Do Proprioceptive Head-on-Trunk Signals Modulate
Spatial Cognition? – Probing Influences of Body Schema
on Working Memory and Spatial Attention

by

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Abstract

Body schema is indispensable for sensorimotor control and learning, but it remains unclear whether it is associated with cognitive functions. Data from patients with spatial neglect support this view; yet observations in healthy participants are inconsistent. Here I conducted two sets of experiments examining influences of trunk position: the first probed attention and spatial working memory using a change detection task and a two-back task; the second used different versions of the Posner paradigm to examine whether head-on-trunk position governs disengagement of attention. In none of the experiments did I observe that trunk turns altered performance in the left versus right visual field in an ipsiversive fashion as reported in neglect. Nevertheless, I found that trunk-right position improved performance at eccentric locations of the visual field. The data are inconsistent with previous findings of head-on-trunk effects in normal participants. Further studies are required to clarify these discrepancies.
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Chapter 1

1 Introduction

Body schema is an integrated dynamic neural representation or model of one’s own body in space that is constantly updated based on multiple sensory signals, including not only somatosensation but also other sources of information such as vision and motor feedback (Coslett, Saffran, & Schwoebel, 2002; Graziano & Botvinick, 2002). Such a body schema is indispensable for sensorimotor functions. Sensorimotor learning requires that the brain form a neural representation of the body (or of body parts) to be able to compute sensory derivatives for implicit supervised learning to adjust sensorimotor processes on an ongoing basis (e.g. Abdelghani, Lillicrap, & Tweed, 2008). Beyond learning, control of sensorimotor functions requires body schemas in so called forward models that enable the brain to predict outcomes of motor actions for online control despite slow sensory signals (e.g. Hermosillo, Ritterband-Rosenbaum, & van Donkelaar, 2011; Wolpert, Ghahramani, & Jordan, 1995).

On the other hand, brain lesions can result in dramatic changes in the way the body is perceived and represented. One example is that right posterior parietal lesions will cause both negative (e.g. disownership of body parts) and positive symptoms (e.g. supernumerary phantom limbs) of body misperception (Berlucchi & Aglioti, 1997). Another example is that damage in certain parts of the basal ganglia and cerebellum will induce profound deficits in motor control and body movements (Doya, 2000). Finally, recent studies have found that stimulation of the temporo-parietal junction and/or nearby angular gyrus in the right hemisphere leads to out-of-body experiences (Blanke, Ortigue, Landis, & Seeck, 2002; Blanke, Mohr, Michel, Pascual-Leone, Brugger, Seeck, Landis, & Thut, 2005).

As another way to investigate the neural substrates of the body schema together with representations of peripersonal space (i.e., the space in which objects can be acted upon), there is a limited possibility to manipulate sensory inputs from the body to examine effects on the body schema. One approach is the rubber hand illusion (Botvinick & Cohen, 1998), during which participants have the strange impression that an artificial hand becomes part of their body and that is associated with changes in activity in several brain areas including parts of the supplementary motor area (Ehrsson, 2007; Lenggenhager, Tadi, Metzinger, & Blanke, 2007).
However, more natural approaches appear to be research on influences of body posture (see the section below on head-on-trunk signals) and the use of tools. Regarding the latter manipulation, recent studies suggest that using tools induce changes in specific neural networks and create a dynamically updated map of body representation in the brain in which the tool is treated as an extension of the body. For example, after tool use, in some of the bimodal neurons (neurons responding to both somatosensory and visual stimulation) of macaque monkeys, the visual receptive fields expanded from being centred on the hand to including the entire length of the tool (Maravita & Iriki, 2004). Similarly, when normal humans were asked to wield tools in a crossed posture, behavioural results would reverse in a consistent way to when the hands were crossed (Maravita, Spence, Kennett, & Driver, 2002).

Consistent with this, some patients with spatial neglect show difficulties that differ depending on whether they are tested in peripersonal space or extrapersonal space. For example, some patients (though not all, Ferber & Karnath, 2001) have difficulties bisecting horizontal lines at their centre (i.e., they put the mark far right from the actual midpoint), and in a subset of these patients the symptoms are only observed when the patients conduct the task within their peripersonal space, that is, within the space that they could naturally reach with their arms and hands. When they were asked to use a laser pointer to perform the task in extrapersonal space, that is, the space beyond the peripersonal space, patients’ responses would become similar to those of unimpaired participants. In contrast, when the patients used a long stick to bisect the distant lines, neglect symptoms would reappear (Maravita & Iriki, 2004). This result can be interpreted such that the stick functioned as a tool that had been incorporated into the patients’ damaged body schema, and/or that the stick made the far space reachable so that the brain selected a damaged near-space neural network to perform the task.

In sum, a body schema (in one or multiple neural implementations) is conceptually indispensable for sensorimotor functions and there is an increasingly better, albeit still incomplete, understanding of how a body schema may be implemented in the brain.
1.1 Body schema and attention

To understand body schema it is also important to discuss the concept of selective spatial attention. Selective attention refers to a set of brain mechanisms that enable a person to orient to relevant information while ignoring others that are less important, irrelevant or distracting (Posner & Petersen, 1990). More specifically, spatial attention encompasses selection processes based on spatial information about where to orient attention to. In addition, the control of these orienting processes depends on structures in frontal and parietal cortex that select targets for motor actions, in particular for eye movements (e.g., Rizzolatti, Riggio, Dascola & Umilta, 1987; Corbetta & Shulman, 2002; Moore & Fallah, 2001; Moore, Armstrong, & Fallah, 2003).

Because spatial attention is intricately associated with target selection for actions and because body schema is an integral part of sensorimotor functions such as in forward models, it appears to be reasonable to assume that both mechanisms are implemented in interconnected neural structures or even share some of their structures. Given this the question arises whether it makes sense to regard body schema as an independent concept or whether it should be considered within a greater framework of sensorimotor control processes that also give rise to attention.

Even more urgent is the question whether research findings on body schema could be explained by trivial attentional effects. That is, experimental manipulations such as the rubber-hand illusion or different kinds of tool use might serve as cues of spatial attention rather than alter body schema. In other words, it is possible that certain effects observed during manipulations of body sensations simply reflect confounds of unwanted attentional manipulations caused by changes in body schema or posture.

However, as I will discuss in detail in the following two sections, current research does indeed support the idea that body schema is a stand-alone phenomenon. In the first section, I will review neurophysiological evidence demonstrating that changes in body schema due to tool use cannot be explained by attentional factors. In the second section, I will look at neuropsychological research that illustrates that certain aspects of spatial neglect are difficult to reconcile with a purely attentional account, at least based on its current understanding. Instead, neglect symptoms can be better explained in the context of body-based processes consistent with a disrupted body schema or access to it.
1.2 Body schema is independent from processes underlying attention: Evidence from neurophysiology

Several studies on bimodal neurons in macaque monkeys could demonstrate that a body schema might not be a form of selective attention itself. For example, Iriki, Tanaka, Obayashi, & Iwamura (2001) demonstrated that the monkeys’ visual receptive fields of somatosensory-visual neurons could alter with their changes in body schema independent of attentional shift. The authors trained macaque monkeys to use a rake to pull the food closer, and they found that when monkeys intended to use the rake to retrieve distant objects, the visual RFs of bimodal neurons in the intraparietal cortex elongated along the axis of the tool as if the tool had been a part of the monkeys’ body. However, the expansion of the visual receptive fields was never induced when the monkeys were trained to fixate at the endpoint of the rake and just grabbing it passively. This suggested that the modification of visual receptive fields was not associated with just paying attention to or mere physical appearance of the tool, but rather with an altered body schema resulting from the active and intentional usage of the tool.

Similar conclusions can also be derived from research findings in patients with cross-modal visual-tactile extinction (Maravita, Husain, Clarke, & Driver, 2001). The phenomenon of extinction is associated with neglect, which indicates the inability to perceive a stimulus to one side of the point of fixation in the presence of another competing stimulus, typically on the other side of the fixation point (Maravita et al., 2001). For patients with cross-modal extinction, a visual stimulus close to the right hand would extinguish awareness of a tactile feeling on the left hand. Such extinction could be reduced if the right visual stimulus was placed in the extrapersonal space. In this specific study, patients were asked to hold long sticks in both hands so that the far right visual stimulus was now “reachable”. Result was that cross-modal extinction symptoms in this situation reappeared and even increased. More crucially, looking at the same stick laying passively on the right of the table did not induce the same effect. This finding confirmed that the change of body schema and remapping of space induced by tool wielding were independent of attention itself.
1.3 Body schema is independent from processes underlying attention: Evidence from research on spatial neglect

Spatial neglect is defined as the inability to perceive or respond to stimuli on the side contralateral to the brain lesion (more frequently in the right than the left hemisphere). Neglect is often regarded as an attentional deficit (e.g., Corbetta & Shulman, 2002). In this section, I will first present evidence in favour of this view and then provide arguments that might speak against the attentional account. Finally, I will review relevant studies that support the alternative view that spatial neglect results from impairments in body schema rather than attentional impairments.

A very large number of studies have claimed to provide evidence that neglect patients have attentional deficits, though often the evidence is merely based on face validity. For example, some neglect patients commit errors in line bisection tasks and this is often taken as evidence that the patients pay less attention to the left side of the lines while other causes for the errors are possible too (Bisiach, Bulgarelli, Sterzi, & Vallar, 1983). Somewhat better support comes from the fact that almost all neglect patients have difficulties with visual search tasks (Mesulam, 2000), for example, in line cancellation test in which the patients are asked to cross out short line segments scattered over the visual display, they usually fail to cancel the line segments displaying on the left side, which means neglect patients barely pay attention to the left visual field (Ferber & Karnath, 2001). But still, visual search involves a multitude of different functions so that it remains unclear which one is exactly affected in neglect patients (e.g., saccade/attention remapping; Duhamel, Colby, & Goldberg, 1992).

Probably one of the best pieces of evidence supporting the attentional account of neglect comes from two classic studies. Posner, Walker, Friedrich, & Rafal (1984) reported that patients with right parietal lesions (and presumably neglect) had specific difficulties with responding to stimuli on the left side of a fixation point when the stimulus was preceded by an invalid cue on the right side but not when it was preceded by a valid cue on the left side (note that these attentional cues are experimentally controlled and they are conceptually different from the unwanted cueing effects that are induced by changes in body schema or posture indirectly). Posner and colleagues concluded that the patients had particular difficulties with disengaging attention from cues on the right side in order to shift attention to targets on the left side. Consistent with this observation, Morrow and Ratcliff (1988) studied patients with neglect over a longer period of time using a
paradigm similar to that of Posner. They found that over time the patients’ disengagement deficit disappeared in correlation with neglect symptoms that improved with natural recovery from neglect.

However, even if these two studies provide some quite strong (though correlative) support for the idea that neglect patients do have difficulties with attention, it does not rule out the possibility that those attentional problems are governed by another deficit in functions underlying attention that is not an attentional deficit itself. That is, it has been argued that spatial neglect may result from a disturbed or altered representation of space (Bisiach et al., 1983; Karnath, Schenkel, & Fischer, 1991) and that only as a consequence neglect patients are less likely to select locations on the left side to direct their attention to.

Inconsistent with the attentional account of neglect, some studies showed that neglect patients could move their eyes normally (Karnath, Fetter, & Dichgans, 1996; Niemeier & Karnath, 2000; Niemeier & Karnath 2003). That is, when neglect patients perform a visual search task, they usually ignore the left side of the search array. However, within the right part of the array their saccades in leftward direction do not differ from rightward saccades, so long as saccade targets are deliberately selected. Because eye movements are closely coupled with attention (Deubel & Schneider, 1992; Kowler, Anderson, Dosher, & Blaser, 1995; Deubel & Schneider, 1996), patients’ attentional shifts must have been unimpaired, at least for voluntary eye movements, inconsistent with the idea of an attentional deficit in neglect.

Niemeier and Karnath (2003) did observe impaired leftward saccades when neglect patients moved their eyes to track a target jumping across the screen from saccade target to saccade target as selected previously during normal visual search. This might be in line with Posner’s disengagement deficit for reflexive attentional shifts. But a deficit of purely reflexive attention cannot explain why neglect patients ignore the left visual field during voluntary search under normal visual conditions (Karnath, Niemeier, & Dichgans, 1998; Niemeier & Karnath, 2003) as well as in darkness (Karnath, Fetter, & Dichgans, 1996; Karnath, 1997).

It is possible that neglect patients show intact voluntary saccades because naturally they make these eye movements within preferred regions of space on the right side of their head or body. Therefore, one could speculate that a representation of space in coordinates relative to the head or trunk determines how severe the putative attention-based neglect deficit is. However, such an
extended attentional account incorporating an additional egocentric reference frame becomes quite similar to the egocentric account of neglect as discussed below.

The hypothesis that neglect is associated with a disrupted egocentric reference frame comes from studies reporting that manipulations of body schema could modulate neglect symptoms regardless of attention. For example, Karnath and colleagues (1991) tested neglect patients with five different body postures; 1) eyes, head and body aligned with a computer screen, (2) eyes and head aligned but trunk turned to the left, (3) trunk turned to the right, (4) head turned to the left with eyes and trunk remaining aligned, (5) head turned to the right. The authors found that neglect patients had difficulty moving their eyes when the saccade target appeared on the left side of the fixation point. However, the deficit was significantly reduced when the trunk (but not the head) was turned to the left side. This motivated Karnath and colleagues (1991) to argue that trunk orientation is the determining factor in spatial neglect syndrome, whereas attentional cueing as a potential alternative explanation is difficult to reconcile with the observation that head turning had little effect on detection times.

Similarly, neglect symptoms change due to simulated head-on-trunk turns induced by neck muscle vibration (Karnath et al., 1993). For some background on this: muscle vibrations are well known to stimulate alpha motor neurons thereby producing proprioceptive illusions of lengthening the respective muscles such as observed in the Pinocchio illusion (Lackner, 1988), in which vibrating a person’s biceps tendon while he/she is holding the nose with the hand of that arm creates the illusion that the nose is growing longer because the arm is perceived as moving away from the face. Karnath and colleagues (1993) used similar muscle vibrations to stimulate proprioceptors in the left posterior neck muscles to cause an illusion of leftward head-on-trunk turning, at least in the absence of visual information. But even under normal light conditions the authors found that the neck vibrations in neglect patients decreased neglect symptoms significantly. Moreover, neck muscle vibration was confirmed to be an effective therapy for neglect rehabilitation, which induces lasting recovery in spatial neglect (Schindler, Kerkhoff, Karnath, Keller, & Goldenberg, 2002). In this context, it is crucial to point out that the neck vibration effects in neglect patients are not due to attentional cueing. Karnath et al. (1993) demonstrated that vibrating the muscles of the left hand of the patients did not induce any effect. Therefore, the amelioration of the symptoms was not simply caused by an arousal or attentional cueing effect.
Last but not least, previous research reported that neglect symptoms could also be significantly reduced with \textit{prism adaptation} (Rossetti, Rode, Pisella, Farne, Li, Boisson, & Perenin, 1998), in which the patients were required to wear goggles bearing rightward wedge prisms. When normal participants were exposed to the rightward optical deviation, typically they pointed accurately to the midline before adaptation and mispointed to the left of midline after adaptation. Since one classic symptom of neglect patients is a pathological shift of the subjective midline to the right, the compensative effect of prism adaptation could adjust patients’ subjective straight ahead back to the midline so that their egocentric coordination system was corrected. In this way, prism adaptation ameliorated patients’ neglect symptoms.

The above-mentioned three lines of evidence (i.e. head-on-trunk signals, neck muscle vibration, and prism adaptation) nicely demonstrated that the afferent information obtained from visual, kinetic, and proprioceptive signals could contribute to the elaboration of egocentric coordinates and a reconfiguration of body schema in space. Furthermore, these results are independent of unspecific arousal and activation on the contralateral side which might lead to an attentional shift to the affected side of space.

1.4 Head-on-trunk signals

Based on the evidence from the previous two sections, we have reason to assume that a body schema is not directly related to attention – but in which way do body schema and attention interact? As one possibility, the body schema might give rise to a representation of space in egocentric coordinates not only for sensorimotor functions but also to serve as a spatial scaffold that can guide the allocation of attention in space – and perhaps other forms of spatial cognition such as visual working memory. To illustrate this, please note that visual receptive fields of neurons, such as in V4, change (e.g., in size) as a function of spatial attention (Moran & Desimone, 1985). But this is different from the visual receptive fields of bimodal neurons, such as in ventral premotor cortex, change as a function of altered body schema such as during tool use. Consider further a scenario in which a person’s attention is focused on one particular point in space while a new object appears at an unexpected location. In this situation neurons such as those in V4 might at first show little responsiveness to the new object. But neurons such as those in PMv retain their responsiveness. That is, thanks to the body schema it is possible to retain
some form of global visual responsiveness or global attention that helps to respond to unexpected stimuli.

Obviously this is a very speculative hypothesis. Furthermore, this is crucially limited by the fact that it is almost exclusively backed by neuropsychological data derived from neglect patients. The problem with neuropsychological data is that they reflect a lack of a certain set of brain functions that are more or less unspecified except by their absence. To complicate matters, the dysfunctions induced by the brain lesion will usually be confounded by the brain’s attempt to compensate for them. To sort out dysfunctions potentially associated with body schema and compensating strategies, it is important to identify and investigate equivalent effects of changes in body schema on neurologically normal brain functions.

Unfortunately however, evidence in normal people has been much less consistent than the data obtained from patients with neglect. Some studies failed to evoke equivalent effects in normal participants using neck vibration (Rorden, Karnath, & Driver, 2001). Research found change in body schema was only effective in biasing participants’ subjective straight ahead, but ineffective in affecting their covert visual attention. However, it is possible that neck vibrations were less effective than other manipulations of body schema (e.g. real head-on-trunk turns).

Two other studies did use actual head turns and produced significant, yet inconsistent, results: Grubb and Reed (2002) combined Posner’s attentional cueing task (Posner et al., 1984) with manipulations of head-on-trunk positions. Specifically for trunk turns to the left they observed ipsiversive effects for invalidly cued targets, that is, responses to targets in the right visual field after invalid cues in the left visual field caused greater delays than targets on the left after invalid cues on the right. The asymmetry reversed for trunk positions aligned with the computer screen or rightward trunk positions, suggesting that trunk-left posture induces a mild version of the attentional disengagement deficit reported in neglect patients (Posner et al., 1984). Importantly, Grubb and Reed (2002) observed no changes in reaction times during valid cue conditions suggesting that head-on-trunk positions did not influence reaction times based on undesired attentional cueing through altered body posture. However, as a potential problem of the study, Grubb and Reed (2002) did not control for eye movements; erroneous eye movements triggered by the cues could amplify cueing effects and so in part explain Grubb and Reed’s (2002) data. As a second possible problem, Grubb and Reed (2002) used a response choice reaction time
paradigm which makes it impossible to distinguish attentional cueing effects from response priming or response conflict effects (Simon, 1969).

The second study avoided the response priming problem by asking participants to use the same button to respond to targets regardless of location (i.e. Hasselbach-Heitzeg and Reuter-Lorenz, 2002). Similarly to Grubb and Reed (2002), responses to targets on the left and right changed with head-on-trunk position. However, there were several important differences to Grubb and Reed’s (2002) study. Unlike that study, Hasselbach-Heitzeg and Reuter-Lorenz (2002) observed specific effects only for right trunk rotation but not for left trunk rotation: they found rightward trunk rotation evoked a decrease in response time and an increase in visual sensitivity for targets on the right visual field. Different from Grubb and Reed (2002), the reaction time differences occurred despite the absence of a (valid or invalid) cue. This makes it difficult to tell whether the reported effects were due to changes in body schema or some less specific attentional cueing effects. Also unexpectedly, Hasselbach-Heitzeg and Reuter-Lorenz (2002) found head-on-trunk effects specifically in female participants (male participants were not tested after pilot tests). Finally and possibly problematically, Hasselbach-Heitzeg and Reuter-Lorenz’ (2002) did not record eye movements. So just like in Grubb and Reed’s (2002) study, it is unclear whether their effects were due to fixation errors or real head-on-trunk signals. Indeed, when we recently conducted a comparable simple stimulus response experiment but controlled for accurate fixation, we were unable to replicate their observations – right/left trunk rotation did not induce respective right/left visual field advantage in response times for lateralized targets. Nevertheless, we did find an effect of head-on-trunk position on reaction times. We found that trunk-right positions widened the range in which stimuli were detected quickly compared to trunk-left and straight-ahead positions (Mohammad, Chen, & Niemeier, 2012; Chen, Mohammad, & Niemeier, 2012).

1.5 Objectives of the present research

To summarize, it is clear that body schemata are indispensable for sensorimotor control. However, it remains a matter of debate whether they are associated with cognitive functions such as the allocation of spatial attention. Data in patients with neglect support this view, however, for neurologically normal participants effects have yet to be demonstrated in a convincing and
consistent manner. Establishing a connection between spatial functions and dysfunctions is central to future progress in this area of research.

Therefore the objective of the current investigation was to revisit the studies by Grubb and Reed (2002) and Hasselbach-Heitzeg and Reuter-Lorenz (2002) in order to try to confirm their findings of head-on-trunk signals on attentional tasks in normal participants. To this end I used several versions of their paradigms in five different experiments while recording eye movements.

In Experiments 1 and 2 I tried to confirm Hasselbach-Heitzeg and Reuter-Lorenz’s findings. Because our pilot experiments (Mohammad, Chen, & Niemeier, 2012) had already failed to produce the reported head-on-trunk effects on simple reaction times, I increased cognitive load by adding cognitively challenging working memory components, a change-detection task in Experiment 1 and a two-back task in Experiment 2. Despite probing performance in a wide range of the visual field, I found no evidence for an ipsiversive improvement of performance due to head-on-trunk position, though I confirmed our previous observation that trunk-right position improved performance at eccentric locations of the visual field.

Likewise, in Experiments 3, 4, and 5, I tested three different versions of experiment that avoided response priming or response conflicts (Simon, 1969). None of the experiments were able to reproduce effects of head-on-trunk signals on invalidly cued targets as reported by Grubb and Reed (2002).
Chapter 2

2 Head-on-trunk signals and spatial working memory

2.1 Experiment 1: Change detection task

The objective of the experiment was to confirm Hasselbach-Heitzeg and Reuter-Lorenz’ (2002) findings that head-on-trunk signals improved simple detection rates of targets in the ipsiversive visual field in normal participants. Because to date there is no corroborating report for a head-on-trunk effect in normal participants (see Mohammad, Chen, & Niemeier, 2012, for evidence against head-on-trunk effects on simple detection); in the current task, I used two strategies to amplify potential head-on-trunk effects. (1) I increased spatial uncertainty by using 16 different spatial target locations across the LED screen, 4 of which occurred at the same time. (2) I increased cognitive load by adding a working memory component to the task. Specifically for the first experiment, I used a change detection task that combined working memory and attention functions (Rensink, 2002). In addition, I measured eye movements to rule out fixation errors.

2.1.1 Method

Participants: Nineteen undergraduate students from the University of Toronto at Scarborough participated in this experiment (11 females, median age = 21 years). All participants gave their informed and written consent prior to their inclusion in the study and received a course credit in exchange for participation. All experimental procedures were approved by the Human Participants Review Sub-Committee of the University of Toronto and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All participants were free of neurological diseases and psychiatric disorders with normal or corrected-to-normal vision, and most of them were right-handed (4 left-handers) as confirmed by the Edinburgh handedness inventory (Oldfield, 1971).

Stimuli and Apparatus: Visual stimuli consisted of luminance-defined Gabors with different orientations and a white fixation point measuring 0.26°. Gabors had a spatial frequency of 0.97 cycles per degree of visual angle with a standard deviation of 0.93°. Each Gabor had eight possible orientations: Tilted 0° (vertical), 22.5°, 45°, 67.5°, 90° (horizontal), 112.5°, 135°, and 157.5° respectively. All stimuli were displayed against a grey background. Proper head and body
alignment was required throughout the entire process of the experiment. Therefore, participants sat in a chair that was mounted on a turn table used to orient the body to different azimuthal positions (30° to the left, straight ahead, or 30° to the right). A chinrest on an aluminum arm and post fixed to the floor ensured that the participant’s head was held aligned with a large 52” LED television screen (Viewsonic, 120Hz refresh rate, 1920x1080 pixels resolution) placed 65 cm away from the participants. The experiment was written in Matlab (Math Works) together with the Psychophysical toolbox and EyeLink toolbox extensions (Brainard, 1997; Pelli, 1997; Cornelissen, Peter, & Palmer, 2002 Brain Research Methods). Eye movements were monitored with a video based eye tracker (Eyelink II: Sampling rate 250Hz, SR Research, Ottawa). In the current experiment, Eyelink detected saccades with amplitude larger than 1 visual degree online, and removed and restarted those trials automatically.

Experimental conditions: Three trunk orientations were tested in the current experiment: (1) Trunk turned 30° toward the left; (2) Straight ahead; (3) Trunk turned 30° toward the right.

Experimental procedure: Participants were tested in a dimly lit room. Once seated, participants put their chin on the chinrest. They were asked to fixate their eyes on a point at the center of the screen. 1500 milliseconds later four Gabors with pseudo-random orientations appeared at different screen locations for 200 milliseconds. Each time the Gabors appeared at the corners of an imaginary square or diamond in a smaller or larger eccentricity on the screen (11.73° or 22.56° visual degrees away from the fixation point respectively). Following a brief presentation of a blank grey screen lasting 500 milliseconds, the four Gabors reappeared at the same locations except that the orientation of one of the four Gabors was changed. Participants used the mouse to click on the changed Gabor during each trial (See Figure 2.1 for the change detection paradigm). After 10 practice trials, the participants completed twelve blocks (four blocks for each body position) with 48 trials per block. Each block had randomly presented but equal numbers of trials in terms of Gabor orientation and Gabor position. The order of blocks was randomized for each participant. Participants’ hit rate and false alarm rate were recorded.
Figure 2.1 Change detection task paradigm for Experiment 1. After four Gabors with pseudo-random orientations appearing at different locations of the screen and then a brief presentation of blank screen, orientation of one of the four Gabors was changed (stimulus in red). Participants clicked on that changed Gabor by using a mouse. Note that stimuli in this figure are not real Gabors.

**Data analysis:** I calculated d-prime and lambda centre values in the form of ‘heat maps’ across all pixels of the computer screen. The d-prime values were used as an unbiased (e.g., strategy-free) measure of *sensitivity* to the target event, that is, people’s ability to detect the orientation change of one of the Gabors. *Sensitivity* was calculated by subtracting *z*-transformed false alarm rate from *z*-transformed hit rate (Wickens, 2001). The lambda centre values were used to measure *response bias*, which refers to people’s tendency to select a specific target location. *Response bias* was calculated by the sum of *z*-transformed hit rate and *z*-transformed false alarm rate multiplied by -0.5 (Wickens, 2001). Specifically, I first determined hit and false alarm rates at each of the 16 possible target locations of the Gabor stimulus. Next I interpolated these rates for all pixel locations on the screen, using Gaussian-based smoothing. To do so, for each target location i, I multiplied the corresponding hit or false alarm rate with a parceling function P_i that served to spread the value across a segment of the screen. This function P_i consisted of a Gaussian G_i (target location i, SD) peaking at the target location divided by the sum of the Gaussians G_{Total} at all target locations. SD was the standard deviation of the Gaussians that I set to 150 pixels to achieve an intermediate level of smoothing (more or less smoothing produced qualitatively similar results). The equations were as follows:

(1) \[ G_{Total} = \sum_i G_i \text{ (target location } i, \text{ SD) } \]

(2) \[ P_i = G_i / G_{Total} \]
(3) Hit rate map $i = \text{hit rate} \times P_i$

(4) False alarm rate map $i = \text{false alarm rate} \times P_i$

An illustration of the resulting $G_{\text{Total}}$ and 3 of the 16 parceling functions $P_i$ are given in Figure 2.2. Next I summed across all hit rate maps and false alarm rate maps, $z$-transformed them, and calculated $d$-prime and lambda centre maps. Note that I calculated $d$-prime and lambda centre values after smoothing to obtain more robust estimates as opposed to calculating the values for each of the 16 target locations separately.

![Figure 2.2 Illustrations of Gaussian-based smoothing. (a) Illustration of the sum of Gaussians ($G_{\text{Total}}$). (b) Illustration of parceling function 1 ($P_1$). (c) Illustration of parceling function 2 ($P_2$). (d) Illustration of parceling function 3 ($P_3$). Superimposed white circles mark the possible locations of Gabors.](image)
2.1.2 Results

**Detection sensitivity:** D-prime maps for all three trunk orientations across all participants (n=19) are given in Figure 2.3. Figure 2.3d demonstrated that overall there was no effect of trunk orientation on d-prime. To improve sensitivity and get quantitative results, I pooled across different regions on the screen and I segmented the screen into four quadrants (left, right, up and down; 90° wide each) times two eccentricities (near and far; I called pixels ‘near’ that lay inside a circular boundary half-way between the two target eccentricities; the rest of the pixels I defined as ‘far’). Averaged d-prime and lambda centre values in different conditions are provided in Figure 2.5. I then conducted a 3 (trunk orientation: Left, Straight ahead, Right) X 4 (visual field quadrant: Left, Right, Up, Down) X 2 (eccentricity: Near, Far) three-way repeated measures ANOVA. A significant main effect of visual field quadrant (F (3, 54) = 6.51, p = 0.0008) reflected lower sensitivity for Gabor locations along the vertical meridian. The main effect of eccentricity was significant: F (1, 18) = 4.96, p = 0.039. There was also a significant interaction between visual field and eccentricity: F (3, 54) = 3.30, p = 0.027. However, I found no influence of trunk orientation. That is, there was no main effect of trunk orientation (p = 0.94), and no interaction with other factors (trunk orientation X visual field: p = 0.76; trunk orientation X eccentricity: p = 0.86; three-way interaction: p = 0.89).

To be sure that no head-on-trunk effects had been overlooked, I also conducted three additional two-way ANOVAs. The first segmented the screen into left and right visual field; the second segmented the screen into upper and lower visual field; the third segmented the screen into near and far regions. However, only the third ANOVA produced a significant effect of eccentricity: F (1, 18) = 4.99, p = 0.0385. No main effect of trunk orientation or interaction with other factors was observed (p’s > 0.15).
Figure 2.3 D-prime maps for Experiment 1. (a) Trunk turned to the left. (b) Straight ahead. (c) Trunk turned to the right. (d) P-values across all three trunk orientations.
**Response bias:** Lambda centre maps for all three trunk orientations are given in Figure 2.4. Similar to the d-prime analysis, I conducted a 3 (trunk orientation: Left, Straight ahead, Right) X 4 (visual field quadrant: Left, Right, Up, Down) X 2 (eccentricity: Near, Far) three-way repeated measures ANOVA. A main effect of visual field quadrant (F (3, 54) = 3.47, p = 0.0223) reflected higher response bias for Gabors located at the bottom of the screen. A main effect of eccentricity: F (1, 18) = 9.18, p = 0.0072 indicated that participants tended to report target locations far away from the fixation point more frequently than locations near the fixation point. But the main effect of trunk orientation, as well as all the two-way interactions and the three-way interaction, was not significant (p > 0.06).

![Lambda centre maps for Experiment 1](image)

Figure 2.4 Lambda centre maps for Experiment 1. (a) Trunk turned to the left. (b) Straight ahead. (c) Trunk turned to the right. (d) P-values across all three trunk orientations.
Figure 2.5 Averaged d-prime and lambda centre values for Experiment 1. (a) D-prime values on left/right/up/down/near/far visual fields on all three trunk orientations. (b) Lambda centre values on left/right/up/down/near/far visual fields on all three trunk orientations. Note that the position of the diamond indicates the medians.
2.2 Experiment 2: Two-back task

Because Experiment 1 failed to confirm Hasselbach-Heitzeg and Reuter-Lorenz’ (2002) report of head-on-trunk effects, I conducted another version of a working memory task that at any given time required participants to focus on a rather small region of the visual field.

2.2.1 Method

Participants: Sixteen undergraduate students from the University of Toronto at Scarborough participated in this experiment (12 females; median age = 19 years). One participant’s data set was excluded because her hit rate did not pass the criterion (hit rate ≥ 50%); therefore the total number of valid data sets was 15. All participants gave their informed written consent prior to their inclusion in the study and received a course credit in exchange for participation. All experimental procedures were approved by the Human Participants Review Sub-Committee of the University of Toronto and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All participants were free of neurological diseases and psychiatric disorders with normal or corrected-to-normal vision, and most of them were right-handed (1 left-hander) as confirmed by the Edinburgh handedness inventory (Oldfield, 1971).

Stimuli, Apparatus and Experimental conditions: See Experiment 1.

Experimental procedure: As in Experiment 1, participants sat with their body oriented 30° to the left or right or straight ahead with their chin always placed in the chinrest and aligned with the screen. Participants fixated their eyes at the fixation point in the centre of the screen, as controlled by an eye tracker. At one of the 16 locations (see Experiment 1) surrounding the fixation point, a single Gabor appeared for 200 milliseconds. 1500 milliseconds later it appeared at a different of the 16 locations, then at another location and so forth. In total the Gabor appeared 64 times per block. Participants were asked to click a mouse key if they believed that the Gabor appeared at the same locations as two trials earlier. Participants completed twelve blocks with four blocks in each body position. Each block had randomly presented but equal numbers of trials in terms of Gabor position. Participants’ hit rate and false alarm rate were recorded (See Figure 2.6 for the two-back paradigm).
**Data analysis:** Eye movement data were inspected offline for fixation errors. Trials with saccades 1.5° away from the fixation were excluded (averaged percentage of valid trials: 97.28%). Methods for calculating d-prime and lambda centre values as well as creating ‘heat maps’ were the same as in Experiment 1.

![Figure 2.6](image)

**Figure 2.6** Two back task paradigm for Experiment 2. A Gabor was presented 64 times at one of 16 locations in one block. Participants clicked the mouse key if the current position of the Gabor was the same as that of the Gabor presented two instances earlier (stimuli in red). Note that stimuli in this figure are not real Gabors.

### 2.2.2 Results

**Detection sensitivity:** As in Experiment 1 I used d-prime as a strategy-free measure of working memory performance. D-prime maps for all three trunk orientations across all participants are given in Figure 2.7. By eyeballing the ‘heat maps’, there was no left versus right visual field difference as a function of trunk orientation; however, trunk position seemed to be associated with performance at eccentric screen locations, that is, when participants turned their trunk from left to right orientation d-prime values improved in the periphery. An exploratory pixel-by-pixel one-way ANOVA showed trends consistent with the eccentricity effect but only at a few Gabor locations (Figure 2.7d). To improve sensitivity, I pooled across pixel regions on the screen. Results from 3 (trunk orientation: Left, Straight ahead, Right) X 4 (visual field quadrant: Left, Right, Up, Down) X 2 (eccentricity: Near, Far) repeated measures ANOVA demonstrated that there was a main effect of eccentricity (Near, Far): F (1, 14) = 15.69, p = 0.0014. Crucially, the
two-way interaction between trunk orientation and eccentricity was also significant: $F(2, 28) = 4.20, p = 0.0254$. Neither the main effect of trunk orientation nor the main effect of visual field quadrant was significant ($p$'s > 0.35). No other interaction was significant ($p$'s > 0.31).

Just like in Experiment 1, I also conducted three additional two-way ANOVAs so as to ensure that no effect was overlooked by the omnibus ANOVA. Results from Left/Right and Up/Down tests demonstrated that there was neither a main effect nor an interaction ($p$'s > 0.14). However, consistent with the previous three-way ANOVA results, Near/Far test showed a main effect of eccentricity: $F(1, 14) = 15.69, p = 0.0014$; and also a significant interaction between eccentricity and trunk orientation: $F(2, 28) = 4.16, p = 0.0262$.

Figure 2.7 D-prime maps for Experiment 2. (a) Trunk turned to the left. (b) Straight ahead. (c) Trunk turned to the right. (d) P-values across all three trunk orientations.
Response bias: Lambda centre maps for all three trunk orientations are given in Figure 2.8. Three-way: 3 (trunk orientation: Left, Straight ahead, Right) X 4 (visual field: Left, Right, Up, Down) X 2 (eccentricity: Near, Far) repeated measures ANOVA revealed neither significant main effect nor significant two-way interactions (p’s > 0.13). However, there was a significant three-way interaction: \( F(6, 84) = 2.55, p = 0.0254 \) due to trendwise differences between quadrants (left and up vs. right and bottom) at far target locations for trunk right orientation (one-way repeated-measures ANOVA: \( F(3, 42) = 2.94, p = 0.044 \); not significant after Bonferroni correction) whereas no other follow-up tests yielded trends (F’s < 2.12, p’s > 0.113).

Figure 2.8 Lambda centre maps for Experiment 2. (a) Trunk turned to the left. (b) Straight ahead. (c) Trunk turned to the right. (d) P-values across all three trunk orientations.
Figure 2.9 Averaged d-prime and lambda centre values for Experiment 2. (a) D-prime values on left/right/up/down/near/far visual fields on all three trunk orientations. (b) Lambda centre values on left/right/up/down/near/far visual fields on all three trunk orientations. Note that the position of the diamond indicates the medians.
2.3 Discussion

In Experiment 1 and 2, I revisited the study of Hasselbach-Heitzeg and Reuter-Lorenz (2002) by conducting two cognitively-challenging working memory experiments during eye movement recording: A change detection task in Experiment 1 and a two-back task in Experiment 2. Both experiments failed to find a visual field (Left versus Right) or trunk orientation main effect, and their interaction was also not significant. Therefore, these two experiments failed to replicate Hasselbach-Heitzeg and Reuter-Lorenz (2002)’s finding that rightward trunk rotation caused a right visual field advantage in detection sensitivity for lateralized targets. However, both Experiment 1 and Experiment 2 found an influence of visual eccentricity on d-prime: Participants’ sensitivity significantly improved when detecting targets at ‘far’ screen locations compared to targets at ‘near’ screen locations relative to the central fixation point. Most importantly, an interaction between visual eccentricity and trunk orientation was found in Experiment 2. Specifically, people’s detection sensitivity became better in peripheral regions of the screen when they rotated their trunk from left orientation to right orientation. This particular finding is consistent with our previous observation that rightward trunk rotation decreased response latency in targets on far-eccentric locations of the visual field (Mohammad, Chen, & Niemeier, 2012). The reason for the difference between Experiment 1 and 2 might be that the former experiment required participants to pay attention to four stimuli, whereas in the latter participants paid attention to just one stimulus. This is consistent with our previous observation. However, further research beyond the scope of the present project will be necessary to investigate the mechanisms underlying this effect.

Since the first set of experiments (Experiment 1 and 2) on visual working memory did not confirm the main findings of Hasselbach-Heitzeg and Reuter-Lorenz (2002) and showed no evidence of head-on-trunk signals on ipsiversive improvement of performance, next I investigated the influence of trunk orientation on valid and invalid cueing of spatial shifts of attention because a previous study (Grubb & Reed, 2002) suggested that trunk orientation could improve people’s detection performance on the ipsiversive side for invalidly cued targets. Thus, in the second set of experiments (Experiment 3, 4 and 5), I tested three different versions of Grubb and Reed’s experiment while avoiding possible shortcomings of that study. That is, I used paradigms that avoided the potential problem of response priming or response conflict (Simon, 1969), and I controlled for eye movements.
Chapter 3

3 Head-on-trunk signals and spatial shifts of attention

3.1 Experiment 3: Speeded discrimination task

Since there was no evidence for an influence of head-on-trunk signals on the attentionally-demanding visual working memory tasks, the results were inconsistent with Hasselbach-Heitzeg and Reuter-Lorenz’ (2002) report. I next investigated whether the effects of head-on-trunk on spatial attention occurred only for a specific form of attention, that is, when attention needs to be disengaged after invalid cues (Posner, Walker, Friedrich, & Rafal, 1984). Therefore, I adopted a Posner paradigm to cue spatial attention as in Grubb and Reed’s (2002) study, but I modified their task to avoid undesired response priming/cueing effect. The aim was to replicate Grubb and Reed’s (2002) results.

3.1.1 Method

Participants: Seventeen undergraduate students from the University of Toronto at Scarborough participated in this experiment (8 females; median age =19 years). Three participants’ data sets were excluded because their hit rates did not pass the criterion (hit rates ≥ 50%); therefore the total number of valid data sets was 14. All participants gave their informed and written consent prior to their inclusion in the study and received a course credit in exchange for participation. All experimental procedures were approved by the Human Participants Review Sub-Committee of the University of Toronto and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All participants were free of neurological diseases and psychiatric disorders with normal or corrected-to-normal vision, and were right-handed as confirmed by the Edinburgh handedness inventory (Oldfield, 1971).

Stimuli and Apparatus: Visual stimuli consisted of a red fixation point measuring 0.26° across, a cue that was a white outline of a circle measuring 4° in diameter, and a target Gabor (spatial frequency=0.97cpd, standard deviation=0.93°) tilting 45° either clockwise or counter-clockwise. All stimuli were displayed against a grey background. Participants were seated in the same way as during Experiment 1 and 2. All the other experimental setups, including head-on-trunk control and eye movement recordings, were the same as Experiment 1 and 2.
**Experimental conditions:** See Experiment 1 and 2.

**Experimental procedure:** For each single trial, participants looked at the central fixation point for 1500 milliseconds. A non-informative white cue circle then appeared 15° on either left or right side of the central fixation point for 20 milliseconds. After 30, 80, and 180 milliseconds respectively (i.e., total stimulus onset asynchrony: 50, 100 and 200 milliseconds), a target Gabor was presented. On valid trials (50% of trials), the target Gabor appeared at the location indicated by the cue circle. On invalid trails (50% of trials), the target Gabor appeared 15° to the side of the fixation point opposite the cue circle. Participants were asked to press number 4 on a number pad if the orientation of the target Gabor was tilted clockwise and number 6 if the orientation of the target Gabor was tilted counter-clockwise. Participants were expected to respond as quickly and accurately as possible. After 10 practice trials, they completed twelve blocks (four blocks in each body position) with 144 trials per block. Each block had randomly presented and equal numbers of trials in terms of cue position and cue validity. Eye movement data were inspected offline for fixation errors (saccades > 1.5°). The remaining valid trials were used to calculate participants’ reaction times as well as d-prime and lambda centre values for target discrimination (See Figure 3.1 for the paradigm of Experiment 3).

![Figure 3.1 Paradigm for Experiment 3.](image-url) Paradigm for Experiment 3. After a 1500 ms fixation time, a white cue circle appeared on either left or right side of the central fixation point. Following 50, 100 and 200 ms’ stimulus onset asynchrony, a target Gabor appeared either on the same side or the opposite side of the cue. Participants pressed number 4 if the Gabor was tilted clockwise and pressed number 6 if Gabor was tilted counter-clockwise. Note that stimuli in this figure are not real Gabors.


3.1.2 Results

**Response latency**: Reaction time data were based on trials during which participants correctly reported the orientation of the Gabors (81.25% of all responses, Figure 3.2h). As can be seen in Figure 3.2a-c, reaction times became shorter with longer SOAs, and there was an advantage for targets appearing on the validly cued side compared to the invalidly cued side. Furthermore, reaction times were faster in the right compared to the left visual field. However, there was no obvious influence of head-on-trunk signal. More specifically, the right visual field advantage did not switch to a left field advantage for invalidly cued targets during trunk left posture (Figure 3.2b black bars), which was contrary to what I had expected based on Grubb and Reed’s (2002) study. To confirm these qualitative observations, I conducted a 2 (visual field: Left, Right) X 2 (validity: Valid, Invalid) X 3 (trunk orientation: Left, Straight ahead, Right) X 3 (stimulus onset asynchrony: 50, 100, 200ms) four-way repeated measures ANOVA on reaction times. There was a significant main effect of visual field: F (1, 13) = 12.80, p = 0.0173, η² = 0.497, suggesting a reaction time advantage for detecting target in the right visual field. A main effect of validity: F (1, 13) = 83.60, p = 0.00128, η² = 0.865 indicated a strong cueing effect. There was also a main effect of stimulus onset asynchrony (SOA): F (2, 26) = 103.00, p = 0.00647, η² = 0.888. In addition, the two-way interaction between validity and SOAs was significant: F (2, 26) = 16.00, p = 0.0343, η² = 0.552, reflecting a more pronounced SOA effect for reaction times during valid than invalid trials. However, the main effect of trunk orientation was not significant (p > 0.28) and all the other interactions were also not significant (p’s > 0.08).

To further investigate the cueing effects, I collapsed across all SOAs and subtracted reaction times of validly cued condition from reaction times of invalidly cued condition (See Figure 3.2c, last 6 bars), and conducted a 2 (visual field: Left, Right) X 3 (trunk orientation: Left, Straight ahead, Right) repeated measures ANOVA, but again failed to find any evidence for an influence of head-on-trunk position on reaction times in any one of the SOAs (p’s > 0.15).

**Perceptual sensitivity**: Next I investigated whether head-on-trunk positions had an effect on perceptual performance (Figure 3.2d and 3.2e). Therefore, I conducted a 3 (trunk orientation: Left, Straight ahead, Right) X 2 (visual field: Left, Right) X 2 (validity: valid, invalid) three-way repeated measures ANOVA on d-prime (I collapsed across the SOA factor to obtain a reliable estimates of d-prime). Although there were no main effects (p’s > 0.06), the interaction between
visual field and validity was significant: $F(1, 13) = 6.72, p = 0.0223$. Specifically, in the validly cued condition there was a main effect of visual field: $F(1, 13) = 6.14, p = 0.0277$, suggesting a sensitivity advantage for detecting target in the right visual field. However, the corresponding effect was not found in invalidly cued condition ($p > 0.82$).

**Response bias:** Similar to the analysis of sensitivity, I examined response biases (Figure 3.2f and 3.2g) by conducting a 3 (trunk orientation: Left, Straight ahead, Right) X 2 (visual field: Left, Right) X 2 (validity: valid, invalid) repeated measures ANOVA on lambda centre. There was a main effect of visual field: $F(1, 13) = 8.485, p = 0.0121$, indicating that people tended to press the left button (number 4) when the Gabor appeared on the left side and the right button (number 6) when the Gabor appeared on the right side. This suggested that responses were somewhat influenced by a Simon effect (Simon, 1969). There was also a main effect of validity: $F(1, 13) = 5.875, p = 0.0307$, suggesting a shift in responses bias depending on validity. These effects were not confounded with the measures of d-prime or reaction times because Gabor location was irrelevant with the required orientation judgments. Therefore, the response conflict was probably small and, at any rate, averaged out across trials. Nevertheless, the finding demonstrated that response conflicts and response priming were possible factors influencing Posner paradigms.
Figure 3.2 Results for Experiment 3. (a) Averaged reaction times on valid trials. (b) Averaged reaction times on invalid trials. (c) Reaction time differences between valid condition and invalid condition. (d) Averaged d-primes on valid trials across three trunk orientations. (e) Averaged d-primes on invalid trials across three trunk orientations. (f) Averaged lambda centre on valid trials across three trunk orientations. (g) Averaged lambda centre on invalid trials across three trunk orientations. (h) Averaged hit rates for three trunk orientations. (L: Target appeared on the left visual field; R: Target appeared on the right visual field; SOA: stimulus onset asynchrony; diamond: median values).

3.2 Experiment 4: Simple detection task

Experiment 3 did not produce the expected ipsiversive effects of head-on-trunk signals, unlike reported by Grubb and Reed (2002). One possible reason for this might be that the previous experiment was a comparatively difficult choice reaction task about orientation. Therefore, in Experiment 4 I used a simple detection task. Furthermore, I chose different target stimuli, in case Grubb and Reed’s (2002) head-on-trunk effects were limited to certain kinds of stimuli, which were different from the Gaborbs that I had used so far. Also, I avoided response conflicts or...
response priming by having only one type of response in a go/no-go fashion. Lastly, I changed the cue in case the cueing effect had not been strong enough before.

3.2.1 Method

Participants: Sixteen undergraduate students from the University of Toronto at Scarborough participated in this experiment (8 females; median age = 20 years). Four participants’ data sets were excluded because their hit rates and false alarm rates did not pass the criteria (hit rate ≥ 80%; false alarm rate ≤ 25%); therefore the total number of valid data sets was 12. All participants gave their informed and written consent prior to their inclusion in the study and received a course credit in exchange for participation. All experimental procedures were approved by the Human Participants Review Sub-Committee of the University of Toronto and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All participants were free of neurological diseases and psychiatric disorders with normal or corrected-to-normal vision, and right-handed (2 left-handers) as confirmed by the Edinburgh handedness inventory (Oldfield, 1971).

Stimuli and Apparatus: The setup for Experiment 4 was similar to Experiment 3 except for the following changes: (1) the cue was changed to the white outline of a square measuring 4.41° instead of a circle; (2) the target was changed to a red dot measuring 1° in diameter instead of a Gabor; (3) cue presentation time was extended to 100 milliseconds for possibly stronger cueing effects; (4) stimulus onset asynchrony was changed to 150, 300 and 600 milliseconds to investigate other time ranges, including the potential influence of inhibition of return (See Figure 3.3 for the paradigm of Experiment 4).

Experimental conditions: Two trunk orientations instead of three were tested in Experiment 4 to be able to collect more data per condition: (1) trunk turned 30° toward the left; (2) trunk turned 30° toward the right.

Experimental procedure: Similar to Experiment 3, participants looked at the fixation point for 1500 milliseconds. A white cue square then appeared 15° on either left or right side of the central fixation point for 100 milliseconds. After 50, 200, and 500 milliseconds respectively (stimulus onset asynchrony: 150, 300 and 600 milliseconds), a red target dot was presented. On valid trials (50% of trials), the target appeared within the cue box. On invalid trails (50% of trials), the target
appeared 15° to the side of the fixation point opposite the cue box. Participants were asked to press number 5 on a number pad whenever they detected the target regardless of target location (note that this avoided influences of priming motor responses, contrary to Grubb and Reed, 2002, who asked participants to use a left and a right button depending on target side). Each block had 144 trials plus 20% catch trials during which the cue was followed by no target. Eye movement data were inspected offline for fixation errors (saccades > 1.5°). The remaining valid trials were used to calculate participants’ reaction times.

**Figure 3.3** Paradigm for Experiment 4. After a 1500 ms fixation time, a white cue box appeared on either left or right side of the central fixation point. Following 150, 300 and 600 ms’ stimulus onset asynchrony, a red target dot appeared either on the same side or the opposite side of the cue. Participants pressed number 5 whenever they detected the target.

### 3.2.2 Results

Reaction time calculations were based on participants’ correctly detected targets (averaged hit rate: 86.72%). As can be seen in Figure 3.4a-c, reaction times became shorter with longer SOAs, but mainly for invalidly cued targets. For valid targets reaction times increased for 600 milliseconds SOA and this produced a negative cueing effect beginning 300 milliseconds after stimulus onset. To examine these effects, I conducted a 2 (visual field: Left, Right) X 2 (validity: Valid, Invalid) X 2 (trunk orientation: Left, Right) X 3 (stimulus onset asynchrony: 150, 300, 600ms) four-way repeated measures ANOVA on people’s reaction times. There was a main effect of validity: F (1, 11) 27.50, p = 0.0329, η² = 0.714, mainly driven by the inhibition of return effect; there was also a two-way interaction between validity and SOAs: F (2, 22) = 44.9, p = 0.00361, η² = 0.803. All the other main effects or interactions were not significant (p’s >
Finally, I reanalyzed the data by collapsing across SOAs 150 and 300 ms (I excluded 600 ms because of the inverted validity) and subtracting valid reaction times from invalid reaction times (Figure 3.4c, last four bars), but I did not observe any significant effects for either trunk orientation or visual field or their interactions (p’s > 0.22).

Figure 3.4 Results for Experiment 4. (a) Averaged reaction times on valid trials. (b) Averaged reaction times on invalid trials. (c) Reaction time differences between valid condition and invalid condition. (d) Averaged hit rates for two trunk orientations. (e) Averaged false alarm rates for two trunk orientations (L: Target appeared on the left visual field; R: Target appeared on the right visual field; SOA: stimulus onset asynchrony; diamond: median values).
3.3 Experiment 5: Simple detection task (revised)

Because once again Experiment 4 failed to produce the ipsiversive effects of head-on-trunk signals as reported by Grubb and Reed (2002), I tried another version of the paradigm. Importantly, to reduce spatial uncertainty I used white outlines of square boxes appearing on both left and right side of the fixation point to mark the locations where the targets could occur. To cue attention, one of the boxes whitened and thickened briefly. Furthermore, I changed the target into a red asterisk that was sufficiently different from the white boxes so as to create a perceptually salient event. Also, I amplified the influence of the attentional cue by making informative; that is, 70% of the time the cue correctly predicted the subsequent target location. Finally, I changed SOAs back to shorter times.

3.3.1 Method

Participants: Twenty undergraduate students from the University of Toronto at Scarborough participated in this experiment (11 females; median=19 years). Five participants’ data sets were excluded because their hit rates and false alarm rates did not pass the criteria (hit rate \(\geq 80\%\); false alarm rate \(\leq 25\%\)); therefore the total number of valid data sets was 15. All participants gave their informed and written consent prior to their inclusion in the study and received a course credit. All experimental procedures were approved by the Human Participants Review Sub-Committee of the University of Toronto and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All participants were free of neurological diseases and psychiatric disorders with normal or corrected-to-normal vision, and right-handed (1 left-hander) as confirmed by the Edinburgh handedness inventory (Oldfield, 1971).

Stimuli and Apparatus: The setup for Experiment 5 was based on Experiment 4 with the following modifications: (1) colour of the fixation point was changed to green instead of red to make target and fixation point perceptually more different; (2) white square boxes appeared on both sides of the fixation point, and whitening and thickening of one side of the box lasting 50 milliseconds served as the cue in this task; (3) the target was changed into a red asterisk measuring 4° instead of a red dot measuring 1°; (4) the visual angle of the target locations was reduced from 15° to 5° to more closely match Grubb and Reed’s (2002) stimulus features; (5) stimulus onset asynchrony was changed back to 50, 100 and 300 milliseconds; (6) proportional
distribution of the valid, invalid and catch trials was changed into 70%, 20% and 10% respectively. Paradigm of Experiment 5 is given in Figure 3.5.

Experimental conditions: See Experiment 4.

Experimental procedure: Similar to Experiment 4, participants looked at the fixation point for 1500 milliseconds with two peripheral boxes located 5° left and right of the fixation point. One side of the box then became thicker and brighter for 50 milliseconds. After 0, 50, and 250 milliseconds respectively (stimulus onset asynchrony: 50, 100 and 300 milliseconds), the red target asterisk was presented. On valid trials (70% of trials), the target appeared within the cue box. On invalid trails (20% of trials), the target appeared 5° to the side of the fixation point opposite the cue box. On catch trials (10% of trials), there was a cue but no target. Participants were asked to press number 5 on a number pad whenever they detected the target asterisk. After 10 practice trials, they completed eight blocks with 240 trials per block. Eye movement data were inspected offline for fixation errors (saccades > 1.5°). The remaining trials were used to calculate participants’ reaction times for target detection.

Figure 3.5 Paradigm for Experiment 5. After about 1500 ms fixation time, one side of the white boxes became thicker and brighter for 50 ms. Following 50, 100 and 300 ms’ stimulus onset asynchrony, a red asterisk appeared either on the same side or the opposite side of the cue. Participants pressed number 5 whenever they detected the target.
3.3.2 Results

Reaction times were calculated based on correct detections of the target (83.68%, Figure 3.6d). Similar to Experiment 4, I conducted a 2 (visual field: Left, Right) x 2 (validity: Valid, Invalid) x 2 (trunk orientation: Left, Right) x 3 (stimulus onset asynchrony: 50, 100, 300ms) four-way repeated measures ANOVA on people’s reaction times. There was a main effect of validity: F (1, 14) = 19.10, p < 0.001, $\eta^2 = 0.577$; valid trials were associated with shorter reaction times. There was also a main effect of SOAs: F (2, 28) = 75.10, p < 0.01, $\eta^2 = 0.843$, indicating that reaction times became shorter with longer SOAs. However, neither the main effect of trunk orientation nor the main effect of visual field was significant (p’s > 0.28), and none of the interactions was significant (p’s > 0.09).

I also subtracted averaged reaction time of validly cued condition from averaged reaction time of invalidly cued condition (See Figure 3.6c), and conducted three 2-way ANOVAs for different SOAs. Results showed that there was a trend interaction between trunk orientation and visual field for the shortest SOA (50ms; F (1, 14) = 5.40, p = 0.0358); however, the effect was insignificant according to Bonferroni’s criterion (p = 0.05/3 statistical tests). Moreover, no equivalent effects were found for medium (100ms) or long (300ms) SOAs (p’s > 0.08), which were SOAs more similar to Grubb and Reed’s (2002) original paradigm.
3.4 Discussion

In Experiment 3, 4 and 5 I tested three different versions of Grubb and Reed (2002)’s experiment by using a Posner’s paradigm to investigate whether invalidly cued targets would influence the effect of head-on-trunk signals on disengagement of attention.

First of all, a main effect of validity was found across all three experiments: p < 0.01 in Experiment 3, p < 0.05 in Experiment 4, and p < 0.001 in Experiment 5 respectively, suggesting
the existence of a strong cueing effect. Specifically, people’s response latency was much shorter in validly cued condition compared to invalidly cued condition when stimulus onset asynchrony (SOA) was smaller than 300 milliseconds.

Secondly, previous studies have consistently confirmed that when stimulus onset asynchrony (SOA) was longer than typically 300 milliseconds, people would counter-intuitively respond faster to invalidly cued targets than validly cued targets in a Posner paradigm experiment (Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985; Klein, 2000). This phenomenon of inhibition of return (IOR) was also found in Experiment 4: The direction of cueing effect was reversed at an SOA of 300 and 600 milliseconds during both left and right trunk orientation (See Figure 3.4c).

Thirdly, an interesting finding was also observed in Experiment 3 wherein the visual stimulus was a Gabor with certain spatial frequency (approximately 1 cpd): There was a right visual field advantage for all three trunk orientations. Specifically in terms of reaction time, targets in the right visual field were detected faster compared to those in the left visual field in both validly and invalidly cued conditions. At the same time in terms of d-prime, detection sensitivity was consistently higher for targets in the right visual field than those in the left visual field across all three trunk orientations only for valid trials, not for invalid trials. This particular finding was consistent with previous reports that the right visual field/ left hemisphere were dominant for higher spatial frequencies in certain tasks (e.g. Christman & Kitterle, 1991).

Nevertheless, based on the results from the three experiments I was still not able to confirm that trunk orientation could elicit an ipsiversive improvement of performance under invalidly cued condition as reported by Grubb and Reed (2002). Although in Experiment 5, a significant interaction between trunk orientation and visual field was found for the shortest SOA (50 ms), still the effect could not be generalized to other SOAs (i.e. 100 and 300 ms) or other versions of the paradigm (i.e. Exp.3 and Exp. 4). Therefore, by controlling for eye movements and by avoiding response priming as potential confounds, the attempts to replicate Grubb and Reed (2002) were not successful.
Chapter 4

4 General discussion

The goal of the present research was to confirm that cognitive functions such as spatial attention and working memory were associated with body schema in neurologically normal people. In this study, I investigated the influence of head-on-trunk signals by two sets of experiments. The first set probed spatial attention and visuo-spatial working memory by a change detection task and a two-back task. The second set examined spatial shifts of attention in three different versions of the Posner paradigm. In these five experiments, I used a wider range of visual field compared to previous studies (i.e., Hasselbach-Heitzeg & Reuter-Lorenz, 2002; Grubb and Reed, 2002); I controlled for eye movements data; I also avoided response priming effect as potential confound.

The results from the first set of experiments (i.e. Experiment 1 and 2) indicated that: (1) there was no evidence for head-on-trunk signals in the sense of an ipsiversive improvement of performance as reported by Hasselbach-Heitzeg and Reuter-Lorenz (2002); specifically, turning the trunk 30° to the left or the right side did not elicit a corresponding left or right visual field advantage; (2) however, people’s detection sensitivity improved in peripheral regions of the screen when they changed their body position from left to right orientation.

The results from the second set of experiments (i.e. Experiment 3, 4 and 5) found that: (1) there was a stronger cueing effect when the stimulus onset asynchronies (SOAs) were longer up to 300 milliseconds; (2) inhibition of return (IOR) appeared when stimulus onset asynchrony (SOA) was longer than 300 milliseconds; (3) for experiment 3 in which the target stimuli were Gabors with a certain spatial frequency, there was a right visual field advantage for validly cued trials across all trunk orientations in terms of reaction time and sensitivity, but there was only a right visual field advantage in reaction time but not in sensitivity for invalidly cued trials. Despite above-mentioned findings, I did not find an effect of trunk orientation on ipsiversive improvement of performance under invalidly cued condition as reported by Grubb and Reed in the three experiments (2002).
4.1 Inconsistency with previous findings

Based on the observations, I could conclude that my data were not consistent with previous findings of head-on-trunk effects in normal participants (i.e. Hasselbach-Heitzeg & Reuter-Lorenz, 2002; Grubb & Reed, 2002), and there might be several possible reasons for the discrepancies of the results.

One argument would be that the numbers of participants in these five experiments were not adequate. However, this is very unlikely because: first, I found other effects sufficiently significant in these five experiments (e.g. eccentricity effect, validity effect, SOA effect); second, actually the current study did not have smaller numbers of participants (19/15/14/12/15) than those in studies of Hasselbach-Heitzeg and Reuter-Lorenz (12/9; only females) and Grubb and Reed (18); third, there was not even a trend for the main effect of trunk orientation or its interaction with visual field (Left/ right) to be significant across all five experiments (p’s > 0.14).

As another possibility, I might have missed some important components in my experimental paradigms. However, in the first set of experiments, I adopted two different working memory tasks; in the second set of spatial shifts of attention experiments, I also tested three different versions of the Posner paradigm. In none of the experiments did I find any evidence for the effect of trunk orientation on Left/Right visual field advantage. Hence, given the variety of employed paradigms it appears unlikely that I overlooked head-on-trunk effects. In contrast, I avoided the potential confound of response priming which was overlooked by Grubb and Reed (2002); because the concern that response priming or response conflict could play a role in eliciting head-on-trunk effects was confirmed in Experiment 3 where I observed a visual field effect for lambda centre. Furthermore, I also examined the eye movement data which were not controlled for in the studies by Grubb and Reed (2002) and Hasselbach-Heitzeg and Reuter-Lorenz (2002).

Therefore, while controlling for eye movement data and minimizing potential response biases, there was no influence of head-on-trunk signals on ipsiversive improvement of performance as reported by previous studies. At least I can conclude that under only a few rather specialized conditions do these head-on-trunk effects occur. What exactly these conditions are needs future research to confirm.
4.2 Implications for neglect research

Sensorimotor control requires that the brain form a neural representation of body orientation in space. Such a body schema has been demonstrated in neurophysiological and psychological studies, and it has been confirmed to be associated with cognitive functions such as spatial attention in patients with unilateral spatial neglect. Specifically, manipulations of body schema such as head-on-trunk turns would modulate neglect symptoms (e.g. Karnath et al., 1991). However, equivalent effects in neurologically normal people were either not found (Karnath et al., 1991), inconsistent (Hasselbach-Heitzeg & Reuter-Lorenz, 2002 versus Grubb & Reed, 2002), or possibly confounded with response priming or conflict effects (Grubb & Reed, 2002). I tried to confirm these effects, but again my data showed no evidence for an influence of head-on-trunk signals on spatial cognition in normal participants as reported in neglect research.

The present study might have several implications for past and future research on spatial neglect. One possible implication is that perhaps previous observations of effects of head-on-trunk signals in neglect patients might be only response biases. For example, in one classic study by Karnath and colleagues (1991) indicating trunk orientation as the determining factor of spatial neglect and physical anchor of body representation, they found the head-on-trunk signal effects merely based on saccadic reaction times. Therefore, in their study it was impossible to distinguish between head-on-trunk effects on attention or on primed oculomotor functions.

A second possibility is that perhaps brain damage causes the brain in neglect patients to change in special nonlinear ways that are very different from functions of an intact brain. This would mean studying spatial neglect does not help much understand the normal brain unless we establish quantitative models that can account for nonlinear effects of simulated brain lesions much like those hypothesized for neglect patients. A tentative explanation for this nonlinearity is that there might be a compensatory mechanism underlying spatial neglect. To compensate for their deficits, neglect patients might recruit some brain regions not engaged by healthy controls in the same task, which causes patients’ lesion settles in a new and quite different equilibrium and further leads to an imbalance between mutually competing hemispheres. This possibility would imply that given our current knowledge, neuropsychological studies are of limited use for any attempt to understand the intact functionality of the normal brain.
A third possibility is that maybe head-on-trunk turns is simply not an effective manipulation; in other words, changes in proprioceptive signals are not sufficient to produce any effects on spatial cognition in the intact brain. One example would be the study by Rorden and colleagues (2001), they found neck vibration (a manipulation of body schema similar to head-on-trunk turns) was only effective in moderating subjective straight ahead, but ineffective in affecting visuo-spatial attention.

In sum, there are several possibilities for the discrepant observations between neglect patients and neurological intact participants. To clarify these hypotheses, further research is required.

4.3 Significance and future research directions

Although I failed to confirm the effects of head-on-trunk signals on spatial cognition as reported in previous studies, I observed a novel and interesting finding that right trunk turning increased people’s detection sensitivity on the peripheral region of the LED screen in a visuo-spatial two-back working memory task. And it is nicely consistent with our previous observation that rightward trunk rotation improved people’s reaction times for detecting targets on screen periphery in a simple target detection task (Mohammad, Chen, & Niemeier, 2012). In addition, my study has several advantages over other similar experiments: first, I presented the participants a larger visual field display (16 possible target locations on a large LED screen); second, I controlled for eye movement errors; third, I avoided the undesired response priming or conflict effect. All these factors ensured the validity of my results.

A tentative explanation for the finding that right trunk orientation facilitated peripheral vision processing could be the global vision hypothesis in which a wider attentional spread was required to register stimuli outside the focus of attention (i.e. the fixation point) in the attentional task. When participants turned their trunk 30° to the right while the head was still facing straight ahead, both left visual field stimuli and right visual field stimuli were projected to the left side of the trunk. As a consequence, the right hemisphere might be more activated for processing the stimuli on the screen. Because the right hemisphere is more dominant for processing holistic global vision of reality (e.g. van Kleeck, 1989; Hellige, 1996), turning trunk to the right
orientation would enhance globally visuo-spatial processing more pronouncedly, and thus participants’ performance was improved when visual targets located on screen periphery.

Someone might argue that the findings from two working memory paradigms were inconsistent. In the two-back task, I found the right trunk turning effects; however, in the change detection task, the equivalent effects were not observed. One reason for the discrepancy might be that the paradigm of the two working memory experiments was different. In the change detection task people had to perceive four Gabors with different orientations one time in a frame whereas in the two-back task 64 Gabors were presented one by one sequentially. That is to say, the set size in the change detection paradigm was four while the set size in the two-back paradigm was one. In a previous study investigating the effects of head-on-trunk signals on simple visual detection (Mohammad, Chen, & Niemeier, 2012), we reported similar results as found in the two-back task; in that experiment, we also presented only one visual stimulus (i.e. a single Gabor) one time in a frame. Therefore, it is possible that the perceptual load of a single visual presentation screen has a subtle influence on the findings, and only a specialized subgroup of visuo-spatial attention or working memory tasks is sensitive to head-on-trunk signals.

Because all the explanations regarding the new finding in the current study are speculative, further studies are urgently required to clarify these possibilities. The first line of future research could be focused on the validation of the global vision hypothesis mentioned in the previous paragraph. Maybe we can design an experiment containing hierarchical figures that globally and locally consist of different letters to examine if trunk right orientation could facilitate people’s processing of global figures significantly. We could also conduct an electroencephalography (EEG) experiment to investigate the activities of the right hemisphere during trunk right orientation. The second line of research could be focused on the influence of perceptual load on head-on-trunk effects as observed in the current two-back task. We could examine if the influence of head-on-trunk signals (specifically right trunk orientation) is qualitatively or quantitatively different as a function of different set size on a single visual stimuli display. The last line of research could test whether the right trunk turning effects found in the current study are replicable in other methods of manipulations of body schema, for example, right neck vibration and prism adaptation.
4.4 Conclusion

To conclude, in the current study I tested the influence of head-on-trunk signals on spatial attention and working memory or spatial shifts of attention using five experiments. However, only in one sub-condition of Experiment 5 did I observe a trend for trunk turning moderating performance in the left versus right visual field in an ipsiversive fashion. Therefore, my data are not consistent with the findings as reported in previous studies among normal participants. Nevertheless, the novel finding that a rightward trunk orientation caused a peripheral visual field advantage in performance suggests a new association between body schema and spatial cognition. Furthermore, the findings of the current study might bring new implications to past and future research on spatial neglect.
References


