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The effect of cerebral asymmetries and eye scanning on pseudoneglect for a visual search task

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ABSTRACT

Pseudoneglect is the tendency for the general population to over-attend to the left. While pseudoneglect is classically demonstrated using line bisection, it also occurs for visual search. The current study explored the influence of eye movements and functional cerebral asymmetry on asymmetries for visual search. In Experiment 1, 24 participants carried out a conjunction search for a target within a rectangular array. A leftward advantage for detecting targets was observed when the eyes were free to move, but not when they were restricted by short exposure durations. In Experiment 2, the effect of functional cerebral asymmetry was explored by comparing 20 right-handers and 19 left-handers. Results showed a stronger leftward bias for the right-handers, consistent with a mechanism related to cerebral asymmetry. In Experiment 3, an eye-tracker directly controlled eye movements in 25 participants. A leftward advantage emerged when the eyes were still, but not when they were free to move. Experiments 1 and 3 produced contradictory results in relation to eye movements, which may be related to task-related demands. On balance, the data suggest that asymmetries in visual search can occur in the absence of eye movements and that they are related to right hemisphere specialisation for spatial attention.

1. Introduction

One of the most striking examples of attentional asymmetries comes from clinical neglect patients. These patients typically suffer a right parietal cortex lesion, which causes them to ignore stimuli located in the left hemispace and over-attend to stimuli in the right (Heilman, Watson, & Valenstein, 1993). Clinical neglect is classically demonstrated using a line bisection task, where patients are shown a horizontal line and asked to place a mark thought the middle. Instead of placing the mark around the true middle, neglect patients bisect the line far to the right of centre (Milner, Harvey, Roberts, & Forster, 1993). This rightward deviation may reflect an abnormal gradient of attention, where the salience of the leftward portions of the line are reduced relative to those on the right (Nichelli, Rinaldi, & Cubelli, 1989). In addition to line bisection, neglect is observed for a range of other tasks including the greyscales (Mattingley et al., 2003), cancellation (Ferber & Karnath, 2001), and cued target detection (Posner, Walker, Friedrich, & Rafal, 1984) tasks. Further, clinical neglect can be object-based (Egly, Driver, & Rafal, 1994), occurring for mental representations of scenes (Bisiach & Luzzatti, 1978), numbers (Zorzi, Priftis, Meneghell, Marenzi, & Umilta, 2002), and letters (Nicholls & Loftus, 2007), which suggests a higher-order disruption in the allocation of attention.

The general population also show attentional asymmetries – albeit in a much more subtle form. Along the horizontal axis, most people pay slightly more attention to the leftward features of a stimulus compared to those on the right (Bultitude & Aimola Davies, 2006; Nicholls & Roberts, 2002). While this attentional bias is in the opposite direction to neglect, it does seem to share many of its features (Jewell & McCourt, 2000) – and for this reason is often referred to as 'pseudoneglect' (Bowers & Heilman, 1980). Like neglect, pseudoneglect is classically demonstrated using line bisection. Irrespective of whether observers manually bisect a line (Learmonth, Gallagher, Gibson, Thut, & Harvey, 2015) or judge the midpoint on a pre-bisected line (McCourt & Jewell, 1999), they will reliably overestimate the length on the left. As with neglect, pseudoneglect occurs for a variety of tasks ranging from line and shape bisection (Churches, Loetscher, Thomas, & Nicholls, 2016) to cancellation (Vingiano, 1991) and greyscales (Nicholls, Bradshaw, & Mattingley, 1999) tasks. Pseudoneglect also appears to be dependent on both space- and object-based coordinates (Orr & Nicholls, 2005) and occurs for the mental representation of scenes (McGeorge, Beschin, Colnaghi, Rusconi, & Della Sala, 2007), numbers (Loftus, Nicholls, Mattingley, Chapman, &

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Bradshaw, 2009) and letters (Nicholls & Loftus, 2007). Thus, like neglect, pseudoneglect reflects a higher-order asymmetry in the distribution of spatial attention.

A number of candidate mechanisms have been proposed to explain pseudoneglect. Foremost amongst these is a model based on functional asymmetries in the control of spatial attention. It is well known that symptoms of clinical neglect are associated with lesions to the right inferior parietal cortex (Vallar & Perani, 1987). Similarly, pseudoneglect has been associated with increased activity of the right parietal region (Bjoertomt, Cowey, & Walsh, 2002; Foxe, McCourt, & Javitt, 2003; Waberski et al., 2008). The activation–orientation model has been proposed to link these functional asymmetries with biases in attention (Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990). This model is based on the notion that spatial attention is governed by two opposing attentional gradients, which are controlled by the contralateral hemisphere (Kinsbourne, 1970). Higher levels of activation within a hemisphere are thought to increase the slope of the gradient – resulting in a bias of attention towards the contralateral hemispace. Support for the activation-orientation account comes from attentional cueing studies (Bultitude & Aimola Davies, 2006; Nicholls & Roberts, 2002) as well as from studies showing that conditions, which might be expected to exacerbate right hemisphere activation, increase the magnitude of pseudoneglect. For example, use of the left hand (McCourt, Freeman, Tahmahkera-Stevens, & Chaussee, 2001) or presentation in the left hemispace (McCourt, Garlinghouse, & Slater, 2000; McCourt & Jewell, 1999) intensifies pseudoneglect. More recently, models of neural connectivity have been proposed, which suggest increased connectivity within the right hemisphere and/or connectivity from the right- to the left-hemisphere (Siman-Tov et al., 2007). This asymmetry in connectivity results in enhanced recruitment of both hemispheres for the processing of stimuli located in the left hemispace (Siman-Tov et al., 2007).

Eye movements have also been implicated in the manifestation of pseudoneglect. Initial saccades to the left side of a stimulus (Dickinson & Intraub, 2009) or more time spent inspecting the left side (Nuthmann & Matthias, 2014) could lead to an overrepresentation of the leftward features compared to the right. Asymmetries in eye movements may be driven by two different mechanisms. The first is related to functional cerebral asymmetries; Nuthmann and Matthias (2014) showed that observers spend more time fixating the left when viewing scenes to make aesthetic or memory judgements. They concluded that eye movements were an overt manifestation of attentional allocation, in line with research showing a common link between target selection and saccades (Deubel & Schneider, 1996).

Another possibility, however, is that asymmetries in eye movements are a cultural artefact. Early research in this field found that readers of Hebrew, with a right-to-left reading habit, showed no pseudoneglect for a line bisection task, whereas readers of French, with a left-to-right reading habit, showed the normal pattern of pseudoneglect (Chokron, Bernard, & Imbert, 1997). While similar results have been reported by Vaid and Singh (1989) for readers of Hindi and Urdu when viewing chimeric faces, no effect of reading direction was reported by Nicholls and Roberts (2002) for readers of English and Hebrew. More nuanced research has recently been carried out by Rinaldi, Di Luca, and Girelli (2014). They compared perceptual asymmetries during a star cancellation task for monolingual readers of Italian and Hebrew and bilingual readers of Hebrew and English. While they found that reading direction had a significant effect on perceptual asymmetries, they also noted these effects interacted with underlying brain asymmetries – suggesting that both processes play a role in perceptual asymmetries.

It is clear that eye movements have the potential to play an important role in pseudoneglect. These eye movements could be a reflection of an underlying functional cerebral asymmetry – or they could be a cultural artefact. This programme of research sought to clarify the impact of eye movements on perceptual asymmetries by manipulating factors related to eye movement, as well as the strength of functional asymmetry. If we are able to demonstrate that pseudoneglect is related to functional cerebral asymmetries and can exist in the absence of overt eye movements, it will further strengthen the argument that pseudoneglect shares a common biological basis with neglect (e.g., Loftus & Nicholls, 2012).

2. Experiment 1

Although a wide variety of tasks have been used to show pseudoneglect, one task that has received comparatively little attention is visual search. This is surprising given the long history of experimentation on visual search (Treisman & Gelade, 1980) and the large impact is has had in the field of Experimental Psychology (e.g., Wolfe, 1998). It is also surprising given that the paradigm has been applied to clinical neglect patients. For example, Wilkinson, Ko, Milberg, and McGlinchey (2008) asked neglect patients to search arrays with the target identified by either a unique colour or orientation. Results demonstrated that the orientation target was detected less efficiently in the neglected hemifield – but that the detection of colour was not affected. Olk, Harvey, and Gilchrist (2002) also found impaired detection of targets in the neglected hemifield in multiple stimulus displays. More importantly, this asymmetry persisted despite the fact that the neglect symptoms appeared to be otherwise recovered – suggesting that visual search is potentially a particularly sensitive test of attentional asymmetry.

Given the apparent sensitivity of visual search, Nicholls et al. (2014) investigated whether pseudoneglect can be observed for visual search arrays. In the array task, participants searched for a target (inverted triangle) amongst 59 distractors (upright triangles; see Fig. 1). The task requires a conjunction feature search related to the three elements of triangle – and therefore entails a top-down search (Treisman & Gelade, 1980). Analysis of both error and reaction time (RT) demonstrated an advantage for detecting targets on the left side and Nicholls et al. (2014) concluded the data were compatible with an attentional asymmetry related to pseudoneglect. That said, given the stimuli were presented for up to 4000 ms, it is clear that eye movements played a major role in the perceptual asymmetry. With this in mind, the array task developed by Nicholls et al. (2014) may be a particularly good means of clarifying the relative importance of both cerebral asymmetries and eye movements to pseudoneglect.

Experiment 1 investigated the role of overt eye movements on pseudoneglect for the array task by manipulating exposure duration. On half of the trials, the array was presented for 4000 ms. This long exposure allowed sufficient time for many exploratory eye movements and therefore any bias could be a

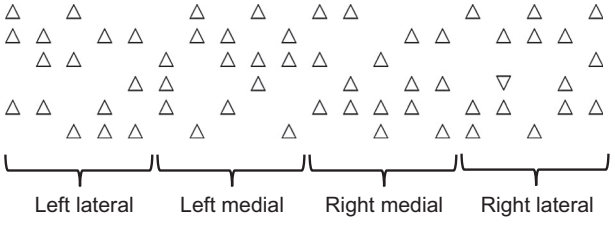

Fig. 1. Illustration of a 'target present' array. The quadrants used in the analysis are shown below the array. In this case, the target is present in the right lateral quadrant.