

Canceling out both the real and the spectral lines

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Accepted 12 August 2004

Abstract

Neglect patients typically show motor perseveration while canceling targets on the ipsilesional side. This behavior can be influenced by the presence vs. absence of targets on the (neglected) contralesional side (Bottini & Toraldo, 2003). As alternative explanations, the authors proposed (i) directional hypokinesia—the patient cannot perform reaching movements towards detected left-sided targets, and thus carries on canceling on the right side, and (ii) allochiria—the patient misperceives left-sided targets as located on the right side, and cancels them there. We report here data from a patient (EZ) that might confirm the second hypothesis. EZ was presented with 19 displays in which the number and position of cancellation targets on both sides were varied systematically. EZ showed motor perseveration while canceling, but this tendency did not vary across conditions. Interestingly though, EZ also drew cancellation marks in the empty space between the ipsilesional targets, and this phenomenon was significantly more intense when there were more targets on the neglected side. As EZ's comments suggested, such a behavior might reflect the attempt to cancel out delusional targets. Our speculation is that those objects were generated by allochiria.

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Keywords: Allochiria; Spatial neglect; Perseveration; Spatial processing; Directional hypokinesia

1. Introduction

The Albert line cancellation task (Albert, 1973) is one of the commonly used tests for the examination of unilateral neglect. On this task, it may happen that a neglect patient not only omits a number of targets on the contralesional side, but also traces further marks over already cancelled targets on the ipsilesional side (Damasio, Damasio, & Chui, 1980; Na et al., 1999). Although this kind of motor perseveration is quite frequent among the neglect population, relatively little theoretical work has been devoted to describing its possible causes. As a first, conservative possibility, there might be

no causal link between the two symptoms. Their association would just be accidental – the random co-occurrence of functionally independent deficits, one an impairment in exploring the contralesional side of space and the second, according to some interpretations, an impairment in interrupting an initiated motor response (see, e.g., Goldberg, 1986; Hudson, 1968). If this were the case, the degree of statistical association between the two symptoms would just reflect the degree of anatomical contiguity of the brain regions involved in the two deficits. Since there is little overlap—neglect can follow lesions in diverse locations of the right hemisphere (see, e.g., Rizzolatti, Gentilucci, & Matelli, 1985; Vallar & Perani, 1986) and perseverative behavior is generally associated with frontal damage often involving both hemispheres (see, e.g., Luria, 1965)—one should predict

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a low degree of association. By contrast, Rusconi, Maravita, Bottini, and Vallar (2002) reported that 88.6% of neglect patients showed perseveration in cancellation,¹ while only 12.9% of non-neglect patients did so (see Table 2 in their paper)—a very strong statistical association. Therefore, the assumption of entirely independent deficits that incidentally co-occur after brain damage is very unlikely—the hypothesis that neglect patients show a specific kind of perseveration is more convincing. Posner, Walker, Friedrich, and Rafal (1984) attributed the classical neglect symptomatology to a failure to disengage the visuo-spatial attentional focus from the ipsilesional stimuli. One might propose that the disengaging deficit causes both an under-exploration of the contralesional side and an over-exploration of the ipsilesional side, thus inducing the patient both to omit contralesional stimuli and to perseverate in the detection of ipsilesional stimuli. Another view has more recently been suggested by Rusconi et al. (2002) themselves (but see also Na et al., 1999), who hypothesized a causal link between the two—otherwise functionally independent—symptoms. According to their proposal, neglect would be induced by damage to a system devoted to the exploration/representation of space (traditionally localized in the right inferior-posterior parietal cortex, see Vallar & Perani, 1986) while perseveration would follow concomitant damage to a frontal-subcortical system (Denny-Brown, 1958). Crucially, Rusconi et al. (2002) suggested that the first deficit, the ipsilesional representational bias, would “trigger” the second deficit, perseveration, which would then develop rather independently (p. 602). This assumption of a “triggering” role of neglect allows one to explain the massive difference in perseveration incidence between neglect (88.6%) and non-neglect (12.9%) patients and the virtual absence of perseveration in left hemisphere patients. In fact, in spite of possible damage to the fronto-subcortical system, left hemisphere patients would not have the representational bias that allows perseverations to emerge. Consistent with Rusconi et al.’s (2002) view, perseveration in neglect emerged almost exclusively when the frontal and/or subcortical regions were involved in the lesion.

However, none of the above hypotheses can account for some experimental results from our lab (Bottini & Toraldo, 2003). Three out of four neglect patients who perseverated while canceling targets on the right side of a display, did so more intensely when there were (neglected) targets on the left side, than when there were not. Even more crucially, one patient (D) perseverated *only* when there were targets on the neglected side. On

grounds of these findings, the authors speculated that (i) directional hypokinesia (Heilman, Bowers, Coslett, Whelan, & Watson, 1985), or (ii) allochiria (Halligan, Marshall, & Wade, 1992; Kawamura, Hirayama, Shinohara, Watanabe, & Sugishita, 1987) might have a causal role in perseveration, at least in a subset of neglect patients. According to the first hypothesis the patient cannot perform reaching movements towards detected left-sided targets, and thus carries on canceling on the right side. According to the second hypothesis the patient misperceives left-sided targets as located on the right side, and cancels them out in that region. (iii) A recent work by Husain et al. (2001) suggests a third possibility. These authors proposed that neglect of left-sided targets is exacerbated by loss of memory of what positions have already been explored during the visual search. The combination of a rightward search bias and a spatial short-term memory (STM) deficit would induce the patient to search on the right side over and over, because he/she is not inhibited in his/her search on already visited positions. If the patient also has a deficit in inhibiting the automatic cancellation response once fixation has landed on a previously visited target, despite the vision of the mark/s drawn over it, the prediction is that extra marks will be produced. Crucially, these extra marks will be the more frequent the higher the load on the damaged STM system, i.e., the higher the number of positions to be remembered. In Bottini and Toraldo’s (2003) condition with targets on the left side, there were more cancelled targets—more positions to be remembered—than in the condition without left-sided targets. The higher memory load in the former condition would therefore account for the more frequent extra marks.

The aim of this study is to report a case that closely matches one crazy prediction that Bottini and Toraldo (2003) did not dare to propose following their allochiria conjecture (ii), and that is less compatible with either of the other views (i, iii). We prepared an experimental set which allowed us to study independently the effects of position and number of contralesional targets on cancellation in the ipsilesional side.

2. Methods

2.1. Case report

EZ, a 75-year-old right-handed lady with five years of education, was admitted at the neurological ward of Niguarda Hospital after a stroke. A CT scan showed a large lesion in the right hemisphere involving the frontal, temporal, parietal and occipital lobes as well as the insula. EZ showed mild left hemiplegia, left hemianopia and left hemianaesthesia. She was anosognosic for the latter two deficits (Bisiach, Cappa, & Vallar, 1983). EZ mislocalized contralesional stimuli as on the ipsilesional side

¹ These data are in sharp contrast with Na et al.’s (1999) results, in which the percentage drops to 35%. The discrepancy is likely to be due to differences between Rusconi et al.’s (2002) and Na et al.’s (1999) task instructions and criteria for defining a patient as “perseverating”.

in a single trial of the visual field examination and in a single trial of the tactile perception test (out of 20 contralesional stimuli in both cases). On Albert's (1973) line cancellation task EZ omitted 1/18 targets on the right side and 6/18 on the left side. She bisected 180-mm long, 1-mm thick horizontal black lines 54.4 mm to the right of true center ($n = 5$). EZ showed strong rightward response bias on both of Bisiach, Ricci, Lualdi, and Colombo's (1998) versions of the Landmark task, as analyzed according to Toraldo, McIntosh, Dijkerman, and Milner (2002; 2004; motor task: $M = .83$; visual task: $M = .96$; input-related neglect was unreliably estimated due to the huge response biases) Toraldo, McIntosh, Dijkerman, and Milner (0/72 words read correctly) EZ obtained scores within the normal range on both Phonemic and Semantic Fluency tests (Novelli et al., 1986; Spinnler & Tognoni, 1987), with no tendency to perseverate. EZ was administered the following cancellation tasks 22 days after the stroke.

2.2. Stimuli

EZ was presented with 19 A4 sheets printed with a variable number of targets, i.e., 30 mm long, 2 mm thick randomly oriented black lines. The distribution of targets varied across sheets. Half of each sheet, either left or right, contained a homogeneous field of 12 targets. This half is shown in light gray in each sheet of Fig. 1. The other half ("experimental") contained a variable number of targets (0, 6, 12, 24). These targets were distributed in three possible ways: all in the top quadrant, all in the bottom quadrant, or homogeneously distributed over both quadrants of that half.² Fig. 1 shows the overall set of conditions: its left column shows the sheets with the experimental half on the left, and its right column shows the mirror-reversed conditions. The sheets were presented in random order ($l, g, p, q, h, c, o, m, n, a, k, s, f, d, e, b, r, j, i$). EZ was given a pen and was asked to cancel out each target by making a single mark on it.

3. Results and discussion

3.1. Results

Left neglect appeared in almost all of the displays. Fig. 1 reports the number of detected targets out of the overall number of targets in the different parts of each display. EZ's cancellation behavior was of the "continuous" type (Sandson & Albert, 1984, 1987): she did not detach the tip of the pen from the paper

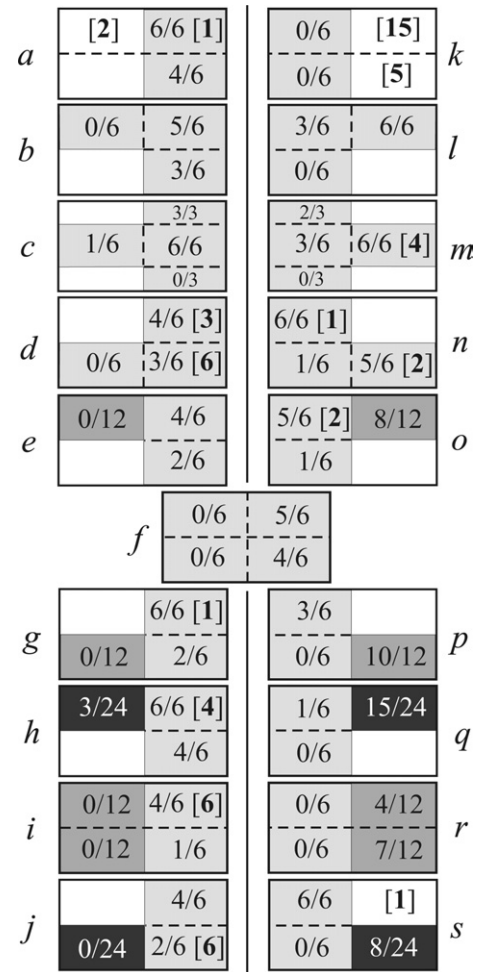


Fig. 1. Each rectangle represents an A4 sheet. Left column: sheets with the "experimental" half on the left; right column: mirror-reversed condition. Row 1, sheets with 12 targets overall; rows 2–4, 18 targets; rows 5–7, 24 targets; rows 8–10, 36 targets. Within each sheet the regions of interest, each containing a homogeneous field of targets, are either distinguished by different shades of gray or separated by dotted lines. Shades of gray indicate target density in each region: white, no targets; light gray, 4 targets per dm^2 ; medium gray, 8 t/dm^2 ; black, 16 t/dm^2 . Fractions represent the number of cancelled targets per overall number of targets in each specific region. Frequencies of "flying" marks (if any) are reported in bold within square brackets.

while canceling, thus producing "inkblots" instead of distinguishable cancellation marks. However, the distribution and characteristics of the "inkblots" did not seem to be a function of the number of targets on the left side, as happened with patients B, C and D in Bottini and Toraldo (2003)—in general, perseveration of proper cancellation marks was not influenced by target distribution across the display. Nonetheless, there was a particularly striking feature in EZ's cancellation behavior: a tendency to produce cancellation marks well away from the targets—either in the empty space between them, or even in completely empty portions of the display. EZ produced 59 such marks overall, 20 of which were placed in the empty right half of sheet k (top-right in

² Two exceptions: in sheets c and m the experimental half's six targets were not distributed homogeneously over it; they were concentrated around the horizontal midline. This was done to avoid having conditions too similar to those of sheets a and k .

Fig. 1; see Fig. 2A for the exact reproduction). These “flying” marks were clearly intentional, and in many cases they were of comparable intensity to that of the marks made over the targets. Although no formal record was taken of the order in which EZ traced the marks, one experimenter (AR) recalled that EZ tended to intermingle “flying” and cancellation marks while exploring the display in an essentially ordered fashion, mostly from left to right and from top to bottom.

We performed an analysis of the distribution of the “flying” marks as a function of the display characteristics.

3.1.1. Definition of “flying” mark

We excluded from further analysis all marks that seemed to have been produced by accidental pen-paper contacts. A “flying” mark was operationally defined as a mark entirely outside the rectangular areas centered

on each target and extending 4 mm outwards from its short side and 1 mm outwards from its long side. All marks extending even partially within those areas were classified as cancellation marks and the involved target was classified as a detected one. By using this criterion we could avoid misjudging marks made in the close vicinity of a target, and thus likely to be proper cancellation marks, as “flying” marks. Fig. 1 reports the resulting distribution of “flying” marks; their frequency is reported in square brackets in any given region. In the next sections we will sometimes use the shortcut “F” for “flying marks.”

3.1.2. Measure of “flying” marks production: density in explored white area

By definition, F could appear only in the sheet’s surface lying outside each rectangular perimeter surround-

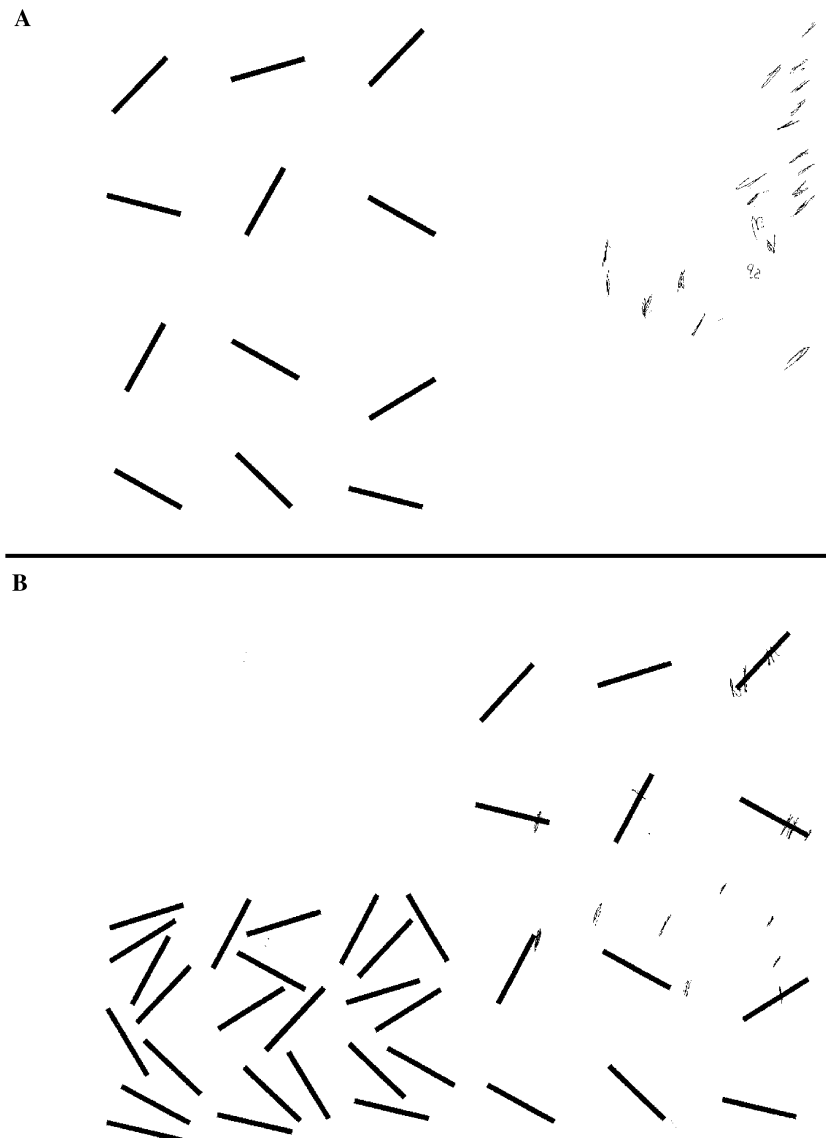


Fig. 2. (A) Sheet *k* (top right in Fig. 1). (B) Sheet *j* (bottom left in Fig. 1).

ing a target—henceforth, the sheet’s “white” area. We measured the *density* of F in the white area that was explored by the patient.³ We chose to use this measure (as also Bottini & Toraldo, 2003; and Na et al., 1999; did) because in our view, a completely non-specific tendency to generate F—as assumed by the most parsimonious hypothesis—should produce a homogeneous distribution of F, an isodensity, within the white area that had been explored in all the sheets. According to this null hypothesis, a patient who cancels out, e.g., all the targets in the rightmost fourth of a display, and half the targets in the middle-right fourth, is expected to produce twice as many F in the former than in the latter, because the explored white area in the rightmost fourth is twice as large as that in the middle-right fourth.⁴ The issue of the measure to be used is also addressed in Section 4.

3.1.3. F density as a function of position and density of targets

Fig. 1 shows the parts in which we divided each sheet: basically, the sheets’ quadrants.⁵ Each quadrant contained a homogeneous target distribution that had a density of 0, 4, 8, or 16 targets per dm². In Fig. 1, densities are shown by colors: white, light gray, medium gray, and black respectively. We studied pairs of adjacent quadrants, one of which was in the left and the other in the right half of the sheet. We kept one quadrant constant (target density: light gray), varied the target density of the other, and measured the “flying” mark density in both the constant and the varying quadrant. Fig. 3A shows results from the design with a constant left quadrant and a varying right quadrant; Fig. 3B shows results from the complementary design. Dashed curves plot the average⁶ F density in the explored white area of left quadrants, solid curves do so for right quadrants. Left quadrants showed a very low frequency of F (five overall); therefore, no statistical test could be applied to the slope of the dashed curves. Nevertheless, the dashed curve of Fig. 3B had a high peak at its left endpoint. This was because of two F drawn by the pa-

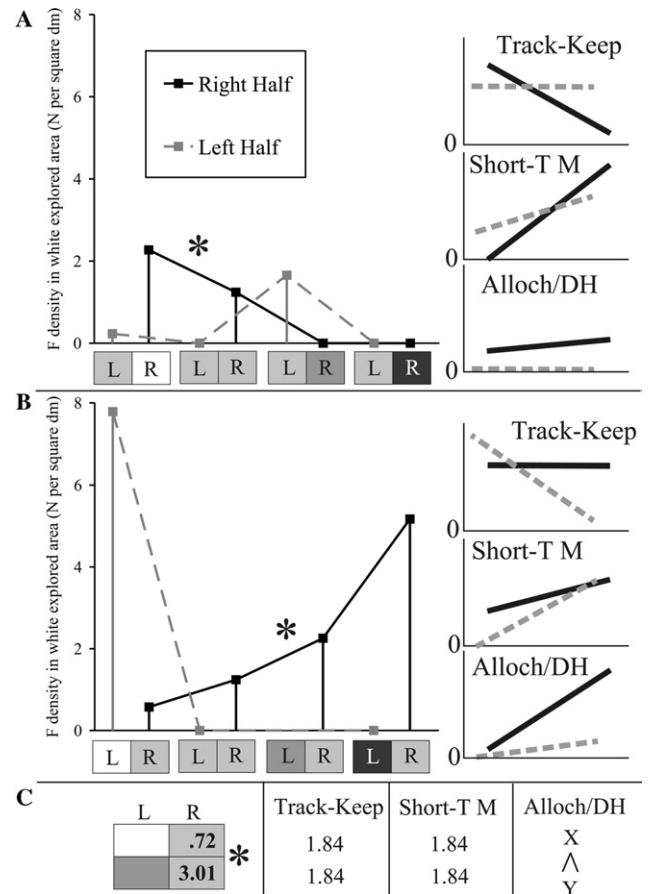


Fig. 3. (A) Pairs of adjacent quadrants, with increasing target density in the right one and constant density in the left one, are shown along the horizontal axis; each quadrant is plotted against the average F density in its explored white area; asterisks: significant effects; small plots show predictions from specific hypotheses: Short-T M, short-term memory; Alloch, allochiria; DH, directional hypokinesia. (B) Mirror-reversed condition. (C) Average F density values (N per dm²) in the right quadrants of the same sheet with (bottom) and without (top) targets to their left; leftmost column: observed values; other columns: values predicted from specific hypotheses.

tient in a left quadrant that had no targets at all (sheet a, top-left in Fig. 1). EZ drew them just beyond the sheet’s vertical midline, 2 and 7 mm from it. Since the estimated explored area for that quadrant was tiny, the F density was consequently estimated as huge. Within the right quadrants, there were plenty of F to analyze. In the left-constant/right-varying situation (Fig. 3A, solid curve), we could detect a significant decrease of the F density with increasing target density [$\chi^2(3) = 11.24$, $p = .0105$]. This means that the more targets were present in the right quadrant, the fewer F were drawn between them.⁷ In the left-varying/right-constant situation (Fig. 3B, solid curve) an opposite, massive ef-

³ The local percentage of explored area was estimated on grounds of the percentage of cancelled targets. For instance, if 3 F were drawn within a quadrant (1.56 dm²) containing 6 targets, 4 of which were cancelled (area within a rectangular perimeter = 0.015 dm²), the density was estimated as $3/[(1.566 \times 0.015) \times 4/6] = 3.06$ F per dm² of explored white area.

⁴ Statistical tests of this isodensity model were carried out by comparing the observed F frequencies in a set of explored areas with the expected frequencies that were derived from the model by taking into account the relative sizes of such areas (χ^2 test).

⁵ Exceptions were sheets c and m, in which the internally homogeneous regions were not properly “quadrants” (Fig. 1). Nevertheless, for brevity, we will call them so. Henceforth, these sheets’ central strip, colored in light gray, will be considered as a pair of “quadrants”; the other pair is composed by merging the top and bottom strips.

⁶ Data were accumulated from all the pairs of quadrants of the 19 sheets.

⁷ This effect was not due to the fact that the more targets, the less room was available for F to be drawn. The measured variable was the density of F in the white area outside the perimeter around each target.

fect was found: the denser the left-sided targets, the denser F in the right quadrant [$\chi^2(3) = 24.77, p = .00002$].

3.1.4. Within-sheet effect of density of left-sided targets

In the previous section, the effect of the density of left-sided targets on the F density in the right quadrants was studied (solid curve in Fig. 3B). However, data regarding different target densities often came from different sheets; e.g., “medium gray” density was studied in sheets *e*, *g*, and *i* while “black” density was studied in sheets *h* and *j*. The same effect could be studied within a same sheet, e.g., *b* (Fig. 1). Although both its right quadrants were identical, the top-right one had targets to its left, while the bottom-right one did not. By comparing the F densities in the white explored areas of those two quadrants, an effect of left-sided targets density, albeit gross, could be extracted. In order to obtain a more powerful statistical test, data were accumulated from all the sheets of Fig. 1’s left column for which the same reasoning could be applied—*b*, *d*, *e*, *g*, *h*, and *j*. Right quadrants *without* targets to their left were explored in 5.56 dm² of their white space; 5.32 dm² were instead explored in the right quadrants *with* targets to their left. If the null hypothesis of F isodensity held true, the proportion of F in the first area out of the overall area should be $5.56/(5.56 + 5.32) = .511$. The observed proportion was .2 (4/20 F), significantly smaller than .511 (binomial test, one-tailed $p = .0027$). “Flying” marks were denser in the quadrants that had targets to their left (see, e.g., sheet *j* in Fig. 2B). The exact F densities are reported in Fig. 3C.

3.2. Discussion

In this section, different hypotheses will be discussed and their specific predictions (small plots in Fig. 3) will be compared to the observed results (large plots).

3.2.1. The “track-keeping” hypothesis

To perform a cancellation task it is necessary to avoid coming back to already explored positions of the display, otherwise the search would be endless. To this purpose, the patient needs to know what position of the page he/she is fixating at any given moment. Neglect patients may have a pathologically restricted attentional focus (see, e.g., Ládavas, Petronio, & Umiltà, 1990). EZ, who had a very large lesion, might have had a tiny attentional focus, thus “seeing” just a small portion of the display, e.g., 2–3 cm across, at any given time. If a patient cannot widen his/her attentional focus enough for including both the fixated position and a relevant landmark, e.g., a sheet’s corner, he/she cannot know where he/she is fixating on the page—a lack of page-centered positional information that makes it impossible to know whether or not the current position has already been visited. One way of compensating for this deficit would be to

scan the page along some egocentrically-defined directions—as indeed EZ tended to do, from left to right and from top to bottom—and make marks everywhere during the search, in order to leave a track that helps avoid returning over an already covered route. When the tiny focus is set over an entirely white sector of page, “flying” marks would be drawn; when the focus includes a target, marks would be made on it, both accomplishing the task and keeping track of the visit. This hypothesis would explain the extreme case of sheet *k*, in which EZ produced 20 “flying” marks (Fig. 2A), as a result of EZ’s attentional focus swimming desperately through the entirely blank right half of the sheet and leaving traces of its passage in order to be able to avoid re-visits.

The most obvious prediction of such a view is that EZ should have produced “flying” marks also on an entirely empty sheet – unfortunately we did not administer this condition to her. Another prediction is that the production of F should also be possible in blank fields lying to the left of the leftmost targets; this actually happened in sheet *a* (Fig. 1), and is a crucial finding because it cannot be predicted by any of the other hypotheses discussed in this paper. Other predictions of the “track-keeping” theory directly refer to the findings shown in Fig. 3. According to the hypothesis, F are produced when the focus is set over an entirely white part of the display; this is less likely to occur, the denser the targets are in the region. Therefore, *the denser the targets in a region, the less dense F should be in the explored white area of that region*. Graphically, if one plots target density against F density, a negative slope should be found (see Fig. 3A, “Track-Keep”: solid curve; Fig. 3B, “Track-Keep”: dashed curve). This negative slope was empirically observed in both cases—albeit not significantly so in the second case—thus confirming the prediction. A more severe test of the track-keeping hypothesis addresses its sufficiency as an explanation: *if different explored regions have the same density of targets, they should also have the same density of F in their white areas*. The left quadrants in Fig. 3A and right quadrants in Fig. 3B have a constant target density. Therefore, according to the track-keeping hypothesis, they should show a constant F density (flat functions in Figs. 3A and B, “Track-Keep”). While the observed function of Fig. 3A is compatible with that prediction, the observed function in Fig. 3B has a significantly positive slope, which violates the prediction.

3.2.2. The hypothesis of a short-term memory deficit

As an effect of a deficit in STM for spatial positions (Husain et al., 2001), EZ might have frequently come back to already explored regions of the display that contained targets. One might assume that EZ produced F in those regions during returns—a problematic point to be discussed later. Returns in each region would be more frequent the higher the memory load, i.e., the larger the overall area of the sheet that has already been ex-

plored, and the longer the time taken for exploring the sheet. Crucially, one can assume that the search time is influenced by the number of *neglected* targets—some form of implicit processing might slow down the patient's search. The indirect effect would thus be of more frequent returns with increasing number of neglected targets. The effects of number of cancelled targets (STM load) and of neglected targets (slowing down) would combine and provide the predictions shown in the small plots “Short-T M” of Figs. 3A and B. Radical discrepancies emerge between those predictions and the observed results; the STM deficit hypothesis seems thus inadequate as a unique explanation.

3.2.3. Combination of the track-keeping and STM deficit hypotheses

Although both the track-keeping and the STM deficit hypotheses, each taken alone, seem inadequate in explaining the results pattern of Figs. 3A and B, one might suggest that their combination could do so. If the two predictive plots “Track-Keep” and “Short-T M” were averaged out by giving more weight to the former, a good fit with the real data would be obtained in Fig. 3A; less so in Fig. 3B where the averaged slope of the solid curve would be virtually zero—in sharp contrast to the observed slope. Nevertheless, suppose that this combination gives a satisfactory explanation for results in Figs. 3A and B. Both the hypotheses, and therefore their combination, predict a null result when one compares F densities in quadrants of a same sheet that have/do not have targets to their left (Fig. 3C). In fact, all the crucial variables are equal between those two comparison terms. Target density, which is important for the track-keeping hypothesis, is the same in the two quadrants; both the overall area explored in the sheet and the overall number of neglected targets in the sheet, which are determinant for the STM deficit hypothesis, are equal for the two quadrants—they are quadrants of a same sheet! The empirical result contradicts the prediction: F density was massively higher when targets were present in the aligned right field (Fig. 3C).

3.2.4. Allochiria and directional hypokinesia

“Flying” marks might have been produced while trying to cross out delusional targets—maybe, undetected targets whose position was misperceived rightwards (allochiria). Another possibility is that EZ made “flying” marks after having “undershot” leftward reaching movements towards targets, i.e., she might have produced the cancellation action that naturally follows the reaching movement, some distance to the right of the target itself (directional hypokinesia). If formulated in this way, both the allochiria and the directional hypokinesia hypotheses provide the same predictions for all phenomena summarized in Fig. 3. Predictions were obtained by simulating reaching actions as directed 10, 15,

or 20 cm to the right of each neglected target, and assuming that a “flying” mark was produced there with probability proportional to the local percentage of explored area. According to the resulting predictions, one should expect (i) negligible or marginal variations in F production in the left quadrants (Figs. 3A and B, “Alloch/DH,” dashed curves), but (ii) notable differences in the right quadrants, according to how dense targets are to their left (Fig. 3B, solid curve) and, to a smaller extent, according to how dense targets are inside them (Fig. 3A, solid curve; this little effect would be due to neglected right-sided targets that were “cancelled” the shortest way—10 cm—to their right). By no means were these predictions fully met when compared to the observed results. Nevertheless, the within-sheet effect of left-sided targets' density on right-sided F's density (Fig. 3C) was correctly predicted; crucially, this effect was not predicted by either of the other models.

3.2.5. One solution

A combination of the allochiria/directional hypokinesia and of the track-keeping hypotheses provides the best model for explaining the pattern of results. By averaging their predictive plots “Alloch/DH” and “Track-Keep” in Figs. 3A and B the resulting slopes adequately match the observed ones. Also the within-sheet effect (Fig. 3C) is predicted by this combination. In general, the allochiria hypothesis is necessary for explaining why an increase in the density of left-sided targets induced an increase in the density of right-sided F (solid curve in Fig. 3B, effect in 3C) and the track-keeping hypothesis is necessary to explain the reduction of the density of right-sided F with increasing number of surrounding targets (solid curve in Fig. 3A). The track-keeping explanation is the only one we could provide for EZ's behavior of making two F to the left of the leftmost targets on sheet *a*, in an entirely empty region—none of the other hypotheses can account for that (see the null value at the left end of the dashed curves, for all predictive plots except “Track-Keep,” Fig. 3B).

4. General discussion

An effect of presence vs. absence of left-sided targets on ipsilesional perseveration in neglect has already been described in previous work (Bottini & Toraldo, 2003). We replicated those results (Fig. 3C). Most importantly, this time “perseveration” is the behavior of drawing marks in the empty space between targets. In an hypothesis-elimination procedure, we analyzed a number of accounts for this bizarre behavior—namely, (i) the idea that EZ was trying to compensate for a pathologically restricted attentional focus by keeping track of the explored territory; (ii) a short-term memory deficit inducing frequent returns over previously visited positions;

(iii) consistently with one previous proposal (Bottini & Toraldo, 2003), allochiria/directional hypokinesia. Each of these views, taken alone, failed to predict all the main features of EZ's behavior (Fig. 3). The best solution we could offer was the combination of the track-keeping and the allochiria/directional hypokinesia models.

The (hypothetical) effects of allochiria and directional hypokinesia are hard to tell apart in a cancellation task. Transferring a perceptual object to the right, or undershooting a leftward reaching movement towards it, produces the same result. Furthermore, there is independent evidence of EZ's directional hypokinesia, namely, her massive rightward response bias on both of Bisiach et al.'s (1998) versions of the Landmark task. Nevertheless, we have theoretical reasons to prefer allochiria as an explanation in this case. The idea of directional hypokinesia *per se* provides a reason why *reaching* movements might be misdirected—undershot—when they are planned towards the left. Yet, once the patient's hand lands in an empty position, he/she should not make marks there: since there is no time limit and there is full visual feedback, the patient should realize that he/she had reached an empty region. In other words, the disadvantage of the directional hypokinesia hypothesis is that it requires a corollary assumption specifying why pen strokes that were originally programmed for a specific target are not inhibited in empty space—in this respect, the allochiria hypothesis provides a natural solution: the patient literally believes the target is under the pen tip. Similar critiques could be applied against the STM deficit model: it needs a corollary assumption specifying why “returns” over previously visited regions should induce the patient to cancel in midair—if anything, one might expect the *targets* to be cancelled over and over. There is another, puzzling reason, albeit anecdotal, for which the allochiria model might be preferable to the hypokinesia one. While making “flying” marks in sheet *k*, EZ spontaneously commented that she did see “some lines, less thick and lighter in color than the other ones.” What she referred to as “the other ones” were the real targets. This is consistent with the view of a productive perceptual phenomenon, and therefore, with our conjecture about the pathological misplacement of perceptual objects towards the ipsilesional side.

Rusconi et al. (2002) argued that while allochiria might well contribute to the pathogenesis of ipsilesional perseveration, it does not provide a complete explanation of the disorder. We agree that the allochiria hypothesis is incomplete, and still of conjectural nature. However, we think that the empirical evidence Rusconi et al. (2002) reported as relevant for evaluating that hypothesis is debatable. The authors (p. 602) state that a prediction of the optic allochiria model is that there should be a direct relationship between *number* of omitted targets and *number* of perseverations. They failed to find such a relationship ($N = 31$; Kendall's $T = .063$,

one-tailed $p = .308$; Spearman's $r_s = .074$, one-tailed $p = .345$). The implicit assumption made by Rusconi et al. (2002) is that the null hypothesis of “no effect of allochiria” corresponds to an equal *number* of perseverations, whatever the number of omissions. In this view, all patients with exactly the same degree of perseveration-inducing pathology [in Denny-Brown's (1958) proposal, a form of disinhibition of the parietal cortex after frontal-subcortical damage], would make (e.g.) 3 ± 1 perseveration marks in the sheet, but would distribute them across explored areas of possibly very different sizes. For instance, a patient with very severe neglect would make the 3 ± 1 marks along the right edge of the sheet, while a patient with identical perseveration-inducing pathology—parietal disinhibition—but very mild or no neglect at all would distribute the 3 ± 1 marks all over the sheet—one might wonder, what makes both patients stop perseverating after having drawn 3 ± 1 marks, in such different neuropsychological conditions? Why should those patients produce the same average *number* of perseverations while producing exploration behaviors that differ massively in timing, dynamics, and extension? To reformulate the same issue in different terms, why should a subject who was given a single sheet and made three perseveration marks in it, receive the same score as a subject who made three perseveration marks overall in 30 sheets? The second subject took many more occasions—much more explored space—to show that behavior. We derived a less problematic null hypothesis by assuming that patients with a same degree of perseveration-inducing pathology but no allochiria effect would produce the same *density*, and not the same number, of perseveration marks in the explored region. Thus for instance, a patient who explores the whole display would make 8 ± 4 perseveration marks, and a patient who explores just half of the display but has an identical degree of perseveration-inducing pathology would make 4 ± 2 such marks. The same logical approach was used by Na et al. (1999) who measured perseverative behavior by computing the percentage of “perseverated” targets out of all *cancelled* targets,⁸ and by Bottini and Toraldo (2003) who used the average number of cancellation marks per *cancelled* target.

Therefore, by following this logic, the correlation relevant for testing the allochiria hypothesis is that between the number of omissions—a measure of neglect severity—and the density of perseveration marks in the explored area. If the allochiria hypothesis were false, that correlation would be zero. We re-analyzed Rusconi et al.'s (2002) data (see Table 3, p. 598 in their paper) by computing the density of perseverations in the explored

⁸ This explains the apparent discrepancies between Na et al.'s (1999) and Rusconi et al.'s (2002) data. The former used a measure of density of perseveration in a given area, the second used the mere number of perseverations.

area as the ratio between number of perseverations and number of detected targets—the latter is used as an estimate of the size of the explored area. The prediction of the allochiria hypothesis was confirmed, as the correlation between perseveration density and number of omissions was significantly higher than zero ($N = 31$; $T = .263$, one-tailed $p = .027$; $r_s = .346$, one-tailed $p = .029$). This replicates the results obtained by Na et al. (1999) who found a significant proportionality between neglect severity and perseveration density. Moreover, the correlation becomes higher if Rusconi et al.'s (2002) four patients with right neglect after left hemisphere stroke are included in the analysis ($N = 35$; $T = .382$, one-tailed $p = .0015$; $r_s = .487$, one-tailed $p = .0015$). The size of the correlation can best be understood by looking at the r_s value, whose scale and meaning are the same as those of Pearson's parametric r (Siegel & Castellan, 1988, p. 251). The value of .487 indicates a correlation of moderate size. On this view, Rusconi et al.'s (2002) non-significant correlation should be interpreted as the result of two opposite (independent) effects that cancel each other out. A first effect would be an increase in the number of the allochiria-induced perseverations with increasing number of neglected targets; a second effect would be a simultaneous decrease in the number of those perseverations that are instead caused by the frontal-subcortical damage (Denny-Brown, 1958), because of the decrease in the explored area.

Although the above correlation (.487) confirms the allochiria hypothesis, this remains still conjectural, and crucially, incomplete as an explanation of perseveration in neglect. For instance, the allochiria model does not explain the higher perseveration scores of anterior cortical and/or subcortical patients with respect to posterior cortical patients (Na et al., 1999; Rusconi et al., 2002): if anything, one would predict that optic allochiria follows posterior cortical damage. Neither does it explain the “complex” variants of perseveration, e.g., the tendency to produce irrelevant material while canceling. One can also state that the allochiria hypothesis cannot explain the cases of florid perseveration without neglect, even though, as a simple dissociation, this pattern might in principle be explained in terms of an artifact of differential test sensitivity (Shallice, 1988). In any case, as suggested by previous work (Bottini & Toraldo, 2003), by the current case report and by our re-analysis of Rusconi et al.'s (2002) neglect data—that replicate those of Na et al., 1999—the role of the allochiria hypothesis in the study of perseveration cannot be prematurely defined as marginal.

Acknowledgments

This research was supported by grants from the Italian Ministry of University and Scientific Research. We

wish to thank Nicola van Rijsbergen for her kind help in revising the English.

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