn, Wong et al., 1990; Lādavas, 1987; Lādavas, Del Pesce and Provinciali, 1989). These experiments have shown that neglect may affect the processing of items in the contralesional parts of both viewer-centered and environment-centered spatial reference frames. Also, Caramazza and Hillis (1990a; 1990b) reported a neglect dyslexic patient in which only a word-centered spatial reference frame — analogous to an object-centered representation — was neglected. These demonstrations that neglect may affect the processing of locations within a particular re-

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ference frame when tested in isolation is evidence that corresponding representations are being used by the human visual system. Moreover, they also indicate that many levels of spatial representation may be affected in visual hemineglect — either in isolation of in various combinations in any particular subject — and, by extension, that the allocation of visual attention across space in normal individuals may be performed on all of the spatial reference frames mentioned here.

One question that needs further clarification concerns the specification of the reference frame(s) relative to which the spatial coordinates of objects within the environment are computed. As indicated above, an environment-centered representation is assumed to define the location of objects relative to one another. But certainly, not all visible objects may serve at the same time as reference points to localize all the others. More probably, within a particular spatial representation, there is, at any given moment, a single reference relative to which other objects are localized. As far as an environment-centered representation is concerned, two candidates, which are not mutually exclusive, may be considered.

One is that observers use features of their surroundings which may be considered stable (e.g. the walls in a room) as the reference frame relative to which other objects are localized. Such a reference may be important for representing a stable environment which is not affected by the movements of the observer. This is the type of environment-centered reference frame that has been isolated in the study of neglect patients by having the subjects tilt their head on one side (Calvanio et al., 1987; Farah et al., 1990; Lādavas, 1987; Lādavas et al., 1989).

Another candidate for an environment-centered representation, which is distinct from the previous one, is that the reference frame may be task-dependent, in that it is based not on stable landmarks in the surroundings but rather on the spatial extent covered by the stimulation which is relevant to the task to be performed at a given point in time. In such a representation, which may be referred to as stimulus-centered, the location of an item is defined as a function of its position within the area occupied by the stimulus ensemble which is relevant to the subject's task. Take for example a task in which subjects are required to process a pair of stimuli aligned horizontally. In this case, the stimulus-relative location of, for instance, the left item is invariant wherever the pair of stimuli is presented relative to the observer or to stable environmental landmarks. We wish to emphasize that the concept of a stimulus-centered spatial representation discussed here is separate from that of an object-centered description, which depicts the spatial relations between the *parts of a single object*. Thus, it is assumed that a stimulus-centered reference frame represents the relative locations of *spatially distinct stimuli* and that it refers exclusively to visible surfaces rather than to a truly volumetric representation of the environment (i.e. in Marr's (1982) terms, the 3D sketch).

The notion of a stimulus-centered spatial representation has been the subject of theoretical discussions before (Caramazza and Hillis, 1990b) and the construct has been used by Riddoch, Humphreys, Cleton et al. (1990) to account for the performance of a neglect dyslexia patient they studied. However, no systematic attempt to provide independent evidence for this type of spatial representation has yet been reported. The aim of the experiment presented here is to conduct a test of the hypothesis that a stimulus-centered spatial representation may be affected by visual hemineglect, and by extension, that it contributes to normal human vision.

To this end, a patient with visual hemineglect was examined with the aid of a visual filtering paradigm which required her to name a target letter presented within a horizontal array of constant configuration. Distractors were filled circles. It was assumed that this task provided a direct measure of the allocation of visual attention across space¹, in that the less attention was allocated to the location at which the target was presented, the more time it would require to respond to it. Five neurologically intact controls were also tested.

¹ The use of the concept of attention allocation is intended to remain neutral as to the hypothesized nature of the primary impairment that may underlie neglect symptoms. As mentioned, this question is presently a matter of debate, with some authors suggesting that neglect results from defective attentional mechanisms while others hold the position that it is due to a faulty representation of space.

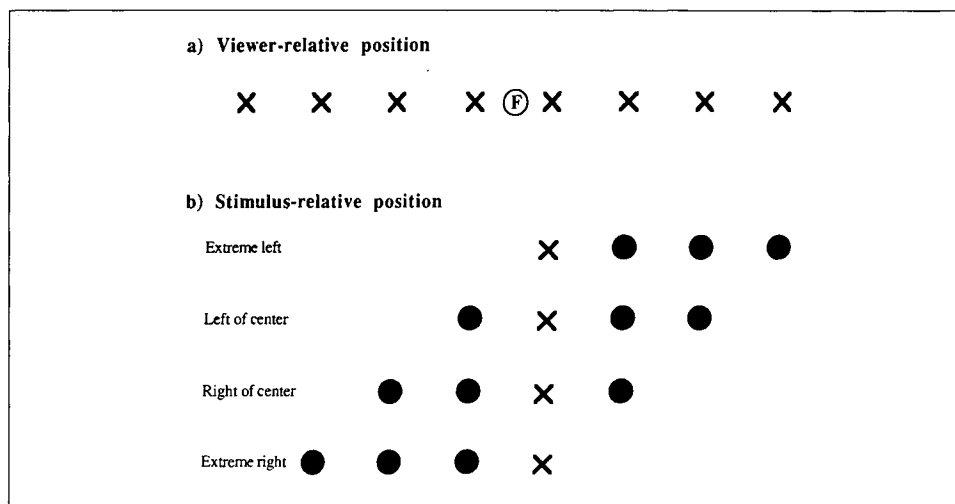


Fig. 1 – (a) Set of possible locations (X) occupied by the target relative to the central fixation point (F). (b) Set of possible locations occupied by the target within the stimulus array. All these within-array locations were tested at each possible target location relative to the fixation point.

The location of the target was varied according to two orthogonal factors (Figure 1). One was the position occupied by the target within the stimulus array (stimulus-relative location). The other was the location occupied by the target relative to stable landmarks in the environment (e.g. the edge of the screen), and also relative to the subject's body and point of ocular fixation — i.e. subjects always sat upright and straight in front of the display screen and the location at which the fixation point was displayed on the screen was kept constant throughout the experiment. For convenience, this latter factor will be called viewer-relative target location. It should be kept in mind however that the location of the target relative to the observer and to stable landmarks in the environment were confounded within this factor. To dissociate these two effects would have required to test the patient while lying on her side, which was not possible within the physical constraints of the testing situation. What is of primary concern here however is that the stimulus-relative factor be truly independent of any other variable which may affect the definition of the location of the target. This independence was achieved here by testing each level of the stimulus-relative location factor across all levels of the viewer-centered factor.

MATERIALS AND METHOD

Subjects

The patient tested (B.A.) was a 79 year-old right-handed woman. She showed EEG evidence for a right parietal lesion, and brain-damage was of vascular origin. She showed normal visual fields on confrontation and a strong left visual neglect. The latter was clearly apparent in a search task requiring the selection of multiple occurrences of a target (a bell shape) presented on a sheet of paper along with other depicted objects (Gauthier, Dehaut and Joannette, 1989). Neglect was also apparent in visual search tasks (longer RTs for contralesional stimuli) and B.A. showed a disorder of disengagement of visuo-spatial attention similar to that reported by Posner, Walker, Friedrich et al. (1987). Finally, evidence for left neglect was also apparent in daily life. In particular, she fre-

quently bumped into objects and doorframes that were located to her left and often ignored persons approaching her from the left. Five right-handed neurologically intact subjects were used as controls.

Apparatus and Stimuli

The experiment was run on a Macintosh Plus microcomputer and response times were recorded to the nearest millisecond. A microphone, linked to the computer, was used as a voice-key to register the verbal response that was required on each trial.

Target stimuli were the consonants B, C, J, K, P, T, V, and Z. On each trial, a single target letter was randomly chosen from this set. Letters were 6.2 mm high and 4.1 mm wide. With the target, three distractors were presented. There were filled circles of 4.1 mm in diameter. Preceding the stimulus array, a fixation dot (4.1 mm in diameter) was presented at the center of the display screen for a duration of 1.5 sec. Subjects were instructed to keep their eyes fixated on this point as long as it was visible, but that after the onset of the search array they could freely move their eyes. All stimuli were white and shown on a black background.

The search stimuli were always displayed as a horizontal array of four equidistant items. The distance separating consecutive items in the array was of 1 cm. The location of the target relative to the central fixation point (viewer-relative location) was varied independently of the location of the target within the stimulus array (stimulus-relative location). Thus, the target could be presented in any of the eight locations illustrated in Figure 1a. Each of these potential target locations was separated from the other by a distance of 1 cm. Moreover, for each of the possible target locations relative to the fixation point, the target location within the stimulus array could be any of the four illustrated in Figure 1b. The stimuli remained visible until the subject responded.

Procedure

The task required subjects to name the target letter as rapidly as possible while avoiding errors. Two factors were involved in this experiment. Those were the location of the target relative to the fixation point (eight levels; viewer-relative location) and the location of the target within the four-item array (four levels; stimulus-relative location). These two factors were orthogonal in that each level of one factor was tested equally often across all the levels of the other. The main dependent variable was response time (RT).

For each subject, the experiment was run in seven separate blocks of 64 trials each. One or two blocks were run in each testing session for B.A. while each control subject was run in a single session of seven blocks. An equal number of trials of each condition was distributed randomly in each block. Subjects were seated at approximately 30 cm from the display screen and always viewed the displays with their heads upright. Some of the trials were eliminated due to failure of the subject's verbal response to trigger the microphone. This happened on 1.6% of the trials for B.A. and on 2.0% of the trials for the normal controls. These were not considered in the data analyses.

RESULTS

Figure 2 shows the mean correct RTs observed in the control subjects (Figure 2a) and in B.A. (Figure 2b) in each of the conditions of the present experiment. Only a single error was made by B.A. in the entire experiment while control subjects made an overall average of 0.27% errors. None of the analyses performed on error rates showed any significant effect.

A two factor analysis of variance for repeated measures was performed on the correct RTs seen in the normal controls. This analysis showed only a main effect of the viewer-relative target location ($F=5.0$; $d.f.=7, 28$; $p<0.001$). The main effect of the stimulus-relative target location ($F<1$, $d.f.=3, 12$) and the interaction of this factor with the viewer-relative target location ($F=1.4$; $d.f.=21, 84$; $n.s.$) were not significant. The main effect

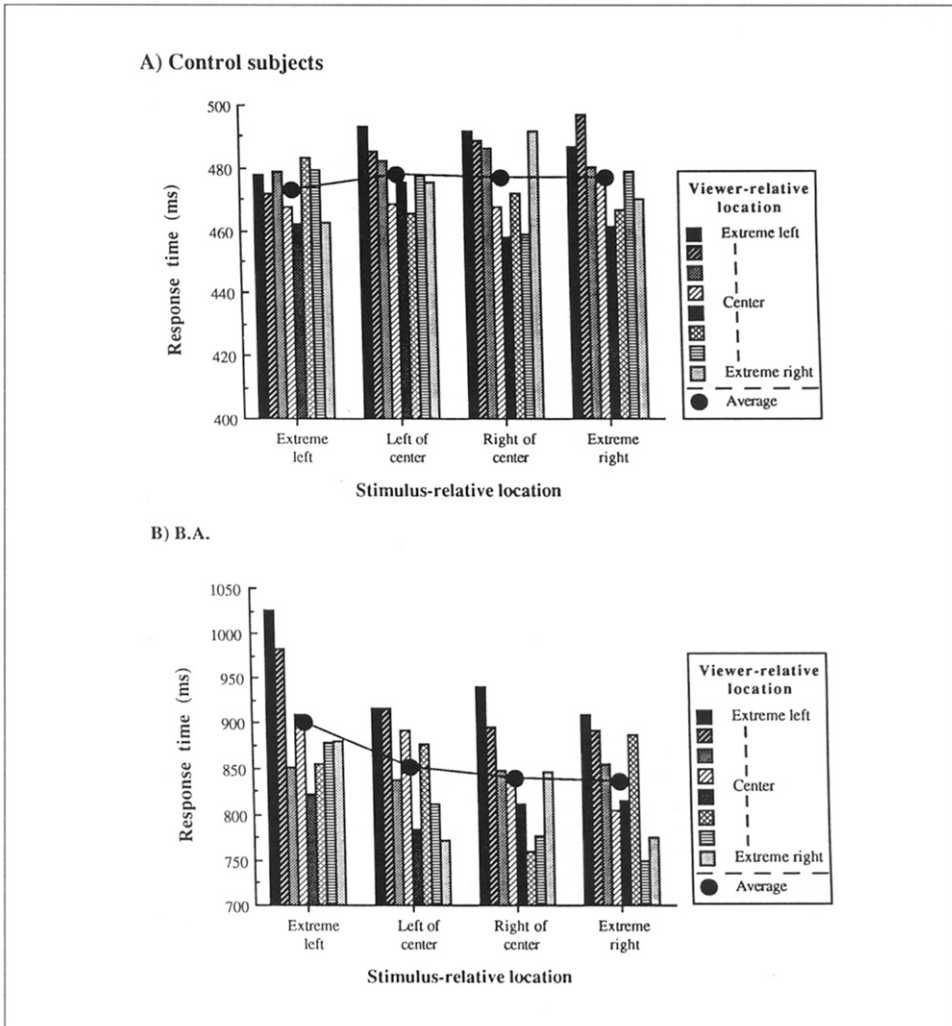


Fig. 2 – RT data from the present experiment. The histograms represent the average RTs observed in the normal controls (a) and in B.A. (b) in each of the conditions. Superimposed over the histograms is a line graph illustrating the RTs, averaged over the different levels of the viewer-centered factor, for each level of the stimulus-centered target location factor. Note that the scale of the vertical axis is markedly different in these two graphs.

of the target location relative to the observer seems to relate to the retinal eccentricity of the target, with possibly a weak left hemisphere superiority in performing the letter naming task. Thus, RTs increased in a very regular fashion with increases in the distance between the target and the fixation location (Figure 2a). It also appears that responses to targets presented to the right of the fixation point were faster than to those presented to the left, but this difference was rather small (average RT difference of 10 ms).

The RTs observed in B.A. were analyzed with a two-factor ANOVA for independent measures — each trial was considered as independent from the others. This analysis indicated main effects of viewer-relative ($F=5.2$; $d.f.=7, 408$; $p<0.001$) and stimulus-relative target location ($F=3.3$; $d.f.=3, 408$; $p<0.05$). No trend which might suggest an

interaction between these two factors was observed ($F < 1$, $d.f. = 21, 408$). As can be seen in Figure 2b, the main effects of subject-relative and stimulus-relative target location both indicate increasing RTs with leftward target displacements.

An interesting aspect of the results emerged in an examination of standard deviations of the patient's RTs across conditions. Thus, a strong positive correlation ($r = 0.98$; $p < 0.05$) was observed between her average RTs and the standard deviations of RTs across the levels of the stimulus-relative target location factor. By contrast, no such correlation was observed for the viewer-relative target location factor ($r = -0.41$; *n.s.*). A relationship between average RTs and standard deviations of RTs was not as readily apparent in the normal control subjects. Thus, the correlations of average RTs to standard deviations were of 0.13 (*n.s.*) and of 0.68 (*n.s.*) across the levels of the viewer-relative and stimulus-relative factors, respectively.

DISCUSSION

The results observed in the normal control subjects were affected very little by the spatial location of the target both relative to the fixation point and relative to the distractors in the stimulus array. Thus, only the viewer-relative target location factor significantly affected their RTs and this effect was rather weak. As indicated earlier, RTs increased with increases in the distance between the target location and the central fixation point. It appears that this effect may most likely be accounted either by a slowed letter identification with increased retinal eccentricity of the target or by an increase in the time necessary to foveate the target if it is more distant from fixation — subjects were free to move their eyes after the onset of the stimulus array.

The observations obtained from the neglect patient studied here contrasted markedly with those of the normal controls. One point in B.A.'s results which should be discussed first is the main effect of the viewer-relative target location factor. As illustrated in Figure 2b, this effect indicated that the more to the left the target was located relative to the fixation point, the longer the RTs were, and, by implication, the less attention they were allocated. The precise origin of this effect cannot be specified however. Indeed, as pointed out in the introduction, the effect of viewer-relative target location can be attributed to either of two reference frames relative to which the target could be localized and that were confounded in this factor. Thus, as the level of the viewer-relative target location was varied, both the location of the target relative to the observer and to stable landmarks in the environment were changed. Since it is not possible to pinpoint the origin of the effect of the viewer-relative factor in the present results, it will not be discussed any further.

Three other aspects of B.A.'s results are more informative. First and foremost, the significant main effect of stimulus-relative target location showed increasing RTs with leftward target displacements within the stimulus array. We take these increased RTs for targets located in the left part of the stimulus array as an indication that less attention was allocated to these locations than to those on the right of the array. Given that the experimental design used here allows an independent assessment of the effect of the target location within a stimulus-centered spatial reference frame, this result leads to the following two conclusions. First, it indicates that this level of representation may be affected in the visual hemineglect syndrome and therefore contribute to the patient's failure to attend to contralesional stimulation. Note here that we do not wish to make any claim as to the generality of such an impairment in neglect cases since, as the literature on the topic suggests, different levels of spatial representation may be impaired in different patients. Second, given the assumption of universality (e.g. Caramazza, 1986), which holds that findings about the cognitive architecture of an individual may be generalized to others, we may extend our conclusion about the particular subject we studied to normal individuals. Thus, we suggest that the concept of stimulus-centered reference frame corresponds to a level of spatial representation that is generally used in human vision and that such a reference frame may serve to guide attention toward specific spatial locations in neurologically intact individuals.

In further support for the hypothesis of an independent stimulus-centered spatial representation, a second interesting aspect of the results observed in B.A. is that no trend was observed for an interaction between the factors of the viewer-relative and stimulus-relative target location factors. This lack of interaction indicates that the effect of target location within the stimulus array was not markedly affected by its location relative to the subject or relative to a stable landmark in the environment. From this, we suggest that the attention gradient observed here as a function of target location within a stimulus-centered reference frame provides an additive — i.e. independent — contribution to the magnitude of the neglect symptoms in our patient.

Thirdly, one last important aspect of the present results in B.A. is the significant positive correlation between mean RTs and the dispersion of RTs across trials within each of the levels of the stimulus-relative target location factor, which was not seen on the viewer-relative factor. Above, it was concluded, on the basis of mean RTs, that less attention was allocated by our patient to the leftmost part of a stimulus-centered spatial reference frame. The correlation observed between RTs and standard deviations on this factor suggests that not only are RTs higher for targets in the left part of the stimulus array, but also that they are more variable from one trial to the next. In turn, this suggests that the amount of attention allocated to the leftmost part of the stimulus-centered representation varies more from trial to trial than the amount of attention allocated to the rightmost part of this representation. Given this, we propose that the effect of the stimulus-relative target location on the RTs observed in B.A. may result from a variation in the probability with which each of the locations within the array is readily attended. Thus, it appears that the assumption of a lowered probability of attention allocation to the leftmost part of the stimulus array can explain the longer RTs observed for this location, as well as the increased variability of those RTs. We further suggest that this result may relate to the tendency of many neglect patients to have their attention attracted to the ipsilesional part of a stimulus array (see for instance Chédru, Leblanc and Lhermitte, 1973) and to their difficulty in disengaging their attention from there and then shift it to the contralesional part of the array (Mark, Kooistra and Heilman, 1988; Morrow and Ratcliff, 1988; Posner, Walker, Friedrich et al., 1984, 1987).

In contrast to the results relating to the stimulus-relative factor, no evidence for a left-right gradient in the stability — or instability — of attention allocation across trials was apparent in B.A. on the viewer-centered factor. Thus, across the different levels of this latter factor, no correlation was observed between average RTs and their standard deviations. This dissociation suggests that, over and above the structural separability of the stimulus-centered spatial representation from other reference frames, this representation may also be functionally separable, in that the attentional processes that are applied to it seem to differ. Thus, while the level of attention allocation as a function of the lateral location of the target relative to the patient or to stable visual landmarks seemed stable across trials, instability in this respect was observed as a function of the target location within the stimulus array.

What is the origin of this variability of attention allocation to the leftmost part of the stimulus-centered representation across trials? One possibility, which unfortunately does not hold up to scrutiny, is that of spatial priming of locations within the stimulus-centered representation from previous trials. For example, it is conceivable that more attention may be allocated to a target presented in the left part of the stimulus array when the target location within the array on the previous trial was on the left than when it was on the right. To investigate this possibility, correlations between RTs for each stimulus-relative target location and the location of the target within the stimulus array on the previous trial were calculated. This analysis failed to show any relationship between RTs to targets at a given location within the stimulus array and the stimulus-relative location of the target on the previous trial — correlations were of 0.07, -0.10, 0.04, and 0.00, for the leftmost, just left of center, just right of center, and rightmost target locations respectively. It therefore appears that spatial priming was not a factor in the increased RT variability for targets on the left of the stimulus-centered representation.

To summarize, the experiment reported here used a filtering paradigm with a patient suffering from visual hemineglect in order to determine whether a stimulus-centered reference frame contributes to the human visuo-spatial representation system. Results re-

vealed that the location of the target within a four-stimulus array significantly affected the patient's performance — with longer RTs for a target located to the left of the array — and that this effect was independent of the target location relative to the central fixation point. These observations are taken as an indication that visual hemineglect may affect attention allocation within a stimulus-centered spatial reference frame. By extension, it is concluded that one level of spatial representation in human vision is based on the relative locations of the stimuli that are relevant to the task to be performed, independently of their locations relative to the subject or to stable environmental landmarks.

ABSTRACT

Previous experiments with patients suffering from visual hemineglect have provided evidence relevant to the organization of the human spatial representation system. We examined the hypothesis that one reference frame used to represent the location of objects in the environment is based on the spatial extent of the stimulation that needs to be processed at a specific point in time; in current terminology, a stimulus-centered reference frame. The paradigm used was one of filtering, and variation of the location of the target within a horizontal array of items (stimulus-relative location) was independent of the target location relative to the subject and to stable reference points in the environment. Results showed that stimulus-relative target location provided an independent contribution to the magnitude of the neglect symptoms. This is taken as an indication that a stimulus-centered spatial reference frame contributes to the representation of the location of visual objects in human vision and that this representation may serve to direct visual attention.

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