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Trunk rotation affects temporal order judgments with direct saccades: Influence of handedness

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ABSTRACT

Manipulation of the trunk midline has been shown to improve visuospatial performance in patients with unilateral visual neglect. The goal of the present study was to disentangle motor and perceptual components of egocentric midline manipulations and to investigate the contribution of individual hand preference. Two versions of visual temporal order judgment (TOJ) tasks were tested in healthy right- and left-handed subjects while trunk rotation was varied. In the *congruent* version, subjects were required to execute a saccade to the first of two horizontal stimuli presented with different stimulus onset asynchronies (SOA). In the *incongruent* version, subjects were required to perform a vertical saccade to a pre-learned color target, thereby dissociating motor response from the perceptual stimulus location. The main findings of this study are a trunk rotation and response direction specific impact on temporal judgments in form of a prior entry bias for right hemifield stimuli during rightward trunk rotation, but only in the congruent task. This trunk rotation-induced spatial bias was most pronounced in left-handed participants but had the same sign in the right-handed group. Results suggest that egocentric midline shifts in healthy subjects induce a spatially-specific motor, but not a perceptual, bias and underline the importance of taking individual differences in functional laterality such as handedness and mode of perceptual report into account when evaluating effects of trunk rotation in either healthy subjects or neurological patients.

1. Introduction

In daily life, we typically look at objects before reaching for them. Thus, the generation of goal-directed actions requires the integration of the location of visual objects with the current position of eye, head and trunk into a body-centered, egocentric frame of reference (Cohen and Andersen, 2002; Colby, 1998). This transformation is thought to take place within the same brain regions that are also involved in spatial attention and visuomotor planning, such as fronto-parietal and superior temporal cortices (Andersen et al., 1993; Brotchie et al., 1995; Crawford et al., 2011). The critical role of those brain areas in the transformation of visual input into an egocentric coordinate system is underlined by the occurrence of spatial neglect after lesions involving the intraparietal sulcus and the temporo-parietal junction (Chechlacz et al., 2010; Chechlacz et al., 2013; Karnath et al., 2001). Spatial neglect, a neuropsychological syndrome that occurs mostly after lesions in the right hemisphere, is characterized by impairments in the ability to orient, perceive, and respond to stimuli in the contralesional hemifield (Chokron et al., 2007).

1.1. Effect of trunk rotation on spatial performance in neglect patients and healthy subjects

One of the core deficits of spatial neglect, the strong bias of exploratory movements towards the ipsilesional space, has been proposed to result from a lesion-induced deviation of the egocentric trunk midline towards the ipsilesional space

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(Fruhmann-Berger and Karnath, 2005; Karnath, 1997, 2015; Ventre et al., 1984). In support of this theory, neuropsychological research has demonstrated that neglect patients experience a subjective shift of their trunk midline towards the ipsilesional (i.e. right) side (Ferber and Karnath, 1999; Karnath, 1994). This subjective shift of the trunk midline in neglect patients seems to be associated with the occurrence of a rightward spatial bias, as the pattern of exploratory eye movements is shifted in respect to the *objective* trunk midline, while being symmetrical in respect to the *subjective* trunk midline (Hornak, 1992; Karnath et al., 1991). Furthermore, several studies demonstrated that manipulations of the physical or perceived trunk midline (via neck muscle or caloric-vestibular stimulation) can alleviate visual neglect symptoms (Johannsen et al., 2003; Karnath et al., 1993, 1991; Rode and Perenin, 1994; Schindler and Kerkhoff, 1997; Schindler et al., 2002). Specifically, those studies reported that either physical or illusory rotations of the trunk towards the contralesional side shortened saccade latencies towards the (mostly left) neglected hemifield (Karnath et al., 1991), re-centered exploratory eye movements, and improved visual detection performance in the absence of an overt motor response (Karnath et al., 1993).

Although trunk rotation has been consistently reported to improve spatial performance in neglect patients (see Chokron et al., 2007 for review), reports of effects for either physical or perceived trunk rotation in neurologically intact subjects are inconsistent. Karnath and co-workers observed spatially biased, neglect-like oculomotor search patterns in darkness with neck-proprioceptive and caloric vestibular stimulation in healthy subjects (Karnath et al., 1996). Two other studies reported significant effects of trunk rotation on attentional and visual detection performance in healthy subjects: Employing a version of the Posner task, Grubb and Reed reported that leftward trunk rotation increased response times for invalidly cued targets in the right hemifield; and Hasselbach-Heitzeg and Reuter-Lorenz reported shortening of response times and improved detection performance in the right visual field with physical rightward trunk rotations, but no effects with leftward rotations (Grubb and Reed, 2002; Hasselbach-Heitzeg and Reuter-Lorenz, 2002). However, several other studies employing either physical trunk or neck muscle/caloric-vestibular manipulations did not find significant effects on visual detection or attentional performance in healthy subjects (Chen and Niemeier, 2014; Rorden et al., 2001). Thus, reported effects of trunk rotation on spatial exploration or visual attention in healthy human subjects are inconsistent, and if reported, rather modest compared to effects in patients with right hemisphere damage.

1.2. Influence of hemispheric lateralization on temporal order judgments

One sensitive tool that is often used to investigate spatial attention and oculomotor biases in neurological patients (Baylis et al., 2002; Ro et al., 2001; Woo et al., 2009) or healthy subjects (Shore et al., 2001; Stelmach and Herdman, 1991; Wada et al., 2004; Zackon et al., 1999) are temporal order judgment (TOJ) tasks. In visuospatial versions of TOJ tasks, as applied in the current study, two stimuli are presented in the left and right hemifield at various stimulus onset asynchronies (SOA) and subjects are required to report the target that has appeared first. Experiments in neurological patients demonstrated that neglect and extinction patients require a lead on the order of 200 ms to judge the contralesional stimulus as appearing simultaneously with the ipsilesional stimulus (Ro et al., 2001; Rorden et al., 1997). Specifically, a number of studies reported a prior-entry bias for visual targets in the right hemifield after right hemispheric lesions due to either stroke-induced structural (Arend et al., 2008; Baylis et al., 2002; Ro et al., 2001; Rorden et al., 1997; Sinnett et al., 2007) or TMS-induced, 'virtual' lesions (Woo et al., 2009). These studies suggest a special role of the right hemisphere in causing a rightward spatial bias, although the influence of left and right hemispheric lesions on temporal order judgment tasks have rarely been compared directly (but see Woo et al., 2009). In addition, studies in neurologically intact subjects provide initial evidence for an influence of *functional* laterality (sometimes regarded as behavioral manifestations of cerebral asymmetry) on TOJ bias, as rightward spatial biases are more pronounced in right- as compared to left-handed subjects (Efron, 1963; Geffen et al., 2000).

1.3. Goals and hypotheses of the current study

The first aim of the present study was to investigate the effect of physical trunk rotation on temporal order judgments as a function of individual differences in functional laterality. To this end, we employed visual temporal order judgment tasks with differing trunk rotations, and tested the influence of individual hand preference and ocular dominance. The second aim of the study was to discriminate between trunk-rotation induced motor biases and perceptual effects. We therefore employed two different versions of the TOJ task: In the first, congruent "motor" version, subjects were required to perform a direct saccade towards the target that had appeared first. In the second, "perceptual" version, subjects indicated the appearance of the first stimulus by performing a saccade towards an incongruent (upper or lower) screen location.

1. We hypothesized that right-handed subjects would exhibit spatially biased TOJ towards the right hemifield (i.e. prior entry bias for right targets) in the straight trunk condition, that would be amplified by rightward trunk rotation. We expected left-handed participants to show a smaller bias or the reversed pattern in the straight trunk condition, and possibly a left hemifield bias with leftward trunk rotation. These predictions were based on the consideration that trunk rotation towards the preferred hand brings the upper body and the respective dominant hand closer to the visual target, placing it in the preferred working space of the subject, and possibly increasing its behavioral relevance. Smaller spatial bias in left-handed subjects was expected based on the fact that they use both hands more flexibly in daily life. Predictions for the trunk rotation direction that does not match the dominant hand were harder to derive, but following the reasoning described above, we expected no change of TOJ bias for leftward rotations in right-handed subjects and a modest bias towards the right hemifield with rightward trunk rotation in the left-handed subjects.
2. We hypothesized that perceptual facilitation of visual stimuli toward the side of trunk rotation would be apparent in both, the spatially congruent and incongruent, task versions. In contrast, a primary effect of trunk rotation on saccade planning and/or execution would be expressed as an effect in the congruent saccade version only.

2. Methods

2.1. Participants

Forty-six volunteers without neurological illness and normal or corrected to normal visual acuity participated in our study. Six subjects (3 right-handed (RH) and 3 left-handed, (LH)) were excluded from further analysis due to poor performance (less than 75% accuracy on trials with the maximum SOA 283 ms, see below). Thus, we report data from 20 RH and 20 LH subjects for the main