

Misprojection of landmarks onto the spatial map

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Abstract

It has been suggested that neglect patients misrepresent the metric spatial relations along the horizontal axis (anisometry). The “fabric” of their internal spatial medium would be distorted in such a way that physically equal distances appear relatively shorter on the contralesional side (canonical anisometry). The case of GL, a 76-year-old lady with left neglect on visual search tasks, is presented. GL showed severe relative overestimation on the left (contralesional) side on two independent tasks evaluating the metrics of her internal representation. A qualitatively similar pattern was found in two out of 10 other neglect patients who performed the second task. This behavior cannot be accounted for by the canonical anisometry hypothesis. Nevertheless, GL produced a relative left overextension (underestimation) when trying to set the endpoints of a virtual line given its midpoint (Endpoints Task). An interpretation of these results is offered in terms of a misprojection of relevant landmarks onto the internal representation without assuming distortion of its “fabric.”

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1. Introduction

A number of authors have suggested that neglect patients may misperceive the metrics of horizontal extents (“anisometry”: see e.g., Bisiach, Pizzamiglio, Nico, & Antonucci, 1996; Harvey, Kramer, & Gilchrist, 2001; Milner, 1987). In particular, Milner (1987) and Bisiach et al. (1996) proposed a model that can be described in terms of the following analogy. Consider the internal spatial medium as a rubber sheet onto which the visual world is projected. The system computes the distances between objects represented in the rubber sheet by quantifying the amount of rubber lying between the two objects. If the rubber sheet were compressed on the ipsilesional side and expanded on the contralesional side (“canonical anisometry”), distances on the ipsilesional side would be seen as longer with respect to physically identical distances on the contralesional side, because the former would contain more rubber than the latter.

The canonical anisometry hypothesis was directly tested on neglect patients by means of a number of

different tasks. For instance, Milner, Harvey, Roberts, and Forster (1993) asked their patients to compare the horizontal size of collinear segments, one on the left and the other on the right side (the Landmark Task; see also Harvey, Milner, & Roberts, 1995); Bisiach et al. (1996) required to set the endpoints of a virtual line given its midpoint alone (Endpoints Task); Bisiach, Ricci, and Neppi-Modona (1998) required to produce segments identical to a sample line, either to the left or to the right of it (Line Doubling Task); Doricchi and Angelelli (1999) required to perform the same task using gaps instead of lines (Gap Reproduction Task). Some left neglect patients showed the pattern predicted by canonical anisometry, i.e., they decided that the left of two physically identical segments was the shorter (Landmark), or produced wider extents on the left side (Endpoints, Line Doubling, and Gap Reproduction). However, other left neglect patients showed either no left–right unbalance or the opposite patterns, i.e., judged the right segment as the shorter or produced wider extents on the right side.

These latter cases would seem to be directly interpretable in terms of a “paradoxical anisometry”—the rubber sheet would be compressed on the contralesional

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side and expanded on the ipsilesional side. However, there are two problems with this interpretation.

A first problem is theoretical. Consider the rubber sheet analogy. It was suggested that distances are computed by quantifying the amount of rubber separating two points. When thinking of a plausible neural substratum, one might assume that the quantification of the rubber corresponds to “counting” how many neurons of an internal spatial map separate two points (Toraldo, 2003; see also Pouget & Sejnowsky, 1997). It is known from neuroanatomy and from neurophysiological evidence (see e.g., Rizzolatti, Gentilucci, & Matelli, 1985) that each hemisphere has, if anything, a higher number of neurons responding to the contralateral field/space. Therefore, the rubber sheet of the left hemisphere (spared by the lesion in left neglect patients) should be “denser,” or more compressed, on its right side. It is thus implausible to assume that a right hemisphere lesion can produce a neural imbalance in favor of the left side of space, as the hypothesis of “paradoxical anisometry” would imply.

A second problem is empirical. Results from the methods listed above cannot be straightforward interpreted in terms of anisometry, especially if they indicate paradoxical anisometry. For instance, a left neglect patient might select the right segment as the shorter on the Landmark Task not because he really perceives it as such, but because of a response bias towards the right side. Similarly a rightward bias on the Endpoints, Line Doubling, or Gap Reproduction tasks might be interpreted in terms of directional hypokinesia (see e.g., Heilman & Valenstein, 1979), without requiring anisometry.

To overcome some of those empirical limits, a new test has recently been developed (Toraldo, 2003). In the Distance Judgement Task (DJT for short), the subject is presented with two fixed reference points, one on the left and the other on the right side of a sheet. A third point (target) is presented whose position between the reference points varies across trials. The subject is asked to say how many steps separate the left reference point and the target point, given that the distance between the reference points is 100 steps. In a control condition the distance between the right reference point and the target point is to be judged. In this way the psychophysical function mapping the physical position of the target point to the subject’s response is obtained and the presence/degree of anisometry can be inferred. For instance, a patient who perceives left-sided extents as relatively smaller will perceive a target point lying *physically* midway between the reference points as if it were to the left of centre. Thus, he will judge the gap between left reference point and target point as less than 50 steps long (“underestimation”), and the complementary gap as more than 50 steps long (“overestimation”). (In this paper, the terms “overestimation” and

“underestimation” are used to refer briefly to the *experimental data*. They do not refer to the *hypothetical* deficits or characteristics of the internal representational processes.) Psychophysical plots were obtained separately for 32 normal subjects and five patients who showed neglect on standard visual search tasks. Two *left* neglect patients, AL and MB, showed a pattern compatible with canonical anisometry, i.e., they overestimated the right side. A third *left* neglect patient, DB, showed some trend in the same direction. Nevertheless, a fourth *left* neglect patient, BC, showed normal performance; furthermore, a *right* neglect patient (MN), showed signs of overestimation of the *right* (contralesional) side. In statistical terms, it was clear that MN did *not* underestimate the contralesional side. However, it was less clear whether his overestimation of the contralesional side could be considered as pathological. In fact, although MN’s spatial distortion parameter k' was out of the normal range, the confidence interval of k' overlapped it. In other words, the parameter instability was of comparable size to that of the (supposed) overestimation deficit, thus rendering a diagnosis uncertain.

The aim of this work is to present and discuss a case of statistically reliable overestimation of the contralesional side. Furthermore an estimation of the frequency of such a phenomenon will be done on grounds of a sample of 10 left neglect patients.

2. Case report

GL was a 76-year-old lady with 9 years of education. She previously worked as a florist. GL was born as a left-handed and was trained to use her right hand (10/12; Oldfield, 1971). She was admitted at the Neurological Ward of Ospedale Di Niguarda, Milano, with signs of acute left hemiplegia and hemianopia. A CT scan showed a right cortico-subcortical temporo-parietal ischaemic lesion. In a few days she recovered from left hemiplegia, which evolved as a mild form of alien hand syndrome, but not from left hemianopia, which remained stable on visual field examination (Bisiach, Cappa, & Vallar, 1983; score = 3). She showed no signs of language impairment. The tests reported in this work were administered from 13 to 32 days post-onset. GL’s “Mini-mental state” score (MMS, Folstein, Folstein, & McHugh, 1975) was 28/30 (day 26 post-onset).

2.1. Neglect assessment by visual search tasks

GL was administered with variants of Diller and Weinberg’s (1977) letter cancellation test printed on A4 (297 × 208 mm) sheets. She cancelled 1/54 targets on the left and 17/54 targets on the right (day 26). This left neglect pattern was confirmed on later administrations (day 29: L 5/54–R 16/54; day 32: L 1/53–R 11/51). GL’s

performance on these cancellation tests indirectly proved that she had relatively preserved visual acuity. In fact, GL could quickly find the targets among the distractors, all of which were 3-mm-high letters seen at normal reading distance. Tegnér and Levander's (1991) mirror-cancellation test was administered on day 28 by using A4 sheets printed with 24 randomly oriented lines, six in each of four spatial sectors (left, center-left, center-right, and right). While she cancelled all the lines in the direct view condition, she cancelled 0, 1, 2, and 1 lines (left to right) in the mirror condition. A visual search task that does not require hand movements was also administered (day 28). GL was presented with a matrix of 180 cells (6 rows \times 30 columns) printed on an A4 sheet whose major axis was horizontally oriented. Each cell contained a vertical trigram, which could be composed of either three letters ("distractor" trigrams) or two letters and one digit ("target" trigrams). GL was required to read aloud only the target trigrams (72 out of 180). Hand movements were forbidden. GL correctly reported 1/36 target trigrams from the left half of the matrix and 13/36 from the right half.

3. Distance judgment task

3.1. Method

The DJT was administered on day 28. A desk was placed in front of the patient, at reading distance. The plane of the desk was set perpendicular to the direction of the patient's gaze during fixation. The stimuli, A4 white sheets, were presented on the desk plane, with their major axis horizontally oriented. Each sheet was printed with three 6×20 mm vertical gray bars. A randomly chosen, 6.5 mm high, capital letter was printed 4 mm above each bar. The centers of the bars lay on the sheet major axis. The two lateral bars were printed in the same positions in all the sheets (250 mm apart, each 125 mm from the sheet center) and defined the reference space. The position of the third (target) bar along the reference space changed across trials. Twenty-four equispaced positions were used: 10, 20, . . . , 240 mm from the left bar. Prior to each trial, each of the three bars was pointed to by the experimenter and cued by asking the subject to report the letter printed above it. After that, GL was asked to say how many steps separate either the left bar and the target (Condition A) or the right bar and the target (Condition B), where 100 steps was the overall distance between the lateral bars (see Toraldo, 2003, for details). GL was not allowed to use her fingers as "landmarks" during the inspection of the stimuli. After the DJT, the patient's basic mathematical abilities were tested. She was asked to solve verbally 32 simple arithmetical problems such as $90 - 15$, 5×6 , $10 + 40$, $36 \div 4$, etc., and to choose the greater (or smaller) number

within 30 pairs of randomly chosen natural numbers within the range [0, 100].

3.2. Results and discussion

GL correctly solved 31/32 arithmetic problems and 30/30 numerical order problems.

The DJT data were analyzed by plotting the real position of the DJT target bar (horizontal axis in Fig. 1A) against the between-conditions mean response (vertical axis). From the plot, it can be seen how GL relatively overestimated distances on the left side. In fact, by projecting the physical midpoint of the reference space from the horizontal axis onto the vertical axis through the best fit curve (see dashed trajectory), a point misplaced to the right (i.e., upwards along the vertical axis) is found. In other words, GL "saw" the left of two physically identical gaps as larger. That this behavior is reliably outside the normal range can be understood by looking at the regression parameter k' (Toraldo, 2003). $k' = 0$ means no distortion, $k' < 0$ means relative overestimation on the left, $k' > 0$ relative overestimation on the right. The normal range for k' is $[-.052, .069]$. GL obtained a k' of $-.582$, with $[-.840, -.324]$ as confidence interval (CI). This means that GL would have perceived a bar placed 33.7 mm to the left of objective center [CI = [19.7, 45.5]] as exactly half-way along the 250-mm reference space.

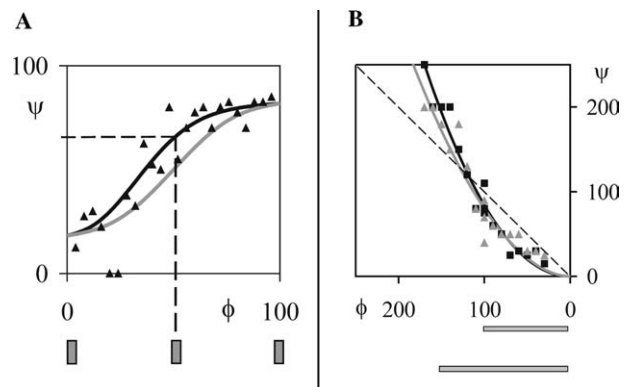


Fig. 1. (A) DJT results from GL. The horizontal axis is the physical position of the target bar between left (0) and right (100) bar. The vertical axis is GL's between-conditions mean numerical response. The best fit function is shown as a black curve; the gray curve is the performance that GL would have produced if she had no space misperception (the residual sigmoidal curvature expresses the effect of biases in the use of numbers). The points "dropped" onto the horizontal axis are responses that were inconsistent between conditions (see Toraldo, 2003, for details). (B) LJT results from GL. The horizontal axis reports the physical length of the target line (150 mm in the stimulus reported as an example below the plot). The vertical axis reports the numerical response by GL. The dashed line indicates the ideal performance ($i = 100$, $n = 1$); the black line is the best fit of the data (black squares) collected on day 13 ($i = 84$, $n = 2.06$); the gray line fits the data points (gray triangles) obtained on day 28 ($i = 79.9$, $n = 1.89$).

As patient MN (Torald, 2003), GL thus showed distance overestimation on the contralesional side. However, MN's degree of overestimation was only mildly outside the normal range (and unreliably, since his CI for k' overlapped the normative interval). By contrast, GL's degree of overestimation was well outside the normal range, and in a reliable way (her CI for k' did not overlap the normative interval).

4. Length judgment task

GLs internal spatial metric was also investigated by means of a test of relative length judgment (LJT), on two separate days (13 and 28). Seventeen subjects (six males, 11 females) without history of neurological disease were administered the same task to obtain a normative range (age: 61.9 ± 12.5 ; education: 8.6 ± 2.4).

4.1. Method

Eighteen A4 sheets were presented with the same procedure as specified for the DJT. Each sheet was printed with two horizontally oriented, 4 mm thick, gray lines (see, e.g., Fig. 1B, lower part). The right endpoints of the lines were vertically aligned, and were 50 mm from the right sheet border. The lines were 50 mm apart along the vertical dimension. The upper line ("sample") was 100 mm long in every sheet. The length of the lower line ("target") varied across trials from 30 to 170 mm, in steps of 10 mm. Each length was presented once, with the exception of length 100 (the stimulus in which the lines were identical and aligned on both endpoints) which was presented four times ("identity" trials). The stimuli were presented one at a time on the desk, in pseudorandom order. Before the first trial, subjects were informed that the right endpoints were vertically aligned in all the sheets, and that while the upper line remained identical across trials, the lower line varied in its length. On each trial, subjects were asked to point to the left endpoint of the upper line, and then to the left endpoint of the lower line, by using their right index finger. If they failed to do so autonomously, they were verbally encouraged by the experimenter till they reached both endpoints. After that, subjects had to judge the length of the lower line, given that the upper line was of length 100. Subjects were not allowed to use their fingers as "landmarks" during the comparison.

The numerical responses ψ (vertical axis) given by each individual were plotted against the physical length of the target line ϕ (horizontal axis), and were approximated by means of a nonlinear regression procedure. The power law $\psi = i(\phi/100)^n$ driven by the two parameters i and n was used as a general formula. Parameter i is the average number given by the subject on the "identity" trials ($i = 100$ in the ideal case). Param-

eter n drives the curvature of the power law. When no misperception of space is present, the function is linear ($n = 1$). In the case of relative overestimation on the right, the curvature is upward ($n < 1$); when the relative overestimation is on the left, the curvature is downward ($n > 1$). The normal range of each parameter was computed as $\text{mean} \pm 1.96 \times SD$ of the control sample. The standard deviation expressed the variability due to "true" individual differences, i.e., it was obtained by subtracting the average within-subject variability from the overall variability.

4.2. Results

GL had no difficulty in pointing to the left ends of target and sample. Fig. 1B shows the psychophysical plots for GL. She showed similar patterns on both sessions. She gave very variable responses on the identity trials, with a trend towards underestimation of the target line [day 13: $i = 84$; $CI(i) = [74.4, 93.7]$; day 28: $i = 79.9$; $CI(i) = [65.7, 94.1]$; normal range = $[92.2, 102]$]. In an extreme case, she judged the target as of length 40. GL showed very strong and reliable downward curvature on both sessions [day 13: $n = 2.06$; $CI(n) = [1.77, 2.35]$; day 28: $n = 1.89$; $CI(n) = [1.43, 2.35]$; normal range = $[.86, .96]$]. As can be seen in Fig. 1B, this means that GL consistently underestimated the length of targets physically shorter than the sample (30–90 on the horizontal axis) and overestimated the length of targets physically longer than the sample (110–170 on the horizontal axis).

4.3. Discussion

Although GL proved to be able to scan the whole of each stimulus pattern by correctly pointing to the left ends of both lines, she probably did not scan the whole pattern during the later comparison process. In fact, GL tended to underestimate the length of the target (lower) line on identity trials, a behavior that cannot be explained in terms of anisometry (in those cases, the two lines were aligned on both endpoints). This phenomenon can instead be accounted for by assuming a combination of incomplete visual scanning of the stimulus pattern and left hemianopia. If a patient with a left-sided visual field scotoma (as GL) does not reach the left end of a line during the scanning, s/he will process just the parts of line that fell into the good visual field. In GL, such an "amputation" of the leftmost part of line might have been more severe for the lower than for the upper line on identity trials. In fact, scanning deficits may have both a horizontal and a vertical component, that combine into a more severe *leftward* scanning deficit in the *lower* parts of space (see e.g., Halligan & Marshall, 1989; Pitzalis, Spinelli, & Zoccolotti, 1997). In principle, this "differential amputation" hypothesis would also account for

GL's trend to underestimate the length of "shorter" target lines (30–90). For example, if a target line of length 80 is amputated proportionally more than the sample line of length 100, the former will look shorter than 80/100 of the latter. Such a theory, though, would predict underestimation of the "longer" target lines (110–170) as well. By contrast, GL massively overestimated those lines. Therefore, amputation phenomena do not provide a full account of GL's behavior.

Overall, the LJT results confirmed the DJT findings. On both tasks, GL relatively overestimated left-sided extents and underestimated right-sided extents.

5. Frequency of the phenomenon

To see how frequent this pattern is in the left neglect population, the LJT was administered to 10 left neglect patients and to 10 age- and education-matched normal subjects.

5.1. Method

Patients were recruited from the Neurological Wards of the Niguarda Hospital (Milan) and of the Istituto Redaelli (Vimodrone, Milan). Their MMS score was higher than or equal to 23/30. They all showed left neglect on screening cancellation tasks (see Table 1 for demographic and clinical details). Control subjects (five males, five females) had been admitted to both Hospitals for non-neurological reasons and did not have history of neurological disease; their mean age was 70.3 ± 7.1, their mean education 7.6 ± 3.8.

The LJT was administered in a slightly different version. This time the target line varied from 50 to 150 mm (in steps of 10 mm), and each length was presented twice (22 sheets overall). In pseudorandom order, each length was presented once in the first 11 trials, and again in the second 11 trials. The procedure was otherwise identical to the one previously described.

5.2. Results and discussion

All of the patients could point to the left ends of the lines, either autonomously or verbally helped by the experimenter.

Table 1 reports the *i* and *n* parameter estimates for each patient. The normal range was computed after subtracting the within-subjects variance from the overall variance. If one considers the simple *n* estimates, four patients showed relative left underestimation (upward curvature, i.e., *n* below the normal range) and two showed the opposite pattern, as GL (downward curvature, i.e., *n* above the normal range). By contrast, if a deficit is diagnosed only when the whole CI for *n* is outside the normal range (see Armitage &

Table 1
Clinical, demographical, and experimental data of left neglect patients

Pt	Sex	Age	Educ	Dur	Lesion site	MMS	Cancellation (hits on the left-hits on the right)	<i>i</i>	CI(<i>i</i>)	<i>n</i>	CI(<i>n</i>)
1	M	62	5	109	FT, BG	27	B4, 6/6-6/6; D4, 34/53-51/51; G3, 7/18-11/17	117.4	[112.0, 122.7]	.823	[.673, .973]
2	M	66	8	12	FTP	24	B4, 0/6-2/6; G3, 0/18-2/17; L3, 0/10-4/10	108.2	[103.4, 113.1]	.474	[.332, .617]
3	M	75	8	154	FTP, BG	26	B4, 3/6-6/6; L3, 0/10-8/10	96.3	[91.0, 101.6]	.781	[.599, .963]
4	M	80	10	11	Unapparent	23	B4, 0/6-6/6; G3, 2/18-4/17; L3, 0/10-7/10	107.1	[97.7, 116.5]	1.283	[.988, 1.577]
5	M	65	8	70	FTP	26	B4, 3/6-6/6; L3, 0/10-8/10	91.6	[86.3, 96.9]	.567	[.381, .754]
6	F	71	13	15	Silv, c-subc	23	B4, 0/6-2/6; L3, 0/10-5/10	92.4	[86.9, 97.9]	.958	[.760, 1.155]
7	M	69	12	50	cm	24	B4, 6/6-6/6; D4, 0/53-36/51; L3, 0/10-7/10	105.2	[100.9, 109.6]	.511	[.378, .644]
8	F	75	5	125	T, Ins, BG	23	D4, 0/53-9/51; D3, 4/53-28/51; G3, 0/18-6/17; L3: 0/10-4/10	98.4	[88.1, 108.6]	1.121	[.772, 1.470]
9	M	65	8	8	Unapparent	26	D4, 33/53-45/51; D3, 41/53-50/51	91.6	[88.6, 94.5]	1.076	[.969, 1.184]
10 ^a	M	70	13	146	cp	23	D4, 0/53-6/51; L3, 0/10-8/10	95.9	[90.4, 101.4]	.720	[.531, .909]
								Normal range:		[90.5, 102.7]	
<p>Notes: Pt, Patient; Dur, Duration of illness (days); MMS, "Mini-mental state" score (Folstein et al., 1975). Lesion sites in the right hemisphere: F, Frontal; T, Temporal; P, Parietal; BG, Basal Ganglia; Silv, Sylvian region; c-subc, cortico-subcortical; cm, cerebri media; Ins, Insula; cp, Cerebri posterior. Cancellation tests. The letter indicates the type of test [B, Bisiach, Luzzatti, and Perani (1979) circle cancellation; D, Diller and Weinberg's (1977) letter cancellation; G, Gauthier, Dehaut, and Joanette (1989) bell cancellation; L, a variant of Albert's (1973) line cancellation]; the number indicates the sheet size, 3 = A3, 4 = A4. Data from LJT are reported in the last four columns; <i>i</i>, <i>n</i>, local estimates; CI(<i>i</i>), CI(<i>n</i>), 95% interval estimates; estimates above the normal range are reported in bold, below the normal range in italic.</p>											

^aPatient AL (Toraldo, 2003).

Berry, 1994, pp. 98–99; Toraldo, McIntosh, & Milner, in press), only three patients showed some impairment, a relative left underestimation in all cases. Thus, the two patients who replicated the pattern of GL in showing relative left overestimation, did not yield n values *reliably* outside the normal range.

Nevertheless there is another indirect way of demonstrating that there were patients in the sample who overestimated extents on the left side. A comparison between the n values of patients and control subjects taken as groups was done. An independent-samples t test showed that the mean n value was similar in the two groups [patients: $n = .831$; controls: $n = .942$; $t(11.463) = 1.19$, $p = .258$]. A substantial difference between the two groups was the variability: the variance of the patient group was 7.168 times higher than that of the control group [patients: $\text{var}(n) = .075$; controls: $\text{var}(n) = .011$; $F(9, 9) = 7.168$, $p = .004$]. If two groups A and B do not differ for their means, but strongly differ in variance ($A > B$), this implies that group A contains both subjects who scored below and subjects who scored above the range of values of group B. Consequently there must have been subjects in the patient group whose n values were above the normal range, i.e., patients who really overestimated extents on the left side. The objection can be made that the higher variability in the patient group did not originate from the presence of both patients overestimating and patients underestimating left-sided extents, but from a higher instability of each patient's performance. In other words, the additional variability might have arisen from *wider* errors made by each patient in *both* directions (over- and underestimation of left-sided extents). This objection can be rejected on grounds of an analysis that considers just the between-subjects variability of each group, after eliminating the within-subjects variability. The within-subjects variability of the n scores was estimated separately for each group on grounds of each individual's standard error of n . After subtracting the within-subjects variance from the overall variance (again separately for each group), the residual (between-subjects) variances were compared. The variance of the patient group was still substantially higher than that of the control group [patients: $\text{var}(n) = .066$; controls: $\text{var}(n) = .008$; $F(9, 9) = 8.641$, $p = .002$].

In summary, there is indirect evidence that relative left overestimation is not (very) rare in left neglect patients. On grounds of the present samples' means and between-subjects variances, it can be estimated that 13.6% of left neglect patients have n values above the normal range. Interestingly, these results are very similar to those obtained from a much larger sample by Bisiach et al. (1998) who used the Line Doubling Task. They also found a much higher variation in the neglect group than in the control group, without clear differences between the means (see Fig. 1 in their paper). Of their 91

left neglect patients, 14 (15.4%) showed relative left underextension (i.e., overestimation), although an interpretation of that symptom in terms of directional hypokinesia cannot be excluded.

6. Endpoints Task

GL's severe overestimation of spatial extents on the left side might be interpreted in terms of a paradoxical anisometry—a higher “density” of the representational medium (the rubber sheet) on its contralesional side. Although this hypothesis is already problematic from the theoretical viewpoint (see Section 1), it allows a straightforward prediction. If the paradoxical anisometry model applies, GL would produce a relative left underextension on Bisiach, Rusconi, Peretti, and Valzar's (1994) Endpoints Task.

6.1. Method

On day 32, GL was asked to bisect three 150-mm gray lines centered on A4 sheets. After that, she had to bisect three 150-mm gaps, also centered on A4 sheets. The gaps were defined by two landmarks (vertical, 12 mm long, 2 mm thick, gray lines). GL was then given 18 sheets with a single landmark at the center, and was asked to set the endpoints of the previously seen gap, taking the landmark as its midpoint. To reduce the effects of possible directional hypokinesia, GL was required to set the left endpoint before the right endpoint. GL performed all these tasks by using a pencil held in her right hand.

6.2. Results and discussion

GL transected the lines at 5, 2.5, and 20 mm to the right of center. The gaps were transected at 16 mm to the left, 4 mm to the right, and 15 mm to the right. Although the single leftward error seemed interesting, and was replicated later on the same day (GL made a leftward 26 mm error when trying to bisect a 193 mm line), these bisection data are uninformative overall because of the possible interference of directional hypokinesia and/or “amputation” effects. GL's performance was much more stable on the Endpoints Task. She set the left endpoint at 130 ± 12.9 mm from the landmark, while the right endpoint was set 98.5 ± 16.6 mm away from it. This performance indicates clear overextension on both sides [both distances were larger than 75 mm; *left*: $t(17) = 18.06$, $p < .001$; CI of the mean = [123.5, 136.3]; *right*: $t(17) = 6.01$, $p < .001$; CI of the mean = [90.2, 106.7]], with relative left overextension [paired $t(17) = 7.72$, $p < .001$; CI of the mean difference = [22.8, 40]]. The correlation between the left and the right length across trials was not significant [$r(18) = .335$, $p = .17$].

Overall, this performance contradicts the hypothesis of a paradoxical anisometry in GL.

7. General discussion

The tasks used in this work to study the internal spatial metrics (DJT and LJT) required a verbal response. Therefore, the patients' performance on them could not be influenced by directional hypokinesia of hand movements, a deficit which may interfere with a correct assessment of the internal metrics in other experimental situations (e.g., Endpoints Task, Line Doubling Task). However, a limit of the LJT derives from the use of lines. As discussed in Section 4.3, patients with left hemianopia who do not scan a horizontal line in its full horizontal extent, internally "amputate" the leftmost part of the line. Nevertheless, if the leftmost portion of each LJT stimulus' longer line had been internally amputated, an upward curvature of the psychophysical function would have been found, i.e., n values lower than 1. GL obtained n values far higher than 1. Therefore, her LJT performance cannot be accounted for by assuming amputation phenomena.

In summary, there seems to be no obvious reason to suspect that the relative contralesional overestimation found in GL is a methodological artifact. Her behavior should reflect some genuine characteristic of her internal spatial representation. Nevertheless, this contralesional overestimation leaves a number of points obscure. It needs to be explained how a right hemisphere lesion like GL's can generate an overestimation of the left side. As argued in Section 1, the (spared) left hemisphere should, if anything, over-represent the right side. Neural resources should in fact be imbalanced in favor of the right side in that hemisphere. Furthermore, a paradoxical anisometry hypothesis (neural resources imbalanced in favor of the contralesional side) would not explain GL's performance on the Endpoints Task, i.e., a relative overestimation of the *ipsilesional* side!

In a recent paper, Doricchi, Onida, and Guariglia (2002b) have found a pattern conceptually compatible with paradoxical anisometry in patients with hemianopia but *without* neglect on visual search tests. Their patients were asked to perform a "Gap Matching Task." Given a central and a left-sided mark, 100 mm apart, patients had to arrange the position of a third mark to the right of the central one, in order to have the three marks equispaced. In another condition, the same task was done by arranging the position of the left mark, with the central and the right marks fixed. The experimenter moved the marks following verbal instruction by the patient. While patients with neglect *and* hemianopia (N + H +) produced a relative contralesional overextension (the pattern predicted by canonical anisometry), patients with hemianopia and *without* neglect (N – H +)

produced a relative ipsilesional overextension. Doricchi et al. (2002b) noted that these results are consistent with the typical bisection performance of the two patient populations: ipsilesional error for N + H +, contralesional error for N – H +. Therefore, all the Gap Matching and bisection data might in principle be interpreted in terms of canonical anisometry in N + H +, and paradoxical anisometry in N – H +. While this pattern of results seems stable, the interpretation is still unsatisfactory: why is the contralesional side of pure hemianopic patients overestimated? Again, neuroanatomy and neurophysiology would suggest under-representation of the contralesional side.

7.1. The "misprojection" account

An (admittedly conjectural) proposal can be made as follows. In Section 1 the construct of anisometry has been described in terms of the "rubber sheet" example. Fig. 2A shows the rubber sheet in a normal subject. There are vertical lines printed on its surface, dividing it into equal sections. Suppose that this rubber sheet is used as a screen for the projection of transparencies. On the transparency, i.e., in the real world, there are three points, X, Y, and Z, horizontally aligned and equispaced. The three points are properly projected onto the screen (Fig. 2A). Now, hypothesize that a mechanism moves the rubber of the screen compressing it on the right and extending it on the left (Fig. 2B). As a result, the vertical lines printed on the screen are not equispaced any more. If you quantify the rubber between the projections of X and Y, this will be now less than the rubber between the projections of Y and Z. Thus the segment XY will look shorter (anisometry).

This is not the only possible way of misperceiving distances. It is also possible to distort the image of the transparency before it arrives on the (not necessarily altered) screen. For instance, the projector might distort the image in such a way that points are misplaced to the left with respect to the ideal situation of Fig. 2A. The more on the left the original position is, the larger the leftward misplacement. Fig. 2C shows an example of such a situation where the rubber sheet is undistorted (the vertical lines are equispaced). According to this proposal, the deficit would arise *before* the implementation of the landmarks in an internal map. The map itself might be preserved—have a balanced distribution of neuronal resources, leading to appropriate distance estimations at a later stage—but it might contain landmarks that have been "drawn" in incorrect positions.

This model explains GL's behavior in detail. When three physically equispaced points are presented on the DJT, the image on the screen (Fig. 2C) is that of a Y point closer to Z than to X. Consistently, GL said that the gap XY is as wide as 65/100 of the whole gap XZ (see dashed trajectory in Fig. 1A). Similar reasoning can

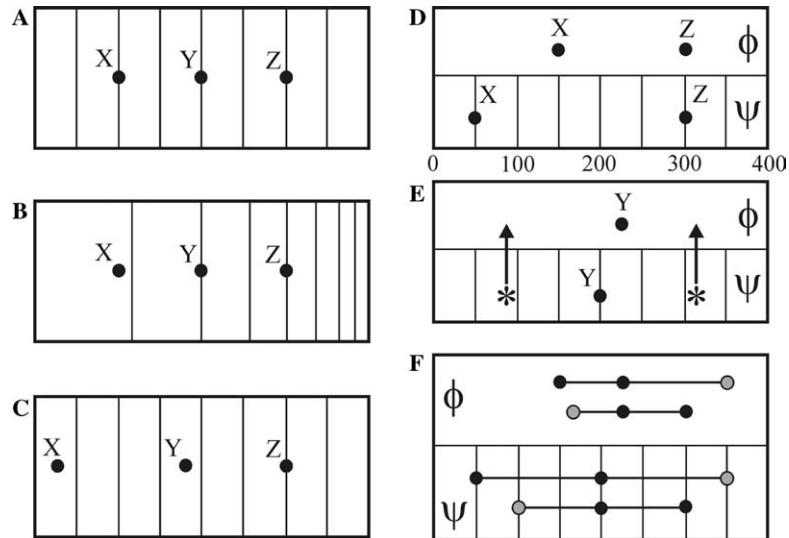


Fig. 2. The overhead projection analogy. Left half (A, B, and C): projection of three physically equispaced points (X, Y, and Z) onto representational space. (A) Normal subject. (B) Anisometry. (C) Misprojection. Right half (D, E, and F): predictions of the misprojection model. (D) Perception of the sample gap on the Endpoints Task. Physical space (ϕ) is shown in the upper half, representational space (ψ) in the lower half. (E) Reproduction of the gap on the Endpoints Task. Asterisks are the imaginary targets of the hand movements. The arrowheads show the positions marked with the pencil in the physical world. (F) Predictions of the misprojection model for the Gap Matching Task. Black dots are fixed, gray dots are moved along the lines by the experimenter following the patient's verbal instructions.

explain GL's performance on the LJT, if one considers the aligned right endpoints of sample and target, the left endpoint of the sample, and the left endpoint of the target as Z, Y, and X (or Z, X, and Y), respectively. On the Endpoints Task, the patient is initially given a sample gap, 150 mm wide in the physical world (points X and Z on the transparency, Fig. 2D, upper half). On the screen, the distance between X and Z is 250 mm (Fig. 2D, lower half). Therefore, the patient remembers the gap as 250 mm wide. The patient is then asked to reproduce the gap, given its center Y (Fig. 2E, upper half). To do so, the patient aims at two imaginary points, lying 125 mm to the left and to the right of Y on the screen (Fig. 2E, the two asterisks in the lower half). If the patient does not use a strategy of visual feedback control, and makes rather "ballistic" movements (as in fact were those executed by GL), the prediction is that of a bilateral overextension, with an imbalance in favor of the left side (see arrowheads in Fig. 2E). This is the pattern of results actually produced by GL. To rewrite this explanation in more intuitive terms, the apparent leftward shift of the endpoints would be the consequence of a leftward shift of the *midpoint* in GL's internal space. GL misperceived the midpoint as being to the left of its actual position in the environment.

An interesting prediction of the "misprojection" model is derived in the case of Doricchi et al.'s (2002b) Gap Matching Task. In this situation, a subject arranges the position of a mark in order to produce a three-mark sequence that *s/he perceives* as equispaced, i.e., that is equispaced on the screen (Fig. 2F, lower part). By illustrating the fixed marks in black and the moveable

marks in gray, Fig. 2F (upper part) shows the prediction of the misprojection model: a relative left (contralesional) underextension. This pattern was found by Doricchi et al. in pure hemianopic patients (N – H+). The suggestion is therefore that pure hemianopia might induce a contralesional misprojection.

7.2. Relation between misprojection and other phenomena

The misprojection hypothesis can be reconciled with other theories proposed in the literature to account for some neglect phenomena. Neglect has classically been associated not only with a lack of exploration, but also with delusions, confabulations, and in general, "productive" phenomena regarding that side (see e.g., Bisach & Berti, 1987). Delusion-like phenomena have been proposed to account for bisection and reading performance of neglect patients. Chatterjee (1995) suggested that left neglect patients' tendency to misbisect very short lines to the left of center (Halligan & Marshall, 1988) can be explained in terms of a pathological "elongation" of the line on its left side. To support his view, Chatterjee noticed how neglect patients may read two-letter strings as three- or four-letter words, by hallucinating letters on the left of those that are physically present. Ishiai, Furukawa, and Tsukagoshi (1989) recorded the eye movements of neglect patients with hemianopia while they were performing the classical line bisection task. Interestingly, such patients did not place their transection midway along the portion of line they had explored with their seeing hemifield. By contrast, they placed the transection very close to the leftmost

point they had fixated throughout the trial. In other words, they were misbisecting the explored portion of line to the *left*. This behavior is also consistent with the view that, at some stage of analysis, a part of the line that was never “seen” is hallucinated on the contralesional side. In those cases where the exploration with the good hemifield is large enough, the resulting bisection error will be on the left of the objective midpoint (see also Halligan & Marshall, 1998; Marshall & Halligan, 1996).

The present proposal is a generalization of Chatterjee’s model. His hypothesis of a delusional elongation of objects on their left side, can be rewritten in terms of a general tendency to misproject visual features (as the end of a line) to the left. The size of the misprojection would be a function of the position of the feature in the real world. The more on the left a visual detail is in the physical space, the more to the left it will be internally misplaced (at least for a portion of the left side of the world). Therefore, the right end of a line will be either mildly misprojected, or not misprojected at all, while the left end will be severely misprojected to the left, with a consequent delusional elongation on that side. Isolated landmarks, as those used in the DJT for instance, will be misprojected in the same way.

As for the neurobiological nature of misprojection, a neural substrate can be hypothesized that, under normal circumstances, processes information coming from the contralesional side of space and that after the lesion, becomes “hyperexcitable” (“disinhibited”) due to loss of input (see Lebedev, Mirabella, Erchova, & Diamond, 2000, for a discussion of the functional meaning of this phenomenon; see Chino, Kaas, Smith, Langston, & Cheng, 1992, for an example regarding the early visual system). If the neurons of a spatial representation are more excitable on one side, the unimodal profile of activation induced by, e.g., a small dot, will have a peak misplaced towards that side. A system that estimates the dot location on grounds of the position of the activation peak will therefore misrepresent the dot as more contralesional than it really is.

This hyperexcitability hypothesis would account for Doricchi et al.’s (2002b) results from patients with and without neglect, and with or without hemianopia. The early visual input, encoded in retinotopic co-ordinates, is remapped onto higher-order spatial representations—the “rubber screen” of the metaphor. The left side of a spatial representation receives on average more input from the left than from the right visual field, and vice versa. Therefore, a left hemianopia will induce a (mild) input loss in the spatial representation, with a gradient from a left-sided maximal loss to a right-sided minimal loss. An over-excitability due to input loss would thus be maximal on the left and progressively decreasing towards the right. This would explain the mild leftward misprojection (i.e., relative right overextension on the

Gap Matching Task, see Fig. 2F) in pure left hemianopia patients. When left neglect co-occurs with left hemianopia, the patient tends not to fixate in the left side of space. As a result, the input loss in the left representational side will be much more pronounced, and cause a quite severe leftward misprojection (as in GL, present paper). Most often, however, left neglect is accompanied by canonical anisometry—the distortion of the rubber screen. This would mask the effects of misprojection and produce the usual patterns seen in N+H+ patients (rightward bisection error, relative left overextension). In patients without hemianopia (see e.g., Doricchi, Galati, DeLuca, Nico, & D’Olimpio, 2002a, N+H–, N–H–) the spatial representation does not lack visual input—it would not suffer from the hyperexcitability phenomenon. Therefore, these patients would show either no behavioral asymmetry, or, if a canonical anisometry is concomitant, a relative left overextension. The frequent association of *severe* canonical anisometry with the combination left hemianopia-left neglect on visual search tasks (Doricchi & Angelelli, 1999; Doricchi et al., 2002a, 2002b) may be explained by assuming anatomical contiguity of the involved functional systems in the posterior regions of the right hemisphere.

7.3. Misprojection related to the literature about visuo-motor control

The theoretical difference between the misprojection model and the anisometry model has further implications. The two models are briefly summarized below.

Anisometry is a deficit of the representational medium (the rubber screen in the example), so that, although points are correctly projected onto it, distances are estimated in a distorted way. On this view, the deficit arises at the stage where spatial extents are estimated on grounds of the (unbalanced) neuronal distribution of the medium. By contrast the misprojection deficit is a perturbation of the mechanisms projecting the points onto the (possibly intact) medium. When the misplaced visual feature is the left endpoint of a line, the final outcome is the construction of a hallucinatory part of line on the contralesional side. When the transposed detail is, e.g., the left reference bar of a DJT stimulus, the patient will perceive the gap on the left as wider than it really is.

At a first glance, the distinction between misprojection and anisometry might seem logically unclear. This depends on how the output of the rubber screen is conceived. The model specifies that spatial extents are “estimated” on grounds of the rubber of the screen (“Screen I”). One might conceive of this estimation as the construction of a new spatial representation, implemented in a further screen (“Screen II”). The relative positions of two points in Screen II would be determined by “counting” the neurons that separate the

corresponding points in screen I. On this view, such a computation would be logically indistinguishable from the other hypothesized process, i.e., the projection from the transparency onto Screen I. However, this is not the way the model has been conceived. The idea is that the output of Screen I is not a further spatial representation, but an abstract representation of the size of a spatial extent, i.e., the distance that separates two selected points. This is different from computing the positions of points to be implemented in a spatial map (the “projection” of the transparency onto Screen I). A similar distinction between “size” and “position” computation has already been assumed in studies of the dorsal (occipito–parietal) stream of visual processing. It has been shown that patients with optic ataxia, a disturbance usually associated with a lesion in the dorsal stream, can dissociate in their reaching and grasping performance (Jeannerod, Decety, & Michel, 1994). Patients may show no deficit in reaching towards the location of an object, thus correctly computing its spatial position, but be impaired at scaling the grip for a proper grasp of the object, thus miscomputing its size. Neurophysiological evidence also supports this view of separate visuomotor pathways for reaching and grasping within the dorsal stream (see e.g., Jeannerod, Arbib, Rizzolatti, & Sakata, 1995). One suggestion is that a similar distinction exists within the ventral (occipito–temporal) stream of processing, which is more likely to be involved in the perceptual tasks used to study the internal metrics (see also Milner, Harvey, & Pritchard, 1998). According to this view, GL’s pattern of performance would be explained by assuming damage to the “position processing” system of the ventral stream, while patients showing patterns compatible with the canonical anisometry model (e.g., AL and MB; Toraldo, 2003) would suffer from damage to the “size processing” system of the ventral stream.

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