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Line bisection error predicts the presence and severity of neglect dyslexia in paragraph reading

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ABSTRACT

Cancellation tasks and line bisection tasks are commonly used to diagnose spatial neglect after right hemisphere lesions. In such tasks, neglect patients often show leftsided omissions of targets in cancellation tests as well as a pathological rightward deviation in horizontal line bisection. However, double dissociations have also been reported and the relation between performance in both tasks is not clear. Another impairment frequently associated with the neglect syndrome are omissions or misread initial letters of single words, a phenomenon termed neglect dyslexia (ND). Omissions of whole words on the contralesional side of the page are generally considered as egocentric or space-based errors, whereas misreadings of the left part of a word in ND can be viewed as a type of stimulus-centered or word-based, perceptual error. As words, sentences and horizontal lines have a similar spatial layout in the sense that they all are horizontally aligned, long stimuli with a canonical left–right orientation (with a defined beginning on the left and an end on the right side), we hypothesized a significant association between the horizontal line bisection error (LBE) in neglect and the extent (number) of neglected or substituted letters within single words in ND (neglect dyslexia extension, NDE). To this purpose, we computed Center-of-Cancellation (CoC) scores in a cancellation task as well as Center-of-Reading (CoR) scores in an experimental paragraph reading test. We found that the CoR was a better indicator for egocentric word omissions than the CoC in a group of 17 patients with left visuospatial neglect. Furthermore, the LBE predicted the severity of ND, indicated by highly significant correlations between the LBE and the extent of the neglected letter string within single words (NDE; $r=0.73$, $p<0.001$) as well as between the LBE and the frequency of ND errors ($r=0.61$; $p=0.009$). In contrast, we found no significant correlation between the CoC and the severity of ND. These results indicate two different pathological mechanisms being responsible for contralesional spatial neglect and ND. In conclusion, the LBE is a more sensitive predictor of the presence *and* severity of the reading disorder in spatial neglect than conventional cancellation tasks.

1. Introduction

1.1. Different reference frames in neglect

Visual neglect has fascinated researchers during the last decades because of the multifaceted nature of the syndrome (see e.g. the recent special issue on neglect edited by Schenk and Karnath (2012)). Patients with visual neglect after unilateral right brain lesions do not report, respond, or orient to contralesional stimuli (Heilman, Watson, & Valenstein, 2012; Kerkhoff, 2001). Neglect patients typically show leftward omissions in cancellation or visual search tasks and a rightward deviation in horizontal line bisection (Schindler & Kerkhoff, 2004; Utz, Keller, Kardinal, & Kerkhoff, 2011). This ipsilesional line bisection error in neglect patients differs from the contralesional shift in chronic (Hesse, Lane, Aimola, & Schenk, 2012) or the slight ipsilesional shift in acute hemianopia (Machner, Sprenger, Hansen, Heide, & Helmchen, 2009). Several studies have shown that ego- and allocentric neglect phenomena are dissociable and rely on different neural structures (Halligan, Fink, Marshall, & Vallar, 2003). These results are consistent with the hypothesis that egocentric visual information processing is linked primarily to parieto-frontal brain areas in the dorsal stream whereas allocentric, object-centered visual processing is linked more closely to ventral stream areas (Grimsen, Hildebrandt, & Fahle, 2008; Hillis et al. 2005; Honda, Wise, Weeks, Deiber, & Hallett,

Abbreviations: COC, Center of Cancellation; CoR, Center of Reading; ND, Neglect Dyslexia; LBE, Line Bisection Error; NDE, Neglect Dyslexia Extension; CN, Contralesional spatial Neglect

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1998; Vallar, Burani, & Arduino, 2010; Verdon, Schwartz, Lovblad, Hauert, & Vuilleumier, 2010). Contralesional spatial neglect (CN) is commonly assessed with cancellation tasks like the bells test (Gauthier, Dehaut, & Joanette, 1989) or with a horizontal line bisection task (Doricchi et al., 2005; Schenkenberg, Bradford, & Ajax, 1980), as patients often show leftsided omissions of targets in cancellation tests and a pathological rightward deviation in line bisection. However, the relation between both tasks is not clear. For example, Azouvi et al. (2002) found that both tasks are correlated but load on different factors whereas Halligan, Marshall, and Wade (1989) found high factor-loads on the same factor. Binder, Marshall, Lazar, Benjamin, and Mohr (1992) reported a non-significant correlation of $r=0.39$ between the line bisection error and the performance in a cancellation test. They therefore concluded that both tasks indicate distinct syndromes of hemineglect, associated with lesions in discrete brain areas. Furthermore, several double dissociations have been reported between line bisection and cancellation tests (Binder et al., 1992; Ferber & Karnath, 2001; Ferro & Kertesz, 1984; Halligan & Marshall, 1992; Marshall & Halligan, 1995; McGlinchey-Berroth et al., 1996). Hence, it is questionable whether impairments in line bisection and in cancellation tests underly the same disturbed cortical processes or reflect distinct aspects of the neglect syndrome based on different affected spatial reference systems and brain areas. In the study of Binder et al. (1992) as well as in an investigation of Rorden, Fruhmann, and Karnath (2006) a pathological LBE was associated with lesions in posterior brain regions whereas patients with abnormal cancellation performance and no LBE were injured primarily in anterior brain areas.

Considering the reported anatomical and behavioral dissociations as well as the evidence that both tasks can be modulated specifically indicate that different reference frames are necessary to perform the tasks. For example, visual search performance in neglect patients depends on the size of the visual scene (Eglin, Robertson, Knight, & Brugger, 1994) and the rightward line bisection error (further termed LBE) increases as a function of line length (Bisiach, Bulgarelli, Sterzi, & Vallar, 1983; Halligan & Marshall, 1988; Marshall, 1998). However, Keller, Schindler, Kerkhoff, Rosen, and Golz (2005) found only the LBE increasing with the distance between the subject and the stimulus whereas the performance in a cancellation task remained unaffected by that manipulation. Interestingly, the LBE seems to be influenced by the subject's reading direction habit. Chokron and Imbert (1993) found in normal subjects that Israeli (who read from right to left) tend to bisect a line at the right of the objective center whereas French subjects placed their bisection mark at the left of the physical middle, a phenomenon well known as pseudo neglect (Jewell & McCourt, 2000). In line with this result, Speedie et al. (2002) found in an intercultural investigation that neglect patients of European languages tend to bisect a horizontal line with a rightward deviation whereas patients of Semitic languages showed a bisection error closer to the physical center of the line. In contrast, they found no such difference in the performance in a cancellation task between both groups.

Taken together, there is ample evidence that both tasks require distinct spatial reference frames, with an egocentric frame for searching spatially distributed targets and a stimulus- or even an object-centered reference frame for the bisection of a single perceptual object (the horizontal line) with a canonical left–right orientation.

1.2. Neglect dyslexia (ND)

Neglect dyslexia (further termed ND) reflects a peripheral reading disorder associated with the neglect syndrome. Left-sided neglect can impair reading in different ways. Patients typically omit initial whole words of a text line (text or space related omissions, Reinhart, Keller, & Kerkhoff, 2010). However, ND in the narrow sense defines word-related errors characterized by omissions or substitutions of initial letters of single words horizontally presented in central vision. These substitutions or omissions of letters mostly lead to reading errors that resemble or form alternative words but not neologisms (e.g., misreading "start" as "art" or "mouse" as "house", cf. Ellis, Flude, & Young, 1987; Kinsbourne & Warrington, 1962). Several single case studies found a clear word-length effect in ND for the frequency of errors (Tegner & Levander, 1993; Subbiah & Caramazza, 2000; Behrmann, Moscovitch, Black, & Mozer, 1990) as well as for the number of omitted or substituted letters which increases with the length of the word in single word reading (Behrmann et al., 1990; Ellis et al., 1987; Subbiah & Caramazza, 2000; Tegner & Levander, 1993). Most of the reported single cases made more substitution than omission errors (for a review see Vallar et al. (2010)) but investigations of groups with ND have shown a variation of these two error types in different patients (Cubelli & Beschin, 2005; Kinsbourne & Warrington, 1962; Lee et al., 2009; Savazzi, Frigo, & Minuto, 2004).

Based on the assumption that words represent a class of visual objects Caramazza and Hillis (1990) adapted Marr and Nishiharas' levels of processing model (Marr & Nishihara, 1978; Marr, Ullman, & Poggio, 2010) for the early stages of visual word recognition. According to their model, words are processed hierarchically at three representational levels from the (1) viewer-centered analysis of visual features of the word followed by a (2) stimulus-centered representation to an (3) abstract word-centered description of the letter string. Disturbances of these different processing levels should be associated with specific reading errors, with viewer-centered omissions of words (or analog omissions of targets in a cancellation task) reflecting impairments on the viewer-centered level and ND errors reflecting impaired stimulus- or word-centered levels.

Even though ND is mostly related to contralesional hemispatial neglect (Vallar et al., 2010; further termed CN) the association of both disturbances is unclear. Several double dissociations have been reported in group studies (Behrmann, Black, McKeeff, & Barton, 2002) and single case studies (Cantoni & Piccirilli, 1997; Costello & Warrington, 1987; Haywood & Coltheart, 2001; Patterson & Wilson, 1990; Patterson & Wilson, 1990). By contrast, Lee et al. (2009) found the severity of CN to be a significant predictor for the frequency of ND errors. In two recent investigations we found that a manipulation of the egocentric reference frame by head rotation (Reinhart, Keller, & Kerkhoff, 2010), or optokinetic stimulation (Reinhart, Schindler, & Kerkhoff, 2011) only reduced egocentric or viewer-centered word omissions whereas the stimulus- or word-based ND errors remained completely unaffected by these manipulations in the same text reading task. Taken together, there is some evidence that neglect assessed with reading tasks can independently occur in the viewer-centered (left-sided word omissions) and object-centered (left-sided letter omissions/substitutions) reference frames but there are also contrary results. These contrary results may be attributable to different assessments of CN that were used to investigate this issue. For example, Lee et al. (2009) assessed the severity of CN with a neglect test battery containing line bisection tasks. By contrast, Arduino, Burani, and Vallar (2002) found that ND was not significantly affected by the severity of CN assessed with a test battery *without* a line bisection task.

As the use of the results of a whole test battery (containing line bisection and cancellation tasks) blends different aspects of neglect (object-centered and spatial neglect), it should be more insightful to investigate the association between ND and other aspects of neglect using the results of the single tests. Using such