Research Report

TRUNK ORIENTATION INDUCES NEGLECT-LIKE LATERAL BIASES IN COVERT ATTENTION

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Abstract—*The purpose of this study was to resolve a paradox in the literature on the effects of body orientation on spatial attention. Neuropsychological studies have found that real or simulated trunk rotation relieves contralesional inattention in patients with unilateral neglect, suggesting that trunk orientation affects how attention is allocated to space. However, in two previous studies, trunk orientation did not affect spatial attention in other populations. In this study, we investigated the effects of trunk orientation on the performance of a covert attention task by neurologically intact adults. The covert attention task allowed the evaluation of the effects of trunk orientation on both the allocation of attention to space and the ability to shift that attention to new locations. As in previous research, trunk orientation did not affect participants' response times (RTs) to validly cued targets. However, rotating participants' trunks to the left increased their RTs to invalidly cued targets on the right and decreased their RTs to invalidly cued targets on the left. These results indicate that trunk orientation induces directional biases in the ability to shift attention. Thus, for intact participants, trunk rotation created lateral biases in the covert attention task similar to those seen in neglect patients.*

In this study, we investigated how trunk orientation influences where people attend. Whether walking or driving a car, people usually move in the direction in which their trunk points. However, as they move, they often look at things that are off to the side. Thus, people literally do not watch where they are going. For people to avoid running into things, it would be helpful if objects directly in front of them were better able than other objects to capture their attention. Therefore, one might reasonably think that trunk orientation affects where people attend. However, few previous studies have addressed this issue.

Most studies that have investigated the effects of trunk orientation on spatial attention have done so in patients with neglect. Such patients fail to acknowledge stimuli presented to the contralesional half of space (Bradshaw & Mattingley, 1995). However, demonstrations of tacit awareness of stimuli in contralesional space (e.g., Marshall & Halligan, 1988) indicate that this is not due to primary sensory deficits and shows that patients form some representation of the neglected region of space.

Researchers have proposed many theories to account for neglect (Bradshaw & Mattingley, 1995). Of particular interest to this study is one theory, here termed the *misalignment theory*, which proposes that neglect results when lesions damage a system for integrating multisensory information, causing a systematic misalignment of a trunk-centered coordinate system for the representation of space (Jeannerod & Biguer, 1987; Karnath, 1997; Ventre, Flandrin, & Jeannerod, 1984). Although reports of object-centered neglect (e.g., Tipper & Behrmann, 1996) seem to contradict this theory, Driver and Pouget (2000) noted that object-centered neglect could be a form of relative egocentric neglect. Thus, although the misalignment theory is couched in egocentric terms, it may generalize beyond egocentric reference frames.

There are several lines of support for the misalignment theory. First, neglect patients show systematic deviations of the subjective body midline to the ipsilesional side of space (Bradshaw & Mattingley, 1995). Second, although intact subjects' visual search patterns are centered on their body midlines, neglect patients' search patterns are centered to the ipsilesional side of their midlines (Karnath, 1997). Finally, rotation of the trunk toward the contralesional side of space and procedures like caloric irrigation, which similarly rotate the perceived position of the body midline, temporarily relieve neglect symptoms (Bradshaw & Mattingley, 1995; Karnath, 1997; Vallar, Guariglia, & Rusconi, 1997).

Although trunk orientation is related to spatial performance in neglect patients, similar results have not been obtained in intact populations (e.g., Rorden, Karnath, & Driver, 2001). Thus, the relationship of trunk orientation to spatial cognition remains unclear. To further explore this relationship, we examined the effect of trunk orientation on intact participants' performance of a standard spatial attention task.

We employed a choice reaction time (RT) version of the covert attention paradigm developed by Posner and his colleagues (Posner, 1980). In this task, while participants fixate a central cross, a cue draws their attention to a peripheral location. In the valid condition, the target appears at the cued location. In the invalid condition, the target appears on the side of the screen opposite from the cued location.

Typically, all participants are slower to react to invalidly cued targets than to validly cued targets regardless of side. However, patients with neglect are particularly slow to react to invalidly cued targets that appear in the contralesional half of space (Posner, Inhoff, Friedrich, & Cohen, 1987). According to the misalignment theory, this biased pattern is related to a rotation of a trunk-centered coordinate system away from the contralesional half of space. If the biases exhibited by neglect patients are linked to the orientation of the trunk-centered coordinate system, trunk rotation should induce similarly biased performance in intact participants. If so, rotating the trunks of intact participants would affect their RTs to invalidly cued targets in the covert attention paradigm. Specifically, they would be slower to respond to invalidly cued targets that were presented on the side opposite the direction in which their trunks were turned than to invalidly cued targets on the side in the same direction in which their trunks were turned.

METHOD

Participants

Eighteen undergraduates from the University of Denver (15 female, 3 male; mean age = 20.1 years, SD = 1.2) participated in this experiment. Each gave informed consent and received partial course credit.

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Stimuli and Apparatus

So that proper head and body alignment would be ensured throughout the experiment, participants sat in a specially designed support apparatus. This consisted of a headrest that held the head aligned in the same direction on all trials and a chair that sat in a wooden base. The base contained holes into which the legs of the chair fit. The holes were positioned so that the chair could be rotated to be either aligned with the headrest or turned 15° to either side. Participants sat with their backs against the backrest of the chair and their legs uncrossed and directly in front of their bodies to ensure that the alignment of their trunks matched that of the chair. This alignment was monitored throughout each trial via closed circuit television.

Stimuli were constructed using Microsoft PowerPoint (Microsoft Corp., Redmond, Washington) and presented on a 20-in. monitor using E-prime Version 1.0 Beta 5 (Psychological Software Tools, Pittsburgh, Pennsylvania). The stimuli consisted of a fixation cross measuring 2°, a cue square measuring 2°, and a target asterisk measuring 1.8°. All stimuli were drawn in black and appeared against a white background. The monitor sat 120 cm away from the participant, and its center was aligned with the midsagital axis of the headrest.

Procedure

Once situated, participants performed a forced-choice version of a standard covert attention task (e.g., Perchet & Garcia-Larrea, 2000). Each participant completed 100 trials at each body orientation. On each trial, the participant fixated on a cross, which appeared in the center of the monitor. On most trials, between 1,500 ms and 3,000 ms later, the cue square appeared 5° to either side of the cross. The target then appeared 200 ms later. On valid trials (70% of trials), the target appeared within the cue square. On invalid trials (20% of trials), the target appeared 5° to the side of the fixation cross opposite the cue square. The remaining 10% of trials were catch trials in which the target appeared without a cue appearing first. Participants indicated the side at which the target appeared on each trial by pressing the corresponding left or right button of a mouse, which was held in the right hand. Participants were asked to respond as quickly and accurately as possible.

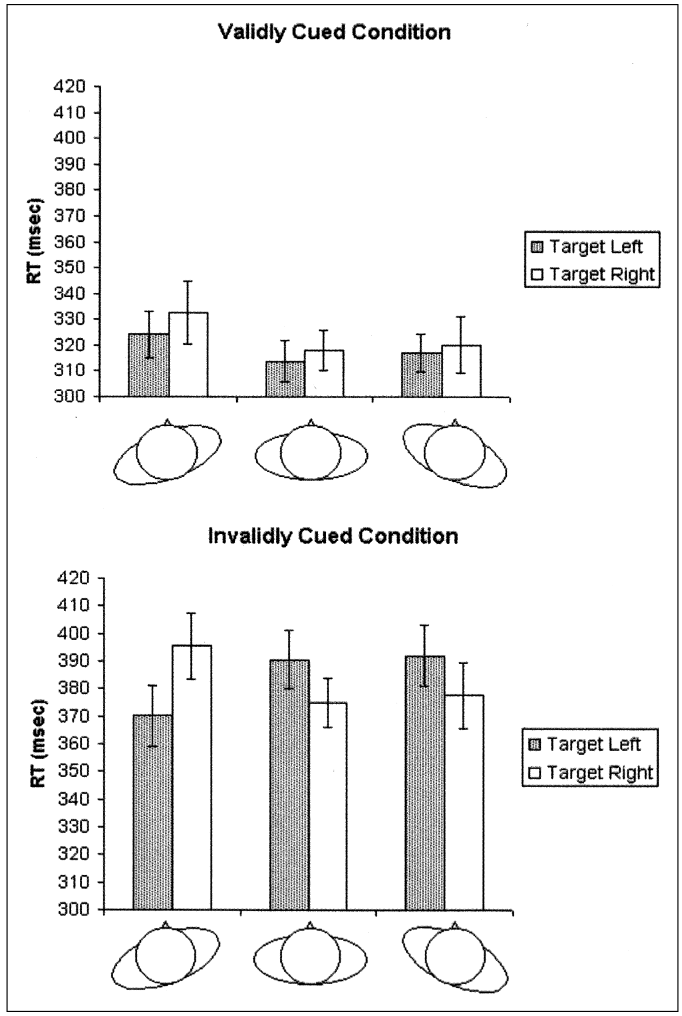

Fig. 1. Effects of trunk orientation on mean response times (RTs) to validly and invalidly cued targets. The illustrations below the graphs show the three orientations included in the study: 15° toward the left, head and trunk aligned, and 15° toward the right.

RESULTS

We separately calculated participants' RTs to targets on the right and left sides, under each cuing condition, and during each trunk alignment. Trials on which participants responded incorrectly or outside a time window from 200 ms to 1,000 ms after the target appeared were excluded. This resulted in the loss of less than 5% of trials from any individual participant. We submitted the mean RTs to a within-subjects analysis of variance with factors of trunk orientation (aligned vs. 15° right vs. 15° left), cue validity (valid vs. invalid), and target side (right vs. left). As in previous covert orienting research, we observed a robust main effect for cue validity, $F(2, 17) = 299$, $p < .001$. Across the board, participants were slower to react to invalidly cued targets than to validly cued targets.

Although the main effect for trunk orientation was not significant, $F < 1$, the impact of trunk orientation on covert orienting was apparent in the Trunk Orientation × Target Side interaction, $F(2, 34) = 4.80$, $p = .015$, and the Trunk Orientation × Cue Validity × Target Side interaction, $F(2, 34) = 6.81$, $p = .003$. As can be seen in Figure 1, participants responded faster to invalid targets that appeared on the right side of the screen than to invalid targets that appeared on the left side of the screen when both their heads and trunks were aligned with the center of the display and when their trunks were rotated to the right. However, this pattern was reversed when participants' trunks were rotated to the left. No effect of trunk orientation is apparent in participants' RTs to validly cued targets. Thus, both interactions appear to be driven by the effect of leftward trunk orientation on RTs following invalid cues. No other main effects or interactions were significant.

DISCUSSION

The goal of cognitive neuropsychology is to provide a common theoretical explanation for cognitive phenomena in both intact and brain-damaged populations. In this study, we investigated the misalignment theory of neglect (Karnath, 1997) by attempting to induce in intact participants spatial biases that are similar to those demonstrated by patients with neglect.

Specifically, we examined whether trunk orientation affected spatial attention by using a classic covert-orienting paradigm in which participants are cued, either validly or invalidly, to a location prior to the appearance of a target. Participants' trunks were either directly aligned with the stimulus display or rotated to the left or right. Body orientation did not affect participants' RTs to validly cued targets regardless of their location. However, leftward trunk orientation increased RTs to invalid targets on the right and decreased RTs to invalid targets on the left. Thus, we demonstrated the classic asymmetrical bias found in neglect patients (Posner et al., 1987) by rotating intact participants' trunks relative to their heads.

These results help resolve a paradox found in previous investigations of the role of body orientation in spatial attention. On the one hand, the manipulation of real or perceived body orientation relieves neglect patients' inattention to contralesional space (Karnath, Schenkel, & Fischer, 1991; Vallar et al., 1997). This observation has led some researchers to propose that people represent space in a trunk-centered coordinate system and that neglect is caused by the systematic misalignment of that system (Karnath, 1997). However, for intact participants or patients with other kinds of brain injuries, the manipulation of real and perceived body orientation has not been found to affect spatial attention (Karnath et al., 1991; Rorden et al., 2001).

Our study resolves this conflict. Although the stimulus arrays used in these previous studies were similar to the one used in the present study, the tasks in both previous studies did not include an invalid-cue condition. By including an invalid-cue condition, we were able to examine the effects of trunk orientation both on the initial deployment of attention and on the redeployment of attention. Our lack of effect in the validly cued condition replicates the findings of previous studies and suggests that trunk orientation does not affect the initial deployment of attention. Instead, the effects in the invalidly cued condition indicate that trunk orientation affects the ability to shift attention once it has already been engaged.

These results support theories positing that neglect results from an inability to shift attention contralesionally (Cohen, Farah, Romero, & Servan-Schreiber, 1994; Posner et al., 1987; Vecera & Luck, in press). For example, Cohen et al. proposed a model in which the neural substrates that represent the different hemispaces interact competitively. Functionally, this means that stimuli in the different hemispaces compete for attention. Cuing works to bias this competition in favor of the cued hemispace. Thus, participants are slower to react to invalidly cued targets than to validly cued targets because they must overcome this initial bias. Similarly, this theory accounts for neglect by proposing that damage to one neural substrate weakens the ability of stimuli in its hemispace to overcome the attentional bias induced by a cue in the other hemispace. On the basis of our results, we propose that trunk orientation is another way to induce an attentional bias. If so, this indicates that manipulations of trunk orientation relieve neglect symptoms by boosting the damaged substrate's ability to compete with the intact substrate.

Pouget and Sejnowski (1997) have proposed a mechanism that would account for biases related to trunk orientation. On the basis of the response properties of neurons in the parietal cortex of macaques, they developed a computer model in which stimuli are represented by units whose response depends on both the retinal positions of the stimuli and gaze direction. Therefore, the strength of the representation of a stimulus in any retinal position changes with gaze direction. Rotating participants' trunks effectively manipulates their gaze direction, and thus the strength of the representation of stimuli presented to different points of the retina.

Our results are also consistent with an interhemispheric difference in spatial processing. As can be seen in Figure 1, for invalidly cued targets, our participants demonstrated a bias toward right hemispace when their head and trunk were aligned. Rightward trunk orientation had no effect on RTs to invalidly cued targets presented on either side. In contrast, leftward trunk orientation increased RTs to invalidly cued targets on the right and decreased RTs to invalidly cued targets on the left, resulting in a reversal of the initial rightward bias.

Various researchers have proposed the existence of interhemispheric differences in spatial processing to account for several lines of data (for reviews, see Bradshaw & Mattingley, 1995; Reuter-Lorenz, Kinsbourne, & Moscovitch, 1990). The lateral bias found in this study is consistent with the findings of previous studies using normal participants (Reuter-Lorenz et al., 1990). Further, left neglect following injuries to the right hemisphere is more common, severe, and persistent than right neglect following injuries to the left hemisphere. These results imply that the two hemispheres differ in their susceptibility to bias (Bradshaw & Mattingley, 1995).

Moreover, studies of patients with neglect also suggest interhemispheric differences in susceptibility to bias introduced by trunk orientation. Real and simulated trunk orientation are more effective at relieving left neglect than right neglect (Vallar et al., 1997). Furthermore, Karnath et al. (1991) found that rotating the trunk to the left decreased left-neglect patients' RTs to targets on the left but did not affect their RTs to targets on the right. Rotating their trunks to the right had no effect.

Our observations in intact participants mirror the asymmetries observed in patients with neglect. Thus, these asymmetries reflect differences in the way that trunk orientation contributes to spatial processing, rather than being merely an artifact of brain injury. Previc (1998) argued that the left hemisphere plays a greater role in representing space beyond roughly 2 m from the body whereas the right hemisphere plays a greater role in representing space within 2 m, and further, that near space is represented in trunk-centered coordinates whereas far space is represented in retinotopic, gaze-centered, or earth-centered coordinates. If this is so, postural information would have a greater impact on spatial representation in the right than in the left hemisphere, thereby leading to the directional asymmetries observed in this and previous studies.

In conclusion, our results indicate that trunk orientation affects the ability of intact participants to shift attention in space, producing spatial biases in a covert-orienting task similar to those found in neglect patients. This pattern of performance indicates that trunk orientation creates biases during interhemispheric competitions for attention. However, much as the strength of unilateral neglect depends on whether it results from a brain lesion in the left or right hemisphere, the strength of the effect of trunk orientation depends on the direction in which the trunk is turned. Together, these findings suggest that a common mechanism underlies biases in spatial processing in brain-injured and intact participants. Thus, any theory of spatial attention should consider not only contributions to attention from the environment (Vecera & Luck, in press), but contributions from the trunk as well.

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