

ACCELERATION PERCEPTION AND SPATIAL DISTORTION IN A LEFT UNILATERAL NEGLECT PATIENT

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ABSTRACT

To explain relative leftward overextension in a line extension task by left unilateral neglect subjects, Bisiach et al. (1998) suggested that the representation of space is distorted – i.e., dilated towards the left side. If perception of the velocity of a moving stimulus is due to a calculation of the distance covered per unit time in representational space, then a stimulus with uniform linear motion should be perceived as decelerating when moving leftwards in the visual field of a subject with left unilateral neglect.

We investigated the perception of acceleration in a patient with left unilateral neglect and spatial distortion (revealed as relative left overextension in a line extension task) using a task in which the stimuli were right and left moving targets with variable acceleration. The patient's ability to perceive acceleration was much lower (higher acceleration threshold) for leftward movements than rightward movements. Fourteen months later unilateral neglect had improved, and the relative left overextension and decreasing acceleration threshold for leftward movements were reduced. By contrast, alterations in the perception of acceleration for leftward movements were not found in a patient with left unilateral neglect and left underextension and in a patient with right brain damage and left hemianopia.

These findings in one patient with left spatial unilateral neglect and a relative left overextension in a line extension task are consistent with the hypothesis that representational space is distorted, with a disproportionate leftward expansion, that affects perception of movement.

Key words: unilateral neglect, motion, acceleration detection, spatial distortion

INTRODUCTION

Several models, proposed to explain performance in line bisection or landmark tasks (judging how well a pre-bisected line has been bisected; Milner et al., 1993) by subjects with left unilateral neglect, invoke the idea that egocentric perceptual space is distorted (Irving-Bell et al., 1999; Kerkhoff, 2000). Milner (1987) proposed non-uniform distortion that increased from right to left; more specifically Halligan and Marshall (1991) proposed that perceptual space was increasingly compressed towards the left.

A distortion of perceptual space also explains the performance of neglect subjects in endpoint and extension tasks. In the endpoint task, the subject has to position the two ends of an imaginary line either side of a given point. The length of this line is equal to that of lines previously bisected. In this task, neglect patients have a significant tendency to place the left end further from the centre than the right end; and this has been interpreted as a progressive expansion of representational space on the left side (Bisiach et al., 1996).

In the extension task, the subject is presented with half a line and is asked to complete it towards the left or right (Ishiai et al., 1994). An extensive study by Bisiach et al. (1998) examined left and right extension in patients with left unilateral neglect. They found relative left overextension in most, but not all, patients which was interpreted as

consequence of a distortion of representational space (anisometry), such that the representational medium is compressed toward the right and dilated toward the left (see Figure 1). In anisometric space a unit length is perceived as shorter in the left than in the right hemisphere.

However not all authors accept that spatial distortion characterizes subjects with left spatial neglect. Karnath and Ferber (1999) found no evidence of compression or expansion of space in left unilateral neglect patients asked to judge the horizontal length of objects of varying length placed in the right and left hemispaces. Furthermore Doricchi and Angelelli (1999) showed that hemianopia was a crucial factor in determining whether space distortion was evident in the extension task. Geminiani et al. (2002) found that left hemianopia was particularly important but that left overextension was only clearly evident when left hemianopia was associated with left spatial neglect.

The hypothesis of this study is that a distortion of representational space will affect perception of the velocity of moving stimuli. If the representation of space for stationary and moving stimuli is the same, and the perception of velocity is achieved via calculation of the distance covered by the stimulus in perceptual space per unit time, then an object moving with uniform velocity should be perceived as accelerating by a subject with left unilateral neglect and spatial distortion if moving from left to right and decelerating if moving from right to left

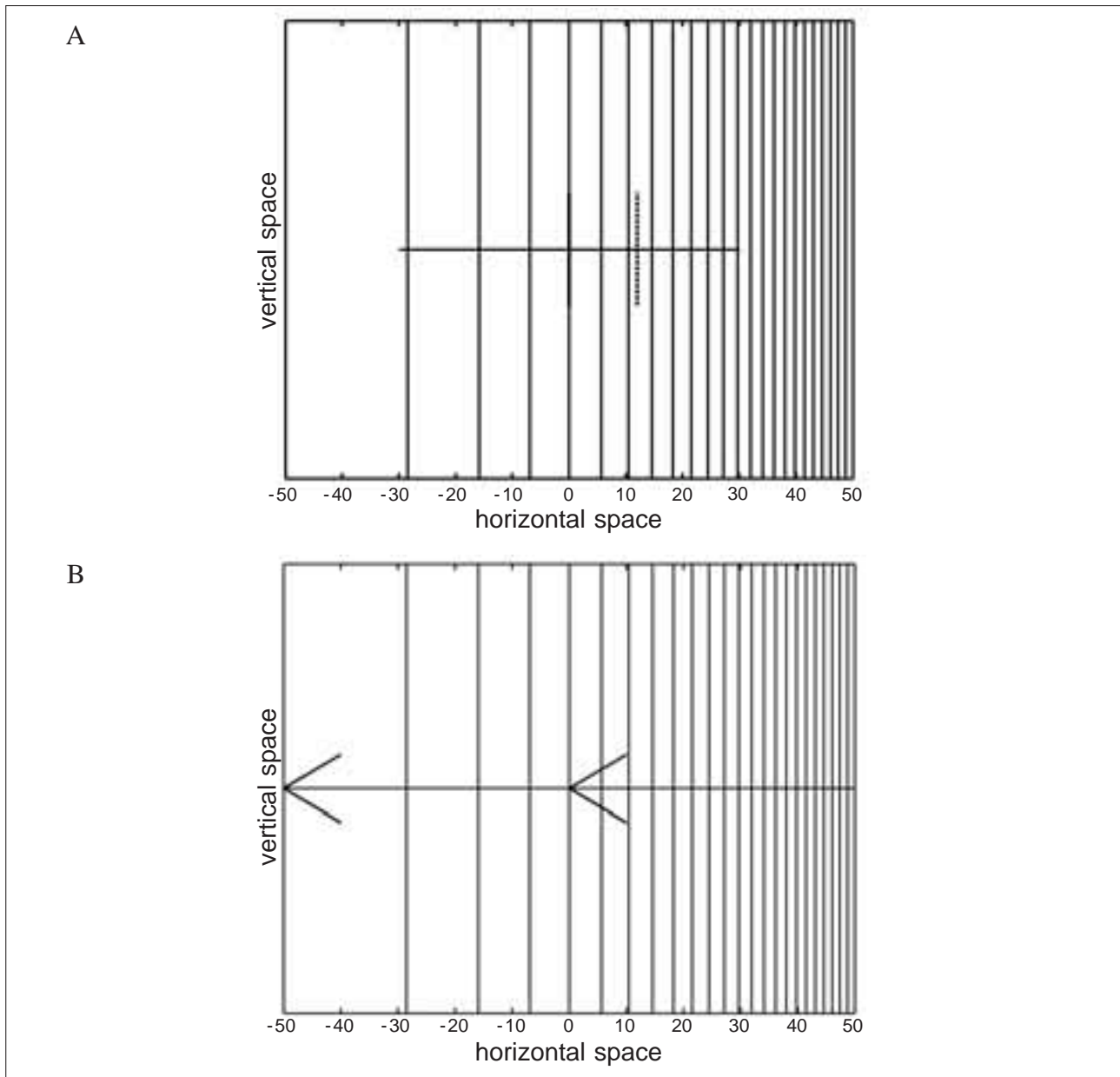


Fig. 1 – In patients with left neglect, the left-right anisometry of the representation of space causes (A) a rightward error in the line bisection task and (B) a perceived deceleration for a constant velocity target proceeding from right to left: the target covers progressively fewer perceptual units.

(Figure 1). We investigated this hypothesis in a patient with left unilateral neglect who also had perceptual distortion, as revealed by overextension in the line extension task, by analysing performance in an acceleration perception task. We also investigated a patient with left unilateral neglect and underextension in the line extension task and a patient with right brain damage and left hemianopia with a mild left unilateral neglect in line bisection, but no asymmetry in the extension task.

METHODS

Patient FZ was a 74 year-old, right-handed man with five years of education. He suffered ischaemic stroke affecting the right temporo-parietal areas

(Figure 2) a month prior to investigation, during which he presented clinical signs of left unilateral neglect and left hemianopia, but no cognitive deterioration [Mini Mental State Examination. (MMSE) = 24] (Folstein et al., 1975). Fourteen months later the patient was re-tested.

Patient VA was a 72 year-old, right-handed woman with three years of education. Two weeks before the assessment, the patient had suffered an ischaemic stroke affecting the right fronto-temporo-parietal areas and the right basal ganglia; she had clinical signs of left unilateral neglect and left hemianopia, but no cognitive deterioration (MMSE = 24).

Patient RE was an 80 year-old, right-handed man with eight years of education who had suffered an ischaemic stroke in the right thalamus

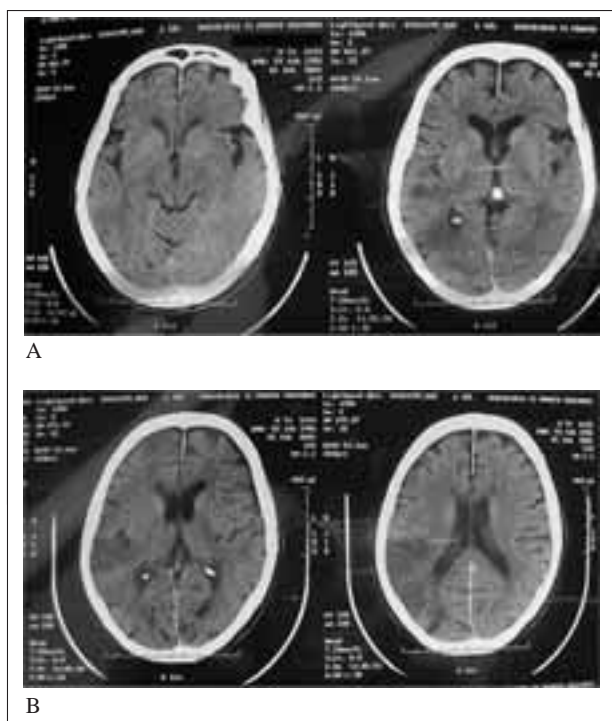


Fig. 2 – CT scan of patient FZ.

and the right internal capsule a month before the investigation. He had left hemianopia, but no clinical signs of left unilateral neglect or mental deterioration (MMSE = 28).

Nine age-matched healthy controls (5 men, 4 women; mean age 69.7 years, s.d. 6.3; mean education 9.1 years, s.d. 6.3), with a MMSE score above 26 were also tested. All patients and controls gave their informed written consent to testing.

Neuropsychological Assessment

Five tasks were performed to assess spatial neglect: four to determine the presence of left unilateral neglect, and the line extension task to determine the presence of spatial distortion.

1. *Line bisection task.* Ten horizontal lines 18 cm long and 1.5 mm thick, each at the centre of a sheet of A4 paper, were presented to the patient who had to indicate the midpoint of each line with a pencil in the right hand. Displacement from the true midpoint was measured to the nearest millimetre, with a negative sign indicating deviation to the left of centre and a positive sign indicating deviation to the right of centre. An average error to the right of at least 18 mm (10% of the length of the line) was considered a sign of left unilateral neglect.

2. *Diller letter H cancellation test.* (Diller and Weinberg, 1977). The patient's task was to cross out 104 uppercase "H" letters (4-mm high), printed in six horizontal lines on a 42 cm × 30 cm sheet, 53 on the left and 51 on the right-hand side. The targets were interspersed among 208 distracters

(letters). The score was the number of omissions on the left- and right-hand sides of the sheet. The omission of four more letters on the left than on the right was considered a sign of left neglect (Pizzamiglio et al, 1989).

3. *Drawing a clock-face from memory.*

4. *Copying* two daisies, a vase of flowers and a chandelier with three branches. In the latter two tests, omission of at least one detail from the left part of the drawing was considered a manifestation of left neglect.

5. *Line extension task.* Ten horizontal lines 75 mm long and 1.5 mm thick, each on a separate sheet of A4 paper, were presented. Each sheet was placed in front of the patient centred on the body midline. The preferred hand (ipsilesional) was used to hold the pencil. Five lines to be extended to the left were positioned on the right side of the paper with the left end in the centre; five lines to be extended to the right were positioned on the left side of the paper with the right end in the centre. The patient had to extend the line from the centre of the sheet to a length double that of the original line. For each extension drawn the error in millimetres compared to the required extension of 75 mm was measured to the nearest mm, with a positive sign indicating overextension and a negative sign indicating hypoextension. The average left extension and average right extension were calculated. The ratio of the average left extension to the average right extension was also calculated.

Acceleration Perception Task

Apparatus and Stimuli

The stimulus or target was a 0.3 cm-diameter red spot on a black background displayed on an 11 inch computer screen (60Hz non-interlaced raster refresh rate) connected to a notebook computer. The target could originate either on the left side of the screen (11.03 deg on the left of the screen centre) and move horizontally to the right, or appear on the the right side (11.03 deg on the right of the screen centre) and move horizontally to the left always in the screen midline. The path length was 19.5 cm (22.06 deg). The target had one of six constant accelerations (a_i): -1.91 cm/sec^2 , -1.07 cm/sec^2 , 0 cm/sec^2 , 1.32 cm/sec^2 , 2.87 cm/sec^2 , 4.67 cm/sec^2 . Thus, there were two negative accelerations, a constant velocity and three positive accelerations. The equation of motion for the target is $V(t) = V_0 + a_i t$, where V is the velocity of the target, V_0 the fixed initial velocity (10.78 cm/sec; 12.31 deg/sec), and t the time. For convenience the accelerations were expressed in terms of the proportional change in velocity (Weber fraction), i.e. $[V_{\text{final}} - V_{\text{initial}}]/V_{\text{initial}}$. The Weber fraction values corresponding to our accelerations were: -0.4 , -0.2 , 0 , 0.2 , 0.4 , 0.6 respectively.

Procedure

The subject sat about 50 cm from the screen, which was centred on the body midline, in a quiet room with dim lighting. Head and eyes were unconstrained. Each trial began with the display of a geometric figure (triangle, square or cross) on either the left or right side of the screen. The subject was asked to identify the figure as an attention test. If the identification was correct, the experimenter went ahead with the trial. After a 500 ms interval, an 800 cps tone signalled the immediate appearance of the moving target on the screen. The target appeared at the same position as the geometric figure, and immediately started moving horizontally towards the other side of the screen, to then disappear off the edge of the screen.

The subject was asked to say whether the stimulus was accelerating or decelerating. No other response was accepted. Judgments were given verbally to prevent motor impairments from influencing responses.

After an introductory explanation by the experimenter, a familiarization phase began in which four accelerating (all of acceleration 0.6 Weber fractions) and four decelerating (all of acceleration – 0.4 Weber fractions) targets were presented in pseudorandom order. After judging the acceleration, the subject was informed whether the response was correct. If the response was incorrect that trial was repeated once only. Subjects unable to complete the familiarization phase did not proceed with testing.

In the subsequent testing phase each combination of motion direction (leftward and rightward) and acceleration was presented 10 times in random order. Thus there were 120 trials, which were presented in blocks of 12 trials. About 45 minutes were required to complete the session. On request short breaks between trials were allowed.

Data Analysis

For each subject and motion direction the probability distribution of the “accelerating” responses was analysed by a probit model of maximum likelihood. This analysis adapted the cumulative normal curve of each patient’s data to a set of forced-choice data. From the parameters of the curve the acceleration threshold and acceleration standard deviation were calculated. This acceleration threshold is the point corresponding to 50% probability that the subject will say the target is accelerating, it corresponds to the point of subjective equality between positive and negative acceleration, or the point of perceived constant motion. For each subject, the difference between the thresholds for leftward and rightward motion was calculated (threshold difference). This is an index of the magnitude of the distortion of perceived acceleration.

The acceleration standard deviation is the standard deviation of the normal function, and corresponds to the slope of the cumulative normal curve. The larger the standard deviation, the lower the ability to discriminate between accelerating and decelerating stimuli. For each subject the standard deviations for the leftward and rightward motions were calculated.

Acceleration, acceleration threshold and acceleration standard deviation were expressed as Weber fractions.

RESULTS

Table I shows the results of the tests for unilateral neglect in the three patients and the controls.

All test results for patient FZ indicated left unilateral neglect, and the line extension task indicated the presence of spatial distortion as shown by the leftward overextension and positive large leftward extension/rightward extension ratio. Figure 3 shows patient FZ’s copy of a chandelier showing elongation of the left part of the stimulus.

Patient VA showed left unilateral neglect and leftward underextension, while patient R.E.’s test results revealed slight rightward deviation in line bisection, and no spatial distortion in the line extension task.

The psychophysical curves for target movement to the left and to the right in the horizontal acceleration perception task are shown in each patient and for the control group in Figure 4.

Table II shows the acceleration thresholds and standard deviations for target movement from right to left and left to right, with threshold differences and standard deviations.

We considered the normal range for acceleration threshold as the mean value for the control group ± 2 standard deviations with cut-offs of 0.485 and – 0.315 for leftward acceleration and 0.365 and – 0.195 for rightward acceleration.

Patient FZ’s leftward acceleration threshold (0.896) was over ten times greater than the mean acceleration threshold for controls and was well beyond the cut-off of 0.485. His rightward acceleration threshold (0.130) was slightly greater than the group mean, but within the normal range. The threshold difference (leftward threshold minus rightward threshold) for FZ was well beyond the cut-off of 0.204. The standard deviations of the cumulative distribution curves for patient FZ were higher than for patient RE and the controls.

Patient VA’s leftward and rightward acceleration thresholds were lower than those of FZ and controls, and her rightward threshold (– 0.258) was beyond the lower cut-off; however, her acceleration threshold difference was virtually zero. For patient RE, leftward and rightward acceleration thresholds, threshold difference and standard

TABLE I
Baseline Neuropsychological Assessment for Spatial Unilateral Neglect in Patients FZ, RE and VA, and in the Control Group

	Patient FZ		Patient VA	Patient RE	Controls (N = 9)
	First assessment	Follow-up			
Diller test*	8-5	0-0	26-7	1-1	2-3
Line bisection**	24.3 (6.8)	10.4 (7.2)	13.6 (16.6)	5.9 (3.6)	0.8 (2.3)
Drawing task***	+	+	+	-	-
Copying task***	+	+	+	-	-
Leftward extension (LE)****	89.6 (12.2)	59.4 (5.2)	40.0 (23.7)	78.4 (7.8)	79.0 (3.8)
Rightward extension (RE)****	45.7 (5.2)	44.0 (4.2)	71.7 (15.7)	71.6 (5.9)	77.8 (3.7)
LE/RE	1.96	1.35	0.56	1.09	1.02 (0.06)

*number of omissions on left-number of omissions on right

**rightward displacement, mean of ten bisections in mm (SD)

*** + = left side omissions, - = no omissions

**** mean of five extensions in mm (SD)

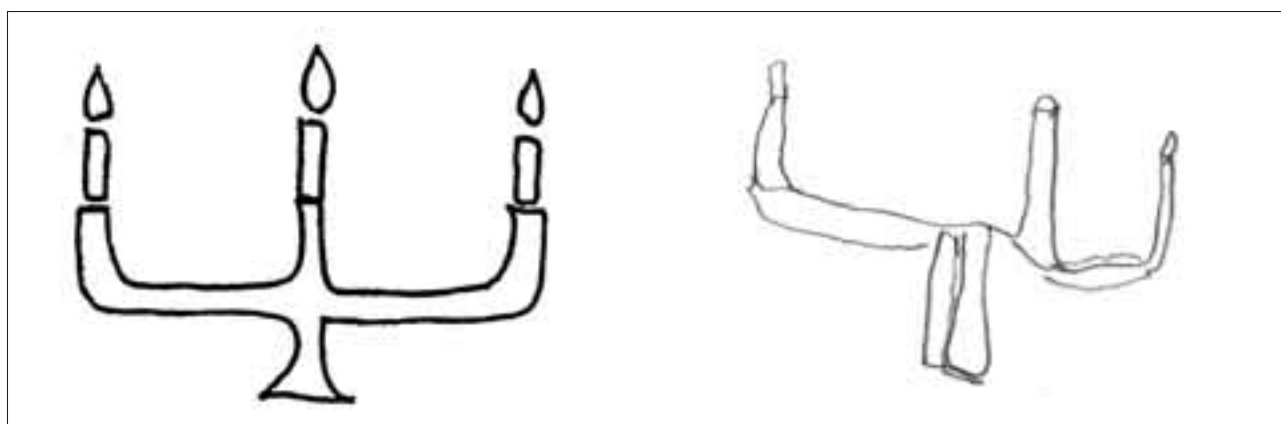


Fig. 3 – Patient FZ: copying a chandelier; the left drawing is the model.

deviations of the cumulative curve were all within the normal range.

When FZ was re-examined 14 months later his left unilateral neglect had improved: he showed no errors in the Diller letter cancellation test, while his performance in the line bisection, drawing and copying tasks indicated persistence of left unilateral neglect. In the line extension task relative left overextension was still present, though reduced, compared to the first assessment. In the acceleration perception task, the patient's leftward acceleration threshold was still well above the cut-off, but slightly lower than in the first assessment (0.789 vs. 0.896); by contrast, the patient's rightward acceleration threshold was now greater than in the first assessment (0.562 vs. 0.120) and above the cut-off of 0.365. The threshold difference was smaller than in the first assessment (0.227 vs. 0.776), though still above the cut-off.

DISCUSSION

Patient FZ showed a left unilateral neglect with spatial distortion as revealed by left overextension in the line bisection task. In the acceleration

perception task FZ had a threshold for perception of acceleration that was much higher than that of controls for targets moving to the left. FZ's threshold for the perception of acceleration to the right was also slightly higher than that of controls, but within two standard deviations from the control mean. Furthermore, in this patient the large difference between the two thresholds for the two directions indicates that he perceived targets moving from right to left as decelerating.

By contrast, patient VA with left neglect showed left underextension (LE/RE ratio < 1) in the line bisection task, suggesting a spatial distortion in the opposite direction. However, patient VA showed no clear left-to-right spatial distortion in the acceleration perception task. In fact, she had negative acceleration thresholds, but only the rightward threshold was beyond the lower cut-off: this finding would suggest a spatial distortion in the *same* direction as in patient FZ. On the other hand, there was no difference between leftward and rightward motion: this last finding suggests that VA perceived targets moving both from right to left and from left to right as accelerated, as in centripetal spatial distortion. Bisiach et al (1998) suggested that leftward

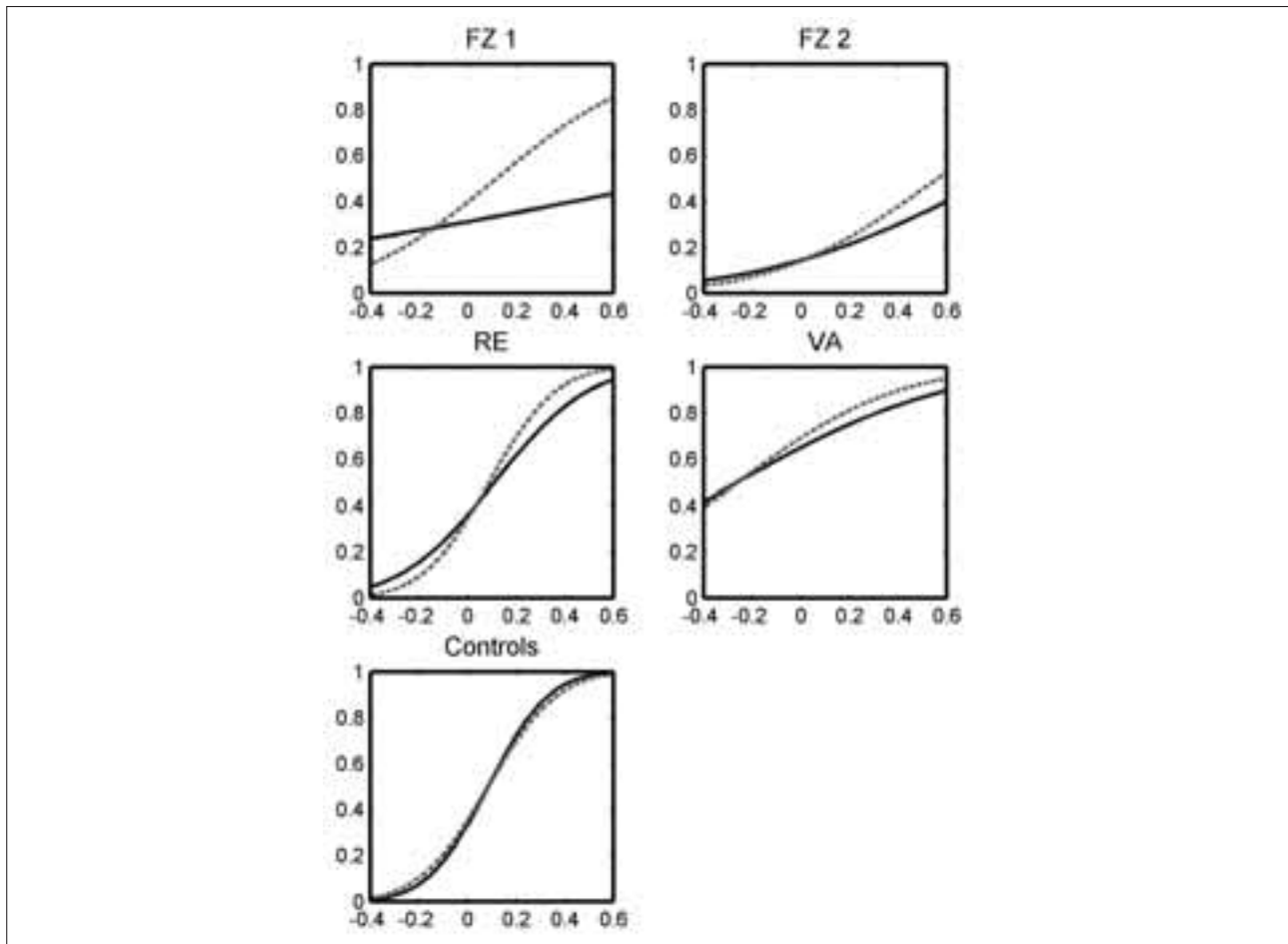


Fig. 4 – Curves of the psychophysical function of the acceleration perception task in patients FZ (FZ 1 = first assessment, FZ 2 = follow-up), RE, VA, and control subjects.

The abscissa represents the stimulus acceleration rate, the ordinate the acceleration responses (expressed as percentages), the continuous line leftward motion, the dashed line rightward motion.

TABLE II
Acceleration Threshold, Threshold Difference, and Standard Deviations for the two Motion Directions, in Patients FZ (First and Follow-up Assessment), VA and RE, with Mean Scores (SD) for Controls

	Acceleration threshold			Standard deviation	
	leftward	rightward	difference	leftward	rightward
Patient FZ					
first assessment	0.896	0.120	0.776	1.817	0.454
follow-up	0.789	0.562	0.227	0.741	0.519
Patient VA	-0.260	-0.258	0.002	0.681	0.521
Patient RE	0.111	0.089	0.022	0.306	0.218
Controls					
mean	0.085	0.085	0.000	0.197	0.224
(s.d.)	(0.200)	(0.140)	(0.102)	(0.048)	(0.054)

underextension in left unilateral neglect is compatible with the contra-intuitive hypothesis of extreme overrelaxation of the representational spatial medium towards the left; however, the lack of asymmetry in VA's performance in the acceleration perception task does not support Bisiach et al's hypothesis.

Patient RE had right hemisphere damage. He presented left hemianopia and a mild left neglect in line bisection, but no spatial distortion in the line extension task; his performance in the acceleration perception task was indistinguishable from that of

controls. In particular, the difference between the leftward and rightward acceleration thresholds was minimal. This finding suggests that, by itself, left hemianopia cannot explain the large difference between the rightward and leftward acceleration thresholds found in patient FZ. It should be also noted also that in the line extension task, patient FZ had an LE/RE ratio close to 2 (Table I), indicating marked spatial distortion, whereas for patient RE this ratio was close to 1 indicating no spatial distortion. These data are in agreement with previous finding from our laboratory (Geminiani et

al., 2002) that left overextension in the line extension task characterises patients with left unilateral neglect and left hemianopia.

Another important finding of this experiment was the high standard deviation of the psychometric curves in the neglect patients (FZ and VA). This suggests a reduced ability to discriminate between accelerating and decelerating stimuli, as expected when the spatial medium is damaged. Nevertheless, patient FZ's acceleration judgements for leftward motions were not haphazard, but mostly that the acceleration was negative (deceleration).

At follow up, FZ's left unilateral neglect and relative leftward overextension had diminished; however his LE/RE ratio remained well above control values. His leftward acceleration threshold and the acceleration difference were also reduced, as one would expect given his improved performance in the extension task indicating reduced spatial distortion. An unexpected finding was that the patient's rightward acceleration threshold had increased well above the cut-off.

Our findings in patient FZ seem to be in contrast with those of previous studies of motion perception in unilateral neglect, which report that both the motion perception threshold and the perception of motion direction are normal in patients with neglect (Spinelli and Zoccolotti, 1992). This contrast can be resolved considering the proposal of Cavanagh (1992) that there are two motion perception systems: a lower-level pre-attentive system and a higher-level system that requires attention processes. Lesions of the inferior parietal lobe typically give rise to neglect (Vallar and Perani, 1987); recent studies suggest that the parietal lobe is also involved in the perception of movement (Raymond, 2000). Battelli et al. (2001) reported a deficit in the perception of apparent motion (a higher-level motion task) in patients with right parietal damage. The present acceleration judgment may be considered a higher-level motion task, while perception of moving gratings is likely to be a lower-level task.

There is evidence the perception of motion and the perception of stationary patterns interact (Giese, 1999). Also findings from patients with neglect support this view. Dunai et al. (1999) report that objects moving towards the contralesional space improve left neglect. Pizzamiglio et al. (1990) and Mattingley et al. (1994) found that leftward movement of background improves the performance of patients with left neglect in line bisection. Kerkhoff et al. (1999) found that slow leftward background motion occurring during a psychophysical size judgment task reduces the left side underestimation of the length of horizontal bars in patients with left neglect.

There are various interpretations of our findings. They are consistent with the hypothesis that the representation of space in left spatial

neglect patients is anisometric (Bisiach et al., 1998). However, they are also compatible with any perceptual spatial distortion hypothesis that predicts underestimation of the size of unit lengths on the left of egocentric space, compared those on the right. It is important to note that perceptual spatial distortion can be due to alterations in spatial attention, and that there is evidence that spatial attention plays a role in the perception of visual motion (Raymond, 2000).

An alternative explanation of our finding invokes a distortion in the perception of the duration of the target stimuli. Basso et al. (1996) investigated time perception in both hemispheres of a left unilateral neglect patient. They found that the patient persistently overestimated the duration of stimuli in the left hemisphere. This implies that constant velocity stimuli going from right to left are perceived as slowed and further implies an increased acceleration threshold for right to left movements – such as found in our patient FZ. However, such an explanation is less parsimonious than that supposing a distortion in space, in that it does not explain the performance of patient FZ (and of many other neglect patients) in tasks such as line bisection and line leftward overextension.

We did not analyse eye movements during the acceleration perception task, while it is possible that the cerebral processes concerned with eye movements may influence the model of perceptual space. In particular, there seems to be a compression of perceptual space in the direction of the saccadic movement immediately before that movement (Ross et al., 1997); and in patients with left spatial neglect there may be selective impairment of leftward ocular movements (Girotti et al., 1983). The resulting discrepancy between the position on the retina of the moving target (due to impaired leftward movement) and the anticipated position of the target (Duhamel et al., 1992) could give rise to a distortion of the perceived velocity. However, if patient FZ's impaired perception of acceleration in leftward moving targets were due to a deficit of leftward ocular pursuit we would have expected a tendency to perceive leftward moving stimuli as more accelerated, yet in fact we found the opposite.

We supposed at the outset that patients with left unilateral neglect would also have a reduced rightward acceleration threshold but this was not found in patient FZ. It has been suggested that the rate of spatial distortion in left unilateral neglect patients is not uniform but increases progressively from right to left (Milner, 1987); this would imply a tendency to perceive targets moving from left to right as accelerated, but this positive acceleration would be more evident at the beginning of the movement (on the left), reducing towards the end of the trajectory (on the right); such "reducing acceleration" could confuse the patient's judgement. Another possible explanation for this

unexpected finding may be that the small geometric figure the subject had to identify before the start of target motion has a cueing role. In our experiment the figure could have acted as a left-side cue for rightward moving stimuli, partially restoring the lesioned spatial representation; as a result, the performance of the perceptual system would be better in this experimental condition.

To conclude, we found an increased acceleration threshold for right-to-left motion in our left unilateral neglect patient FZ; however, we do not claim that all left unilateral neglect subjects will show a similarly increased threshold. In fact, patient VA had left neglect but no difference between leftward and rightward motion perception. This phenomenon probably occurs in the subgroup of neglect patients with spatial distortion, as revealed for example by relative left overextension in line extension tasks. Clearly, more extensive studies on the perception of acceleration in left unilateral neglect are required.

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