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Research report

Biased temporal order judgments in chronic neglect influenced by trunk position

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ABSTRACT

Numerous studies have reported that temporal order perception is biased in neurological patients with extinction and neglect. These individuals tend to perceive two objectively simultaneous stimuli as occurring asynchronously, with the ipsilesional item being perceived as appearing prior to the contralesional item. Likewise, they report that two stimuli occurred simultaneously in situations where the contralesional item is presented substantially prior to the ipsilesional item. Therefore, they exhibit a biased point of subjective simultaneity (PSS). Here we demonstrate that the magnitude of this effect is modulated by the relative position of the stimuli with respect to the patient's trunk. This effect was only observed in patients who still exhibited neglect symptoms, and neither the pathological bias nor substantial modulation were observed in individuals who had recovered from neglect, those who never had neglect or neurologically healthy controls. Crucially, our design kept the retinal and head-centered coordinates of these stimuli constant, providing a pure measure for the influence of egocentric trunk position. This finding emphasizes the interaction of egocentric spatial position on the temporal symptoms observed in these individuals.

1. Introduction

Biased spatial perception is a common consequence of predominantly right hemisphere brain injury. For example, visual spatial neglect is a syndrome where individuals are impaired at detecting stimuli on their contralesional side. A popular test for neglect is cancellation where individuals are asked to find all occurrences of the letter 'A' on a piece of paper cluttered with characters. People with neglect tend to only find the targets on the ipsilesional side of the page. One well established finding is that this exploration and attentional orienting performance tends to be modulated by trunk position (for review Karnath, 2015), such that more targets are found if the paper is shifted ipsilesionally with respect to trunk position. On the other hand, task performance is not similarly influenced by head position or initial gaze position (Karnath, Christ, & Hartje,1993; Karnath, Schenkel, & Fischer, 1991). While this syndrome is defined by this spatial deficit,

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previous work has suggested that many individuals with perceptual deficits following stroke also experience problems in temporal processing (for review, see Becchio & Bertone, 2006). For example, in the 'temporal order judgment task' when observing two objectively simultaneous items, individuals with extinction and neglect tend to perceive the events as asynchronous, with the contralateral item reported as appearing first (Rorden, Mattingley, Karnath, & Driver, 1997). However, the relationship between these spatial and temporal deficits remains largely unexplored. One possibility is that the temporal deficits are completely independent of the spatial deficits, and associations between these symptoms merely reflect that the neighboring spatial and temporal modules are often injured together. This notion is consistent with claims that the human brain has a dedicated 'when' system (which resolves the temporal sequence of events) in addition to the well established ventral 'what' (object identification) and dorsal 'where' (stimuli location) systems (Battelli, Pascual-Leone, & Cavanagh, 2007; Battelli, Walsh, Pascual-Leone, & Cavanagh, 2008). Alternatively, it is logically possible that these temporal deficits are a consequence of the core spatial disorder. According to this view, contralesional stimuli are under-represented in these patients (Driver & Pouget, 2000), and therefore responses are weaker and take longer to reach the threshold required for detection. These two competing models make testable predictions. Specifically, if temporal and spatial deficits are independent, we should see similar temporal deficits regardless of spatial perception. On the other hand, if the temporal deficit is an emergent property of the spatial deficit, the temporal deficits should by modulated by spatial location. Our goal was to directly test this prediction using the popular temporal order task.

According to an integrated view of the temporal and perceptual deficits seen in spatial neglect, these patients suffer from a continuous rather than categorical spatially-modulated impairment of perceptual capacity (Driver & Pouget, 2000): they do not merely have a 'good' and 'bad' visual half-field, but rather a gradient from relatively intact perception in the ipsilesional field to a weaker representation in contralesional field. According to this model, contralesional stimuli generate weaker signals than ipsilesional competitors, and therefore require longer to reach a threshold sufficient to be perceived (Desimone & Duncan, 1995). This would explain the explicit neglect for relatively contralesional items as well as their delayed perception (reflecting the weaker signal). Therefore, one of the predictions of this unified model is that all the deficits associated with these syndromes become less severe for information on the right side of the space.

However, any explanation of the spatial deficits observed in neglect needs to define the frame of reference that defines the contralesional side: in theory this could be based on eye position, head position, trunk position, object-based position, or any combination of these (potentially modulated by gravitational direction). Here we leverage the fact that prior studies have emphasized that the core spatial deficit observed in neglect appears to be dominated by the stimuli's position relative to the observer's trunk, rather than with respect to the location of visual fixation or head position (for review Karnath, 2015). In fact, this is fortunate, as retinal eccentricity is well known to influence temporal processing, as we discuss later.

Individual differences in determining the temporal sequence of events have been explored for years. For example, astronomers measured the 'personal equation' to account for temporal biases that differ between observers (Spence & Parise, 2010). One popular task is the 'temporal order judgment' (TOJ) paradigm, where an observer is asked to report the sequence of events. This task is analogous to the job of a baseball umpire who needs to determine the temporal sequence of distant visual events, e.g., determining whether the batter's foot touched the base before or after the ball touched the catcher's glove. Studies of the TOJ have revealed that an individual's point of subjective simultaneity (PSS, where an observer does not reliably report one item occurring before another) can be influenced by bottom-up (reflexive) as well as top-down (strategic) attentional cues (for review see Spence & Parise, 2010) as well as visual eccentricity (Westheimer, 1983). Numerous studies have demonstrated that patients with neglect and/or extinction exhibit pathologically biased temporal order judgments (Baylis, Simon, Baylis, & Rorden, 2002; Berberovic, Pisella, Morris, & Mattingley, 2004; Dukewich et al., 2012; Robertson, Mattingley, Rorden, & Driver, 1998; Rorden, Jelsone, Simon-Dack, Baylis, & Baylis 2009; Rorden et al., 1997; Sinnett, Juncadella, Rafal, Azañón, & Soto-Faraco, 2007) where the item on the contralesional side must be presented much earlier (typically in the order of 200 msec) than the item on the ipsilesional side in order to be perceived as being simultaneously. On the other hand, neurologically healthy individuals who are accustomed to left-to-right reading tend to a subtle effect in the opposite direction, tending to perceive the left item as occurring first when confronted with two simultaneous stimuli (for review, see Pérez, García, Valdés-Sosa, & Jaśkowski, 2011).

We hypothesized that the pathological temporal order judgment biases observed in stroke patients would be more severe if stimuli were presented on the contralesional side of the individual's trunk, compared to identical stimuli presented on their trunk's ipsilesional side. This would provide clear evidence that the temporal deficits observed in the temporal order task interact with or are driven by the spatial biases. Crucially, across all conditions we presented the stimuli at the same locations with respect to the fovea (as eccentricity can influence TOJs, Westheimer, 1983) and the head, (thus varying only trunk-centered egocentric coordinates). We predicted that trunk-based modulation of TOJ would be specific to individuals who actively exhibit the core symptoms of spatial neglect, which are associated with biased egocentric, body-related internal maps (Karnath et al., 1993, 1991; Karnath & Rorden, 2012). To test this hypothesis, we recruited both neurologically healthy controls as well as three groups of chronic stroke survivors: those who never exhibited neglect, those who had exhibited neglect at the acute stage but had recovered by the time of experimental testing and those who still suffered from spatial neglect. We predicted that only the final group had a trunk-based bias and thus would exhibit an interaction between trunk position and perception.