Brief communication

Pseudoneglect in back space

Gianna Cocchini, Rosamond Watling, Sergio Della Sala, Ashok Jansari

Department of Psychology, Goldsmiths’ College, University of London, UK
School of Psychology, University of East London, UK
Human Cognitive Neuroscience, Psychology, University of Edinburgh, UK

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Abstract

Successful interaction with the environment depends upon our ability to retain and update visuo-spatial information of both front and back egocentric space. Several studies have observed that healthy people tend to show a displacement of the egocentric frame of reference towards the left. However, representation of space behind us (back space) has never been systematically investigated in healthy people. In this study, by means of a novel visual imagery task performed within a virtual reality environment, we found that representation of right back space is perceived as smaller than the left. These results suggest that there is a selective compression or distortion for mental representation related to the right space behind us.

Keywords: Pseudoneglect; Neglect; Back space; Representation

1. Introduction

Right-brain damaged patients showing unilateral neglect bisect horizontal lines to the right of the real mid-point (Heilman, Watson, & Valenstein, 1993). Healthy volunteers show a similar, even if less dramatic, bias in bisecting horizontal lines but in the opposite direction, i.e. towards the left (e.g. McCourt, Garlinghouse, & Reuter-Lorenz, 2005). This phenomenon, known as pseudoneglect (Bowers & Heilman, 1980; see Jewell & McCourt, 2000 for a recent review), suggests that representation of the egocentric mid-sagittal plane is deviated towards one side, and it cannot be accounted for by inaccuracies of visual perception (see e.g. Matin, 1986). Information related to healthy volunteers’ performance on spatial tasks has been directly or indirectly (i.e. healthy volunteers acting as control group for brain damaged patients) assessed, and it has been investigated by means of different methods: asking participants to align a rod with their mid-sagittal plane (Richard, Rousseaux, Saj, & Honoré, 2004), to point straight ahead (Chokron et al., 2002), to judge location of acoustic stimuli (Lewald, 2002; Vallar, Guariglia, Nico, & Bisiach, 1995), to point or look towards the source of acoustic stimuli (Lessard, Paré, Lepore, & Lassonde, 1998; Lewald, 2002; Ruff, Hersh, & Pribram, 1981; Zwiers, van Opstal, & Cruysberg, 2001) or to indicate the mid-point between two acoustic stimuli (Ruff et al., 1981). However, most of these studies focussed on the representation of the space in front of us and very little is known about the representational space behind us (back space).

Farnè and Làdavas (2002) observed that acoustic stimuli presented in the back ipsilesional space of brain injured people can induce extinction of tactile stimuli applied on the patients’ contralesional side of the neck. Interestingly, tactile extinction was significantly more pronounced when the acoustic stimulus was delivered in the back rather than front space, and when the acoustic source was closer to the patient’s head. These results suggest that information from the back space is actively integrated in a more general representation of space extending along the three dimensions.

Our understanding of how the back space is represented can be inferred only from very few studies assessing the
processing of acoustic stimuli sources in patients with neglect and healthy volunteers (e.g. Vallar et al., 1995). When healthy volunteers were asked to locate acoustic stimuli in the front and back spaces, they tended to show a small displacement of the sagittal plane (around 7–9 degrees; standard deviation is not reported) towards the left side in the back space, while the displacement was negligible in the front space. The outcome suggests that healthy people tend to show a relatively mild shift of the sagittal plane selectively for the back space and towards the left hemispheres.

The aim of the present study was to assess directly how healthy people represent their left and right back space by means of a novel visual imagery task performed within a virtual environment.

2. Method

2.1. Participants

Twenty-two healthy volunteers (11 females and 11 males), whose mean age was 29.9 ($SD = 7.1$; range = 20–45) and mean level of formal education was 14.9 years ($SD = 1.3$; range = 13–18), took part in the experiment. They were all right-handed. Handedness was assessed asking which hand they usually use to write, draw, hold a fork, or press a key-button. Participants included in the study unequivocally stated that they used the right hand in at least three of these tasks.

2.2. Procedure and material

The study was conducted in the Virtual Reality Laboratory available in the School of Psychology, University of East London. The VR-based experiment was constructed using World-Up software and was run on a Duel Xeon PC using two LCD projectors (one displaying the left image and one displaying the right image) to project a stereoscopic image. Participants were comfortably seated 110 cm from a large screen where 3D stimuli were projected (see Fig. 1). They were asked to wear a pair of polarized glasses in order to induce the 3D effect. A simple drawing of a white and red ball (about 10 cm in diameter and five visual degrees wide) rolled around in a large virtual circle.

Fig. 1. Experimental paradigm. Example of clockwise condition: estimation of right back space.
(approx. 2.70 m in diameter), against a background showing a 3D empty room. The participants were located in the centre of the imaginary virtual circle. The ball appeared spherical and it rolled along the floor of the virtual room forming a semi-circle at eye level (i.e. at about 1 m from the real floor). They were facing either the right or the left border of the large screen (see below for description of conditions) and were looking at the starting point, having the entire screen on their left or right side, respectively. The participants were asked to look at the starting point straight ahead where a stationary ball was visible. As soon as they pressed a key-button with their right hand, the ball started rolling. While the ball was moving, the participants were asked to maintain the fixation point at the starting position where a white cross (4.5 cm high and wide), initially placed behind the stationary ball, remained visible until a new trial commenced.

No movement of eyes, head or body was allowed. A pilot study, during which eye movements were monitored by means of a mirror placed just below the screen, ensured that participants could easily maintain the fixation position. During the experiment proper the mirror was removed to avoid providing reflected visual information on other parts of the space. Participants were asked to report immediately whenever they felt that they moved their eyes so that the related trial could be excluded. Moreover, in all instances whereby the examiner (seated far behind the volunteer) observed that the participant moved their body or head, the relevant trial was dropped from the analyses and the participant’s egocentric co-ordinates were re-aligned.

In the back-right condition, the starting point was on the left side of the screen, and the ball moved clockwise, from left to right, around the virtual circle. After having covered approx. 80 degrees of the circle (i.e. falling in the right visual field) the target reached the right border of the screen and disappeared. Participants were instructed to visualize the target going around in a circle, imagining the back right side of the path, and to press a key (a large button they held on their lap) with their right hand as soon as they thought the target should have reached their back midline, (i.e. the point on the circle placed exactly behind them at 180 degrees from the starting position). The screen then became blank and a new trial started. No feedback was given.

In the back-left condition the target moved anticlockwise, from right to left. The participants were looking at the right starting point and asked to imagine the left trajectory at the back of the virtual circle.

Since the target was visible whilst moving across the front space, no estimation of front space was required. In both conditions, the speed was constant within trials but it changed randomly across different trials. This was clearly stated in the participant’s instructions. Following the outcome of a pilot study, the speed of the ball was set at between 10 and 15 seconds to cover 180 degrees.

Participants were explicitly instructed to use a visual imagery strategy. However, to avoid a counting strategy, they were asked to shadow single digits (from 1 to 9 randomly presented) that they heard through stereo headphones during both the conditions. Latencies between digits varied randomly between 1 to 3 s.

Sets of 10 trials for each condition (back-right and back-left) were balanced within participants following the ABBBA scheme, and the order of presentation was counterbalanced across participants. Each participant was given a total of 40 trials (20 for each condition) plus 4 run-in trials, one at the beginning of each 10-trial set.

The dependent variable was the latency between the first key-press (ball starts to move) and the second one (subject’s estimation of ball reaching the back midline). The latency represented the participant’s estimation of the time required by the target to move from the starting position to their back midline (i.e. to run 180 degrees along the virtual circle).

2.2.1. Preliminary phase

Before starting each condition, participants were asked to fixate the ball located in its starting position (left for the back-right condition and right for the back-left condition) and to report if they could see, in peripheral vision, the opposite border of the screen (i.e. where the target would disappear). All participants entered in the experiment reported seeing the opposite border. This means that all participants could see the target for the entire visible trajectory in the front space.

In order to induce as much as possible the impression of being in the centre of a circle, before starting the experimental phase, each participant was asked to run a few practice trials in which the target reappeared at about 350 degrees from the starting point, giving the impression to complete the virtual circle. It was clearly stated that in the experimental phase the ball was not going to reappear.

3. Results

The mean speeds of the target for right and left back conditions were 12.27 s ($SD = .40$; range $= 11.5–12.8$) and 12.26 s ($SD = .42$; range $= 11.6–12.8$), respectively.

A participant (no. 12) had to be excluded since he reported having changed his strategy and mental representation of the circle during the experiment. For each of the remaining participants and each trial the subject’s time estimation was compared with the real time that the ball required to cover half a circle (i.e. 180 degrees). As the target speed varied across trials, real time varied accordingly (i.e. the faster the target, the shorter the real time). Were participants’ data reliable, a positive correlation between the real time and the subjective estimation would be expected. Negative correlations or positive correlations lower than the arbitrary cut-off of $r = .35$ in one or the other condition (back-right or back-left) indicated that the participant’s data were not sufficiently reliable. Two
participants (nos. 6 and 17) showed very low correlations ($r = .06$ and $r = -.19$) in one condition and one participant (no. 15) in both conditions ($r = -.18$ and .22). Data from these three participants were then excluded from further analyses.

For the remaining eighteen participants the percentage of discrepancy (ERR%) between real time and the subjective estimation for each trial was calculated according to the following formula:

$$\text{ERR\%} = \frac{\text{Subjective estimation} - \text{Realtime}}{\text{Realtime}} \times 100$$

where ERR% = 0 indicates perfect estimation without error; ERR% > 0 indicates overestimation; ERR% < 0 indicates underestimation.

ERR% at two standard deviations from the participant’s mean were excluded. No more than one value was excluded for each volunteer in each condition.

ERR% were entered in a one-way (gender) ANOVA. No significant effect of gender was found ($F < 1$). Fig. 2 shows that participants were quite accurate in estimating the left back space (ERR% mean = 0.66; SD = 19.59) but they underestimated the right back space (ERR% mean = -7.66; SD=19.77). An ANOVA with repeated measures (left versus right) demonstrated that this difference was highly significant ($F(1, 17) = 24.6; p < .0001$), suggesting that the right back space was perceived significantly smaller than the left back space. Moreover, the group %ERR standard deviations for the right- (i.e. clockwise) and left- (i.e anticlockwise) conditions were very similar (i.e. mean = 9.31 SD = 4.68 and mean = 9.30 SD = 4.68, respectively), and the analysis established that the difference of .01 was far from significance, confirming the similarity of error variance in estimation ability across the two conditions.

However, the group mean reflected different individuals’ tendencies for the left and right back space to overestimate or underestimate (see Fig. 3). Five participants (nos. 1, 2, 5, 10, and 20) underestimated the right space and overestimated the left space; three participants (nos. 3, 8, and 16) overestimated both spaces but more the left one; seven participants (nos. 4, 7, 9, 13, 14, 21, and 22) underestimated both spaces but more the right space; two (nos. 11 and 19) overestimated both spaces but more the right one; finally one participant (no. 18) underestimated both spaces but more the left one.

Because of this difference in individuals’ tendencies to generally over- or under-estimate the hemispaces, we calculated the subjective difference between the two left and right back spaces. For each participant we subtracted the left ERR% from the right ERR%. According to this procedure, values equal to zero indicate that right and left back spaces are perceived as having the same size; negative results indicate that the right space is perceived smaller than the left space; while the opposite is true for positive results (regardless of the individual’s general tendency to over- or under-estimate). Fig. 4 shows the individual and the group mean differences between right and left spaces. Fifteen out of eighteen participants (83%) perceived the right back space smaller than the left, and the right back space was perceived by the entire group as 8.32% (i.e. right ERR% – left ERR%) (SD = 7.12; range = from −19.91 to +1.54) smaller than the left. Individual t-test analyses were run on left and right ERR% of the fifteen participants who perceived the right back space as smaller than the left. For 11 participants the right back space was significantly ($p < .05$) smaller than the left. Only three participants (nos. 11, 18, and 19) perceived the left back space slightly smaller than the right (differences = 0.9%, 1.2%, and 1.5%, respectively) but individual differences between ERR% for right and left spaces were far from significant in all instances.
Finally, a correlation between the individual estimation ability (i.e., the average coefficient between real and estimated time of both conditions) and the degree of the effect (i.e., right-left ERR%) proved to be far from significant ($r = .138$), suggesting that general estimation ability could not predict performance in right or in left space.

4. Discussion

Our findings suggest that most (83% of our sample) healthy people represent the right space behind them as smaller than the left. The difference between the two hemispatial representations of back space as derived from acoustic stimuli, the subjective asymmetry between left and right back space, would be due to a displacement of the sagittal plane. In Vallar et al.’s (1995) paper, healthy volunteers showed a shift of the sagittal plane of about 7–9 degrees towards the left. Such sagittal plane displacement cannot account for the data of the current study for a number of reasons. First, the right-left subjective difference in our study was about 14 degrees, nearly twice the displacement of the sagittal plane observed by Vallar and colleagues. Of course this discrepancy could reflect a difference in the methods used. However, further considerations make an alternative account plausible. If the sagittal plane is deviated towards one side, this side should be underestimated in our task, as the trajectory to be covered from the starting point to the subjective deviated mid-point would be shorter. The opposite pattern (i.e., overestimation) should be observed for the other side. Therefore, a displacement of the sagittal plane towards the left would predict (a) that the left hemispace should be perceived smaller than the right, and (b) that a “mirror effect” of over-estimation should be observed for the right space. Both predictions mismatch with the current data. Indeed, the right, not the left, space was underestimated in our task, as the trajectory to be covered from the starting point to the subjective deviated mid-point would be longer. However, the right underestimation was not coupled with an overestimation of the left. On contrary, the participants were able to estimate the left side quite accurately. This finding converges with evidence from the literature that no or minimal shift of the sagittal plane has been observed (e.g., Vallar et al., 1995), and that, when this shift was observed, it occurred towards the left rather than the right, suggesting that the hypothesis of a deviation of the mid-sagittal plane towards the right is rather unlikely. Therefore, an underestimation of the right side seems the best account for the left-right asymmetry observed. Of course these data do not exclude the possibility of a concomitant presence of a sagittal plane displacement towards the left, which, though, would attenuate the underestimation of the right back space rather than inducing it.

Alternatively, the asymmetry reported here may reflect a different representation of the hemispheres per se. As the “perceived border” (i.e., sagittal plane) between left and right back spaces overlaps with the real one, or it is mildly shifted towards the left and the target appeared to travel faster when reaching this border when travelling through the right side, it derives that the right back space was perceived as smaller (distorted or more compressed) than the left back space. Heilman, Jeong, and Finney (2004) observed that “objects that receive more attention appear to have a greater magnitude than objects that received less attention” (p. 1995). Therefore, since each hemisphere attends primarily to the contralateral space, and since the right hemisphere plays an important role in spatial processing, it is reasonable to assume that the right space may receive “less attention”, and being perceived as smaller, i.e., compressed. Moreover, this asymmetrical attention hypothesis cannot be reduced to a general effect of the hand used to respond. Indeed, Jewell and McCourt (2000) found that the use of the right hand (as in our study) tends to rebalance the hemispheric asymmetric activation rather than enhancing it. Moreover, the average error variance of estimation was in our study very similar across the two conditions (right- and left-back space), making it hard to account for our findings in terms of a different ability of the two hemispheres in performing the estimation task.

Further support for the compression hypothesis can be drawn from an effect known as representational momentum or forward displacement (FD). FD consists of a systematic error in judging the position of a moving target when it is no longer in view. The end position of a moving target tends to be shifted in the direction of the motion (Hubbard, 1995), regardless of the direction of movement (e.g., Hubbard & Motes, 2002). In our paradigm, the FD error would be translated in an underestimation, as the unseen moving target (in the back space) should be perceived closer to the end point (i.e., the participant’s mid-sagittal point). Interestingly, left-right asymmetry has been observed for FD, where displacement of target was significantly different from zero only with targets moving within the right visual field (e.g., Kerzel, 2003). However, White, Minor, Merrell, and Smith (1993) found that FD difference between right and left space faded away when the retention time was increased from 500 to 800 ms, suggesting that “memory distortion begins and fades more quickly in the LH [Left Hemisphere, i.e. right visual field] than in the RH [Right Hemisphere, i.e. left visual field]” (p. 168).

This interpretation does not, and does not intend to, account for the shift of the sagittal plane found by some authors with acoustic stimuli (Richard et al., 2004; Vallar et al., 1995). Whether or not our findings could be considered as evidence for a possible distortion of the imaged trajectory or for a more homogeneous compression of one side should be a matter for further studies. Finally, it is worthwhile mentioning that some data in literature suggest caution about this interpretation. Indeed, pseudoneglect effects in the front space vary with the distance from the individual (larger in peripersonal space and superior visual...
field than extrapersonal space and lower visual field, e.g. McCourt & Garlinghouse, 2000). Taken together these outcomes suggest a complex spatial representation, not necessary homogeneous and not necessary organised only around a left-right asymmetry.

The basic finding of our study is that for the first time clear evidence of pseudoneglect in the back space has been shown and that this phenomenon cannot be simply accounted for by a possible shifting of the sagittal plane or by a general error in monitoring the position of an unseen moving target in the imagery trajectory.

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References


