Brain Research 1648 (2016) 144–151

Contents lists available at ScienceDirect

Brain Research

journal homepage: www.elsevier.com/locate/brainres

Research report

The role of parieto-temporal connectivity in pure neglect dyslexia

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ARTICLE INFO

Article history:
Received 6 March 2016
Received in revised form
1 July 2016
Accepted 19 July 2016
Available online 20 July 2016

Keywords:
Visual attention
Reading
Neglect dyslexia
Spatial neglect
Parietal lobe
Temporal lobe
Disconnection

ABSTRACT

The initial stages of reading are characterised by parallel and effortless access to letters constituting a word. Neglect dyslexia is an acquired reading disorder characterised by omission or substitution of the initial or the final letters of words. Rarely, the disorder appears in a'pure' form that is, without other signs of spatial neglect. Neglect dyslexia is linked to damage involving the inferior parietal lobe and regions of the temporal lobe, but the precise anatomical basis of the pure form of the disorder is unknown. Here, we show that pure neglect dyslexia is associated with decreased structural connectivity between the inferior parietal and lateral temporal lobe. We examined patient DM, who following bilateral occipito-parietal damage presented left neglect dyslexia together with right visual field loss, but no signs of spatial neglect. DM's reading errors were affected by word length and were much more frequent for pseudowords than for existing words. Most errors were omissions or substitutions of the first or second letter, and the spatial distribution of errors was similar for stimuli presented left or right of fixation. The brain lesions of DM comprised the inferior and superior parietal lobule as well as the cuneus and precuneus of the left hemisphere, and the angular gyrus and lateral occipital cortex of the right hemisphere. Diffusion tensor imaging revealed bilateral decrease of fibre tracts connecting the inferior parietal lobule with the superior and middle temporal cortex. These findings suggest that parieto-temporal connections play a significant role for the deployment of attention within words during reading.

1. Introduction

Perceiving and acting toward objects requires computing representations that relate the spatial coordinates of the object to the viewer (egocentric coding) or to other objects in the environment (allocentric coding). In an egocentric reference system the horizontal and vertical coordinates of the stimulus are defined with respect to the viewpoint of the observer while in an allocentric system they are independent of a subjective viewpoint. The study of spatially lateralized deficits of visual attention such as extinction or neglect has strongly contributed to the understanding of how the human brain processes spatial relationships between objects and the viewer or the environment (Halligan et al., 2003; Hillis, 2006). The study of neglect dyslexia, a reading disorder affecting the letters of a word that are located opposite to a unilateral brain damage, has provided particularly abundant findings concerning spatial reference systems in the brain (Ellis et al., 1987; Vallar et al., 2010). Neglect dyslexia is characterised by omissions or substitutions of the initial or final letters of words, leading to neologisms or the replacement of a word by another. Given that words are almost always presented in a canonical view and reading always proceeds in the same direction one may expect words to be coded exclusively in an egocentric reference system. However, based on David Marr's (1982) model of the coding of visual objects and on observations of patients with distinct patterns of reading disorders Hillis and Caramazza (1995) proposed that words (as a special case of visual 'objects') are coded in distinct spatial reference frames. At the most basic level of representation – the viewer-centred frame – the position of the word is related to a vertical axis defined by the viewer's body, head or retina. Given that the position of the word is specified with respect to the viewer, this representation is crucial for the programming of eye movements during reading. The simplest way to test whether neglect dyslexia depends on a viewer-centred representation is to show words at different horizontal positions. A purely viewer-centred deficit would be expected if the neglected proportion of letters were greater for words placed more contralesionally respective to the egocentric viewpoint. At the next level, the

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http://dx.doi.org/10.1016/j.brainres.2016.07.033
0006-8993/

Please cite this article as: Ptak, R., et al., The role of parieto-temporal connectivity in pure neglect dyslexia. Brain Research (2016), http://dx.doi.org/10.1016/j.brainres.2016.07.033

cognitive representation is defined by the intrinsic vertical axis of the word, and is therefore independent of the word's position respective to the viewer. The representation is stimulus-centred, which means that reading errors will not depend on the horizontal position of the word: a comparable proportion of letters will be neglected for words placed in left or right space (Ellis et al., 1987; Hillis and Caramazza, 1991). Finally, at the most abstract level of representation – the word-centred frame – the intrinsic coordinates of the word are not only independent relative to the viewer, but also its orientation in space. A deficit affecting this representation will become manifest in neglect errors that are independent of whether words are presented horizontally or rotated (Caramazza and Hillis, 1990; Miceli and Capasso, 2001). This model has the advantage that it allows understanding partly the heterogeneity of error patterns presented by different patients with neglect dyslexia.

In one of the first papers on neglect dyslexia Ellis et al. (1987) concluded that the disorder has no specificity, but is a simple consequence of other neglect symptoms. Indeed, while the presence of neglect is not a systematic predictor of neglect dyslexia (Behrmann et al., 2002), most patients with this disorder also exhibit other signs of neglect (Vallar et al., 2010) or may show disturbed oculomotor behaviour that is not confined to reading (Primativo et al., 2013; Primativo et al., 2015). Among the classic paper-and-pencil tests used to assess neglect line bisection appears to be the only significant predictor of neglect dyslexia (Ptak et al., 2012; Reinhart et al., 2013). Nevertheless, several case studies of ‘pure’ neglect dyslexia (i.e., dyslexia without other neglect symptoms; Arduino et al., 2005; Haywood and Coltheart, 2001; Riddoch et al., 1990) or of dyslexia that is dissociated from other signs of neglect (e.g., left dyslexia with right neglect in cancellation tasks; Costello and Warrington, 1987; Cubelli et al., 1991; Humphreys and Riddoch, 1995) have been reported. However, all patients classified as ‘pure’ neglect dyslexics had at least partial visual field loss that may have influenced the reading disorder, in particular if combined with subclinical symptoms of neglect. Thus, the degree of interdependence between neglect dyslexia, visual field loss and other neglect symptoms is not entirely clear.

Another relevant question regarding neglect dyslexia concerns its anatomical correlates. Of particular interest are anatomical dissociations between neglect dyslexia (as special form of ‘stimulus-centred’ deficit) and viewer-centred deficits, which would support the independence of egocentric and allocentric representations in the brain. Unfortunately, anatomical correlates have not been the focus of previous reports of pure neglect dyslexia. However, two group studies examined lesion location in right-hemisphere damaged neglect patients with signs of dyslexia, compared to neglect patients without the reading disorder. Lee et al. (2009) reported that neglect dyslexia was selectively associated with damage to the right fusiform and lingual gyrus, though the lesions in their patients also encroached upon more dorsal regions including the inferior parietal cortex. We performed a similar study on 19 patients with neglect dyslexia and found that the disorder was best predicted by a combination of damage to the posterior parietal lobe (including the angular gyrus and the intraparietal sulcus) and middle and inferior temporal gyri (Ptak et al., 2012). This finding suggests that stimulus-centred reading deficits may be a consequence of combined damage to the dorsal and the ventral stream of visual information processing (Ungerleider and Mishkin, 1982; Ungerleider and Pasternak, 2003).

Here, we studied a patient with pure neglect dyslexia following bilateral occipito-parietal lesions. Despite the presence of right homonymous hemianopia reading errors concerned the left side of the stimulus. A detailed structural imaging and tractography study revealed bilateral disconnection between damaged inferior parietal cortex and preserved middle/superior temporal cortex. These findings indicate that stimulus-centred deficits in reading result from parieto-temporal disconnection.

2. Materials and methods

2.1. Case report

DM, a 45 years old, right-handed (lateralization index: 100; Oldfield, 1971) coachbuilder suffered bilateral cerebral infarctions due to disseminated intravascular coagulation following manifestation of acute myeloid leukaemia. MRI showed a large left parietal lesion as well as a smaller right inferior parietal and superior occipital lesion. The patient had complete right hemianopia and initially showed visuo-perceptual deficits characterised by optic ataxia, impossibility to detect or localise visual targets when several distracters were present (simultanagnosia) as well as slight difficulty disengaging gaze from a fixated object (ocular apraxia). Reading was very difficult and frustrating for the patient. The signs of a Bálint syndrome regressed within the first weeks and the patient regained his independence in most activities of daily life. However, he continued to exhibit difficulty with reading, often transforming the beginning of a word (e.g., he would read the word ‘distraction’ as ‘contraction’). The present study was performed two years following onset of the symptoms. At this time the patient was completely independent in daily life and showed excellent compensation of his right visual field loss. Approval for this study was obtained from the ethical committee of the University Hospitals Geneva, and DM gave written informed consent.

A neuropsychological examination including detailed assessment of DM's visual and visual-spatial impairments was performed 1.5 years following injury. The patient had an average verbal IQ (94), but low performance IQ (68) at the WAIS (Wechsler, 2008) due to impaired performance on picture completion, digit-symbol and block design subtests. He had normal spoken language including naming (100% correct on the Boston naming test), praxis and verbal and nonverbal recognition memory (Warrington, 1984). Humphrey Perimetry revealed a right homonymous hemianopia with macular sparing of $\sim$5 degrees in the upper quadrant (Fig. 1). The patient had normal colour perception as tested with the Ishihara test and a short form of the Farnsworth test, and normal object (including identification of silhouettes, Table 1) and face perception (Benton faces test). Table 1 shows that DM had moderate to severe impairments of visual-spatial functions while he scored comparatively better in object identification. He had no neglect on cancellation tasks (always starting on the left), or complex figure drawing, and line bisection performance was only slightly biased (compatible with slight over-compensation towards the side of hemianopia), but remained within the range of healthy controls (Ronchi et al., 2012). On a variant of the Posner task (Zimmermann and Fimm, 2010) the patient showed no signs of a disengagement deficit (Table 1) which is strongly associated with left neglect (Losier and Klein, 2001; Morrow and Ratcliff, 1988). Together, these findings indicate that though DM had non-lateralized visual-spatial impairments, he had no sign of left neglect in classic paper-and-pencil tests or of a deficit of attentional disengagement.

2.2. Stimuli

Two sets of words and matched non-words were used for the experiments. Set 1 was constructed in order to test linguistic factors such as word length (in terms of the number of letters), frequency and lexical status. It comprised 180 words of 3–10 letters, 1–4 syllables and 0–25 orthographic neighbours, and a mean frequency of 78.5 per thousand according to the Lexique database of

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