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The two sides of spatial representation in neglect patients: The same spatial distortion for different patterns of performance

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ABSTRACT

Patients with neglect show disorders in horizontal space perception. It has been argued that these disorders may depend on a distortion of space that takes the form of a left–right relaxation of the representational medium that becomes progressively "relaxed" toward the contralesional space and progressively "compressed" toward the ipsilesional space (the space anisometry hypothesis). In the present paper we tested this hypothesis by using the Oppel–Kundt illusion that consists of the perception of a filled space as larger than an empty space of the same size. Two experiments were carried out with 14 brain-damaged patients with neglect, 9 brain-damaged patients without neglect and 12 healthy subjects. In the first experiment participants were requested to bisect and read words with different letter spacing simulating the way space is thought to be distorted in neglect. In the second experiment we asked the participants to physically and numerically bisect numerical intervals. The results of the two experiments are in line with the predictions of the space anisometry hypothesis. Specifically, with a background resembling the space distortion proposed by the space anisometry hypothesis, neglect signs are ameliorated in reading words and in numerically bisect numerical intervals, while they are worsened in bisecting words and physically bisect numerical intervals. These results support the idea that the abnormalities observed in typical neglect tests are due to a distorted internal representation of the outside world that takes the form of a mental continuum logarithmically distorted along the horizontal dimension.

1. Introduction

Patients with neglect fail to report, respond, or orient to stimuli presented on the opposite side of their brain lesion (Heilman & Valenstein, 1979). Neglect patients often, but not always, do not eat from the left part of their dish, they bump their wheelchair into obstacles situated on their left, and have a tendency to look to right-sided details as soon as a visual scene deploys. They are usually unaware of their deficits, and often obstinately deny being hemiplegic. The presence of neglect is an important predictor for poor functional outcome and it has a dramatic effect on rehabilitation efficacy and on quality of life (Gillen, Tennen, & McKee, 2005). Spatial neglect has been described as resulting from a distortion of space (Bisiach, Ricci, & Modona, 1998b; Bisiach, Neppi-Modona, Genero, & Pepi, 1999; Bisiach, Neppi-Modona, & Ricci, 2002). More specifically, the space anisometry hypothesis put forward by Bisiach and colleagues, proposes that the representational medium, in which within- and between-objects spatial relationships are represented, is pathologically anisometric along the horizontal dimension. That is, the representational medium is progressively "relaxed" toward the contralesional space and progressively "compressed" toward the ipsilesional one in a logarithmic manner.

Several pieces of evidence support this hypothesis. In the nineties, Bisiach, Pizzamiglio, Nico, and Antonucci (1996), Bisiach, Rusconi, Peretti and Vallar (1994) found that when asked to reproduce left and right end-points of a previously seen horizontal line, some neglect patients place the contralesional left end-point disproportionately further in the neglected hemispace and the right end-point disproportionately nearer in the attended hemispace. Similarly, in a line extension task, in which the participants are requested to extend horizontal lines to double their length either rightwards or leftwards, some patients with unilateral neglect tend to overextend the line contralesionally and underextend them ipsilesionally (Bisiach et al., 1996; Chokron, Bernard, & Imbert, 1997).

These biases can be found not only in reproducing but also in perceiving lengths, either in the visual (Irving-Bell, Small, &

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Cowey, 1999; Milner & Harvey, 1995; Milner, Harvey, Roberts, & Forster, 1993) or in the tactile domain (Milner, Harvey, & Pritchard, 1998). Indeed, when presented with a pair of identical horizontal lines or shapes, one on the left and one on the right, and asked to indicate (visually or by touch) which stimulus is larger, some patients with neglect perceive the horizontal extent of stimuli on the left side of their egocentric space as shorter than those on the right side. The anisometry hypothesis seems also to be able to account for the line length effect (Bisiach, Bulgarelli, Sterzi, & Vallar, 1983), by which the rightward bisection errors made by neglect patients decrease as the length of the lines decreases (Savazzi, Posteraro, Veronesi, & Mancini, 2007). This effect has also been found when the lines are perceived as longer, even if their physical length remains unchanged (Ricci, Calhoun, & Chatterjee, 2000): lines judged as longer were bisected more rightwards than lines perceived as shorter.

Interestingly, the nature of the spatial distortion in neglect according to the anisometry hypothesis is similar to the effects of the Oppel–Kundt illusion (OKI). This illusion consists of the phenomenon that a filled space looks longer/larger than an empty space of the same size (Kundt, 1863; Watt, 1994). Quoting Bisiach (1997, page 491): "the distortion underlying neglect and related phenomena has been likened to a pathological remapping of an Euclidean onto a logarithmic scale, with spatial expansion on the contralesional and compression on the ipsilesional side, giving rise to something similar to the Oppel–Kundt illusion".

In agreement with the space anisometry hypothesis, Ricci, Pia, and Gindri (2004) found that an anisometric background resembling the OKI, which creates an illusory distortion of space, can modulate neglect. In their experiment, the authors used several tasks (line bisection, line extension and cancellation tasks) and reported that when the illusion induced a representation of distances and lengths opposite to the hypothesised representational deficit, the errors of neglect were reliably reduced. Very similar results have been found by Savazzi et al. (2007) with lines of different length: when the illusion induced a representation of space that acted in reverse to the way space is distorted in neglect, the bisection errors were reliably reduced. In addition, these authors also found that the strength of the illusion diminished as the line length decreased, and reversed with very short lines (thus providing a convincing explanation to the crossover effect, i.e. the reversal to the left of the rightward error in bisecting very short lines, see Halligan & Marshall, 1988; Marshall & Halligan, 1989).

Taken together these results show that neglect can be explained by an anisometric representation of space that acts in a similar way as to the Oppel–Kundt illusion (Savazzi, Emanuele, Scalf, & Bech, 2012). However, in apparent contradiction with these pieces of evidence is a paper by Savazzi, Frigo, and Minuto (2004) reporting data in a reading task. The authors investigated the effect of the Oppel–Kundt illusion in patients presenting with neglect dyslexia, a reading disorder because of which patients commit reading errors in the side of the stimulus (a text line, a word or letter string) contralateral to the side of the lesion (see Vallar, Burani, & Arduino, 2010, for a recent review on neglect dyslexia). In this paper, neglect dyslexia ameliorated when neglect patients were requested to read words with an anisometric letter spacing that acted in accord (instead of in reverse as in Ricci et al., 2004 and Savazzi et al., 2007) with the distortion of the representational medium proposed by the space anisometry hypothesis. In all these papers, the authors predicted their results on the basis of the space anisometry hypothesis: that is, Ricci et al. (2004) and Savazzi et al. (2007) with line bisection tasks, predicted an amelioration of neglect signs when using an illusion that acted in reverse to the distortion of space in neglect and a worsening when using an illusion that acted in the same manner as the distortion of space in neglect. Conversely, Savazzi et al. (2004) with a reading task, predicted an amelioration of neglect signs when using an illusion that acted in the same manner as to the distortion of space in neglect and a worsening when using an illusion that acted in reverse to the distortion of space in neglect.

How could these contrasting predictions and, more importantly, these contrasting results be reconciled within the space anisometry framework? One possibility could be ascribed to the way the same material needs to be represented in order to solve a specific task. In a line bisection task, the line to bisect is represented as a single object (Robertson, Eglin, & Knight, 2003) with a specific horizontal extension (the length of the line in mm). To bisect a line, then, the subjects only need to process the global horizontal extension of the object presented to them. In a word reading task instead, at the early stage of word processing, the orthographic-visual analyser, the word needs to be represented as an ordered series of elements, in which the identity (Bigsby, 1988; Coltheart, 1981), and the position (Ellis, 1993; Ellis, Flude, & Young, 1987; Humphreys, Evett, & Quinlan, 1990; Peressotti & Grainger, 1995) of each letter matters. To read a word, then, the subjects need to represent each correct letter at its correct position. Relevant for the present reasoning, a deficit in the encoding of the relative position of letters within the word results in Letter Position Dyslexia, characterised by the migration of letters within the word (Friedmann & Gvion, 2001, 2005; Friedmann & Rahamim, 2007; Friedmann & Haddad-Hanna, 2012).

To test the possibility that contradicting findings result from the requests of the different tasks at hand, in the first experiment of the present paper we will use the same material (words) and ask neglect patients to both bisect and read the words. If the space anisometry hypothesis can account for both the findings by Ricci et al. (2004) and Savazzi et al. (2007) and those by Savazzi et al. (2004), we expect to find that the same neglect patients would show opposite results depending on the task at hand: that is, an anisometric background acting in the same manner as the distortion of space in neglect would produce a better performance in reading words and a worse performance in bisecting words. In the second experiment, we will further test this possibility by using a different sort of material that is thought, like words, to be made of an ordered sequence of elements represented along the left–right dimension: that is numbers. Indeed, it has been established that numbers seem to be represented with small numbers to the left and large numbers represented to the right, an effect exemplified by the metaphor of the "mental number line" (Dehaene, Dupoux, & Mehler 1990; Dehaene, Bossini, & Giraux, 1993). Interestingly, it has been found that in neglect patients the "mental number line" is disrupted (Zorzi, Priftis, & Umiltà, 2002). Indeed, when requested to bisect an orally presented numerical interval, neglect patients tend to report a number larger (rightward along the "mental number line") than the number dividing the interval in two equal halves. Moreover, similarly to what happens with physical lines, the rightward bisection bias with numerical intervals decreases as the length of the interval decreases and with very short intervals the bias reverses towards the left of the true midpoint (i.e. the crossover effect, Zorzi et al., 2002; Savazzi et al., 2007).

The exact interpretation of the nature of the "mental number line" and its possible dissociation with other tasks is beyond the scope of the present paper (see Zorzi et al., 2012 and van Dijck, Gevers, Lafosse, & Fias, 2012 for an interesting debate). Instead, what is relevant for the purposes of the present paper is the fact that to solve the representational task of finding the middle of a numerical interval, the subjects need (like with words) to represent the numbers as a series of elements ordered along the left–right dimension.

These effects have been reported also when the presentation of the numerical intervals were presented written on a page (Pia