The influence of the body and action on spatial attention

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Abstract. Research on spatial attention traditionally focuses on how it is influenced by the location of objects within the visual environment. However, a primary function of spatial attention is to plan physical actions. When events occur in the world, visual information needs to be integrated with current body position to help prepare effective responses to these events. Further, current actions can subsequently influence further deployments of attention. Thus, spatial attention must be considered within the context of the body. Here we present research demonstrating that one's own body and the actions of others can influence spatial attention mechanisms, influencing the prioritization of functional space near the body and the direction of attention. This work emphasizes a need for an embodied theory of spatial attention and a more dynamic neural model of attention that adjusts to meet the demands of the current environment and the perceiver's goals.

Keywords: spatial attention, embodiment, covert orienting, human body

1 Introduction

Human perceptual and attentional systems operate to help us perform functional and adaptive actions [1][2]. In our everyday world, we need to know how to respond effectively when an enemy throws a rock at our head or when a friend tosses us an apple. The current location of our hands in these situations influence the speed and success with which we can either knock the rock away or grab the apple. These common examples emphasize the dynamic nature of the environment and the need for our spatial attention system to effectively incorporate visual information with information from our own and other people's bodies. Spatial attention refers to the cognitive process through which certain visual stimuli are selected to the exclusion of other stimuli based on their spatial location [3]. One of the primary functions of spatial attention is to select objects and locations in space that are functionally relevant to what an organism is doing now [4] or sometime in the near future. To interact with the environment, one must orient attention to relevant events. Spatial attention helps us select the most relevant task information and improve perceptual processing by amplifying signals associated with salient regions of space [5] [6] [7]. Moreover, given that the current orientation of our bodies and the positions of our limbs provide an anchor or reference for current and upcoming action, the body and its limbs may aid in the selection of relevant perceptual information. Thus, it makes sense that our bodies and actions should play an important role in spatial attention processes. However, few studies have examined how our bodies and action influence attention.

This functional view of spatial attention has important implications for how sensorimotor experience, the body, and its actions influence our visual perception. Skilled activity requires the integration of past, present, and future events. Performers need to acquire perceptual information to determine the outcomes of past actions, to monitor on-going actions, and to plan how to respond to upcoming events. At the same time, performers are producing their own activity that is based on this information and contributes to that information. Spatial attention can influence this dynamic interaction between top-down goals of what one intends to do and bottom-up influences from the environment and the body by prioritizing processing in certain regions of visual space based on intentions and functions of the body.

This perspective implicates a dynamic, multimodal, whole-brain network in attentional processing. Desimone and Duncan [8] have proposed that selective visual attention is an emergent property of competitive interactions that work in parallel across visual space and that objects compete for limited processing resources and control of behavior. The competition is biased by both bottom-up and top-down inputs. Bottom-up mechanisms help to distinguish objects from their backgrounds. Top-down mechanisms help select regions of space and objects that are relevant for on-going behavior. The underlying neural mechanisms associated with more bottom-up biases for resolving competition among multiple objects include the visual ventral stream which connects visual cortex with inferior temporal cortex [9]. Neural mechanisms involved in resolving competition for several relevant regions of space include the dorsal stream connecting visual cortex with parietal regions. Top down selection for both objects and locations is thought to be derived from neural circuits mediating working memory and the prefrontal cortex. Further, medial temporal and hippocampal regions provide information that permits past experience to inform future actions.

In this paper, we extend this view of attention to include contributions from the body and its actions. We propose neural circuits involved in determining the current position of the body to prioritize spatial locations for upcoming function interactions and current active behavior should be included in the biased competition model of spatial attention. The addition of the neural substrates representing the body and its actions creates a more dynamic model of attention that constantly adjusts to meet the demands of the current environment and the perceiver's goals. Under this view, spatial attention emerges as a distribution or topography of activation across visual space and the body and its actions would serve to increase relative activation near functional effectors or change/shift the location of relatively high activation regions through bodily action and action goals.

Despite the relevance of the body and its actions to spatial attention processing, few studies have examined how the body and its actions can influence attention. In this chapter we will review recent findings that have begun to explore contributions from the body and its actions in spatial attention processes. First we will examine how the orientation, location, and functional properties of our own body parts can shape the allocation of attention and prioritization of certain regions in space. Next, we will consider how attentional mechanisms change to incorporate the body in action. Finally, we consider how our perception of other people's bodies and their implied actions can influence our future oriented behaviors. Together this research argues for an embodied model of spatial cognition that helps explain how we predict and respond to the dynamic world around us.

2 How Do Our Own Bodies Influence Attention?

An embodied theory of spatial attention implies that our bodies help shape how attention is distributed in space and how visual stimuli are processed as a result. To the extent that the current configuration of our body parts constrains our actions at any moment, they influence where spatial attention is allocated across visual space. Even without movement, the body's positioning should have an effect on attentional processing.

2.1 Effects of Trunk Orientation on Spatial Attention.

Attention should make salient or increase the activation of those regions of space that are most relevant for performing upcoming actions. Although researchers have identified a number of factors that influence the deployment of visual attention, until recently the influence of trunk orientation has often been overlooked. The trunk is the structural hub to which our head, arms, and legs are attached. As a result, trunk orientation and perceived body configuration influences sensorimotor planning for many typical actions [10] [11] and, thus, should affect the distribution of spatial attention.

The trunk is often aligned with behaviorally important regions of space. First, although we may turn our head and eyes to look in other directions, we usually move in the direction in which the trunk points. The direction of attention toward the path of motion helps us to avoid collisions when locomoting through the environment. A trunk-orientation bias for attention would literally help us to watch where we are going. Second, it is convenient to align the trunk with objects that we intend to manipulate. The external space immediately in front of the trunk can be easily reached with either or both hands. Assuming that people tend to do what is naturally most convenient, comfortable, and effective, people should align their trunks with the longer-term focus of attention (i.e., their primary interest), especially when locomoting through the environment, and turn their heads only to temporarily focus on secondary interests. As such, trunk orientation is a marker for behaviorally important regions of space. An attentional bias toward such a region would alert us to sudden events occurring there even as we temporarily look elsewhere.

An influence of the trunk on spatial attention is found most reliably in studies of patients with unilateral neglect. Following brain injury, typically to the right temporoparietal region, patients with neglect fail to attend to and explore contralesional space [12]. Patients with neglect are better able to explore and to detect targets in contralesional space when their torsos are rotated toward contralesional space [13] [14]. Additionally, patients' symptoms improve during procedures that induce a displacement of the perceived orientation of the body midline toward the contralesional side. These procedures include cold caloric irrigation of the contralesional ear [15], warm caloric irrigation of the ipsilesional ear [15], vibration of the contralesional posterior neck muscles [16], and viewing of a contralesionally moving optokinetic display [17]. These same procedures affect the perception of body midline in neurologically intact participants [18]. In sum, patients' symptoms improve when the actual or perceived orientation of their trunk is rotated toward the neglected region of space. Thus, attention appears to follow perceived trunk orientation for patients with neglect.

Effects of trunk orientation, however, have been less consistently demonstrated in healthy participants. Karnath and colleagues did not find equivalent trunk orientation effects in neurologically intact or even in brain-injured controls as in neglect patients for saccadic response times [14], detecting and naming contralesional targets [13], or neck muscle vibration and caloric irrigation in conjunction with tasks known to be sensitive to manipulations of spatial attention [19]. In contrast, other studies of healthy participants have revealed effects of trunk orientation. In a lateralized, target-detection paradigm, Hasselbach-Haitzeg and Reuter-Lorenz [20] found that participants were slightly faster to respond to targets presented on the right relative to targets presented on the left when their trunks were turned to the right. Further, Grubb and Reed [21] used a covert-orienting paradigm (see Fig. 1) to demonstrate that participants demonstrated neglect-like effects when their trunks were turned to the left: participants were slightly faster to detect invalidly cued targets on the left and slightly slower to detect invalidly cued targets on the right. Although both of these studies demonstrated effects of trunk orientation, the effects were to different sides. Thus, it is unclear whether the lateralized effects can be attributed to lateralized brain function or something specific to the tasks and testing situations.

To address the question of what conditions can reliably produce effects of trunk orientation, we investigated factors that may necessitate a trunk-orientation bias in everyday life. We hypothesize that the relevance of the trunk to the task can influence the prioritization of regions of space based on the trunk. The trunk is important for action because it guides the direction of locomotion through the environment and influences the parts of space in which the hands can interact.

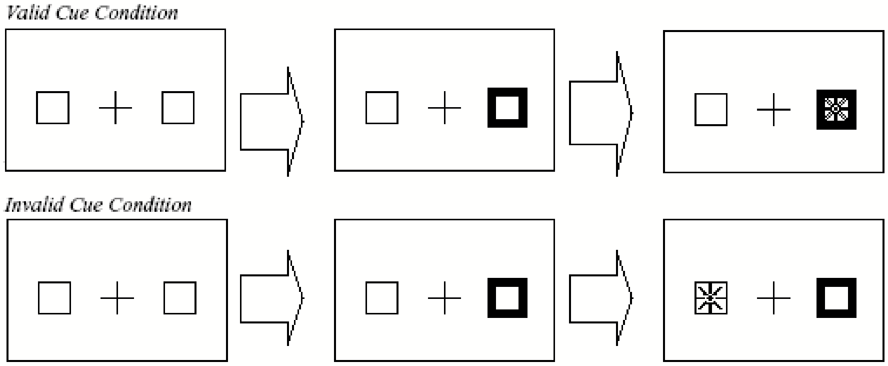

Fig. 1. Typical covert-orienting paradigm: progression of trials. Participants focus on the center fixation point. One of the two boxes brightens. On valid trials, a target appears in the cued or brightened box. On invalid trials, a target appears in the uncued or opposite box. Validity effects refer to the finding that participants detect targets more quickly when they appear in the cued box compared to the uncued box.

For example, the trunk orientation may be more relevant when one is walking than when one is standing still because it can influence whether or not one will walk into an obstacle. In addition, walking may induce a trunk-orientation bias via the introduction of locomotion plus additional motor and cognitive processing demands. Trunk orientation biases have been observed in patients with unilateral neglect and attributed to their reduced processing capacity in terms of arousal and/or attentional demand [22] [23] [24] [25]. Thus, reliable trunk orientation effects may not be found in neurologically intact participants because the experimental tasks did not impose strong enough processing demands. In most of the studies for which trunk orientation effect on spatial attention was not found, healthy participants performed a simple attention task while sitting in a static environment. We argue that trunk orientation was not relevant to the task requirements or the responses because participants were able to give undivided attention to the task, thus effectively eliminating any effects of trunk orientation bias. Thus, healthy participants should be more likely to demonstrate an influence of trunk-orientation bias on tasks for which the trunk is relevant to task performance and that have sufficient motor and cognitive demands.

We addressed this hypothesis in a recent study [26] by examining a task for which the trunk is relevant, namely walking, and by increasing the processing demands of the task. In each experiment we compared lateralized visual detection performance [20] and compared the influence of trunk orientation on detection time under standing, walking forward and walking sideways conditions. Trunk bias was revealed only in walking conditions, regardless of the perceived direction of motion. We found faster response times to targets in front of the trunk than to ones on the side when participants were walking but not when they were standing. In subsequent experiments, we investigated whether attention to the body via increased physical demands or attention to the task via increased cognitive and motor demands influenced the trunk orientation bias. We found that although cognitive load induced by a secondary pitch-counting task influenced detection performance overall, a trunk orientation effect was only found when motor demands on attention were increased by disrupting automatic walking pace with enforced slower paces. By pitting cognitive load against motor load conditions, we were able to disambiguate the relative contributions of physical demands, motor load, and cognitive load on trunk orientation biases during walking. In summary, the trunk tends to prioritize space consistent with its orientation when the task requires bodily action and places motor demands on processing.

2.2 Effects of Hands and Effectors on Attention.

In addition to the trunk, our hands should also affect the prioritization of processing in regions of space that they can perform functional actions. The current configuration of sensory and effector organs necessarily affects the way that actions are performed to accomplish our goals. For example, to grasp a visually detected object, one needs to know not only the object's location relative to the eye, but also its position relative to the hand in order to plan an appropriate reach. To perform this functional action, a sensorimotor transformation is required to integrate current information regarding the placement of the hand and arm relative to the orientation of eye and head [27] [28]. Thus, the location and functional properties of exploring effectors such as the hands should influence spatial attention mechanisms.

Attention to an object or region of space may be affected in at least two ways when the hand is near it. One is that the region near the hand may be prioritized so that the potential relevance of cues and targets appearing in that space is increased. In other words, the presence of the hand could change the spatial distribution of attention, increasing the importance of stimuli near it.

One reason that the hand and body may influence the relative salience of specific regions of space is that space near the body-peripersonal space– is represented differently from other regions of space [29]. The presence of the hand near an object may change the functional implications of the object. More importantly, it potentially changes the need to attend to that object. If objects close to hand were represented differently from objects away from the hand, then this difference in representation could affect how attention is allocated.

This difference may arise from processing contributions of visual-tactile bimodal neurons. In order to manipulate objects, it may be important to form combined visual and tactile representations based on the body part that is closest to the object [30] [31] [32]. Researchers have postulated that bimodal visuotactile neurons may be involved in reaching and grasping behavior as well as in basic haptic functions and fear avoidance [33]. In terms of attention, it is important to detect an event occurring near the hand so that the appropriate action-either grasping or defense movements-can be performed. Physiological recordings from non-human primates have identified populations of neurons that respond to both tactile stimuli on the hand as well as to visual stimuli near the hand. In macaques, bimodal visuotactile neurons are distinguished by their characteristic response properties in peripersonal space [34] [35] [36] [37] [30] [38] [39] [40] [41] [42]. The response of these neurons is largely limited to visual stimuli presented in space immediately surrounding a particular body part such as the hand and appear to encode space based on hand-centered coordinate systems. That is, neuronal response is relies on the position of the visual stimulus relative to the hand that is important, not the position of the visual stimulus in space). The response of bimodal neurons is also spatially graded in that neuronal response decreases as the visual stimulus is presented progressively further from the hand. In sum, these visuotactile neurons appear to integrate multimodal sensory information in near, visual, peripersonal space that surrounds specific body parts such as the hand.

Evidence that humans have bimodal neurons also comes from cross-modal extinction studies of patients with right parietal lobe damage [43] [44] [45] [46] [47] [48]. Tactile extinction refers to inability to perceive a contralesional tactile stimulus when a competing ipsilesional tactile stimulus is presented simultaneously. Supporting the existence of bimodal representations of peripersonal space, these patients demonstrated cross-modal extinction in which a visual stimulus presented near the unaffected ipsilesional hand induced the extinction of a tactile stimulus presented on the contralesional hand; however, an identical visual stimulus at the same location in space did not elicit cross-modal tactile extinction when the hand was absent.

A second way in which hand presence could potentially influence attention would be for it to affect changes or shifts in the prioritization of specific regions of space. Even if the visual environment provides valid, predictive cues to upcoming events or targets, it is possible that the presence and functional capabilities of the hand can alter the distribution of spatial attention. The current position of the hand could potentially interact with the expectation that a target will appear in a specific region of space. This interaction of hand and expectancy could increase the salience or signal to regions of space in which a relevant object or target is expected, thereby reducing the ability of the system to detect targets in regions of space in which targets are not cued.

Recent studies have demonstrated that the body and the orientation of its parts can attentionally prioritize certain regions of space for better perceptual processing. Studies of neurologically intact individuals have demonstrated that the location of a body part facilitates processing [21][49] [50]. Reed and colleagues have demonstrated that the body can influence two different aspects of attention, spatial prioritization and the shifting of attention. First, we have demonstrated that the location and functions of body parts can influence the prioritization of space near that body part. In Reed, Grubb, and Steele [49] participants were tested in a standard predictive covert orienting task with lateral target locations (Fig. 1). One of the two locations was cued visually before a target appeared. Shifts of attention were indicated by faster responses to validly cued targets (i.e., the target appears in the cued location) relative to invalidly cued targets (i.e., the target appears in the non-cued location). While performing target detection task, participants held one hand up next to one of the target locations (see Fig. 2 for the hand condition). The hand was not relevant to the purely visual attention task and did not move. Thus, any effect of the hand on performance had to results from an interaction between the hand's location and attention processing. Results showed that the hand influenced processing in that it speeded responses to targets appearing near the hand, regardless of cue validity (see Figure 2 for an example of this data pattern). This facilitation depended on the hand's physical proximity to the target location and did not occur when an arbitrary visual anchor replaced the hand (see Fig. 2 for standard data pattern). Further, the effect appeared to be multimodal in that it was found even when direct visual or direct proprioceptive inputs were removed.

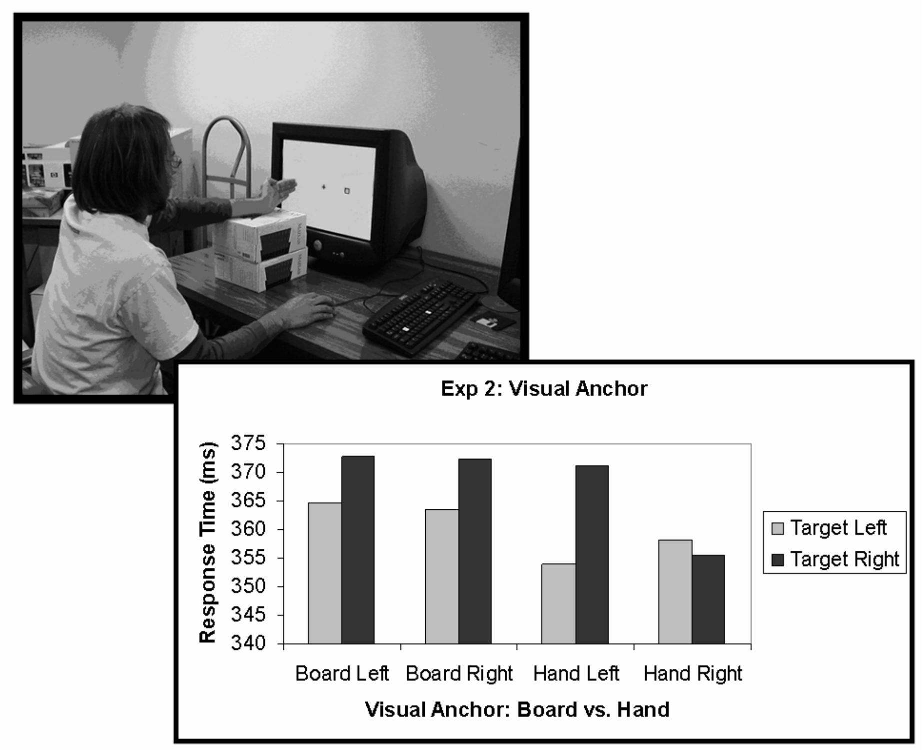

Fig. 2. Example of hand condition and data from Reed, Grubb, and Steele [49] Experiment 2 that represents typical data patterns across the reported experiments. Results show that targets appearing near the hand speed response time but targets appearing near visual anchors such as a board do not.

In sum, space near hand was attentionally prioritized for enhanced processing. The space near the hand appears to be represented bimodally in terms of visual and proprioceptive/tactile inputs, which may underlie prioritization effects by amplifying signals from that location. Such an amplification would ultimately increase the signal to noise ratio for these stimuli, thereby improving response times and target detection to stimuli. These findings that correspond to the properties of bimodal neurons suggest that in addition to the visual neurons typically used to perform the task, bimodal neurons, presumably in frontal and parietal cortices that respond to tactile or visual stimuli presented near various body parts, might be involved in detecting targets appearing near a body part [37][32][42] .

Presumably, spatial prioritization exists to facilitate the processing of stimuli that will be important for potential execution of actions. In other words, if objects near the hand grab attention, does the hand's ability to grab objects influence attention? In a subsequent study, Reed, Garza, Roberts and colleagues investigated the functional topography of this prioritized space near the hand [50]. Using a similar paradigm as the one described above, we compared the relative prioritization for targets appearing near different regions around the hand. Our results showed a relatively greater prioritization for targets appearing near the palm in "grasping space" versus near the back of the hand in "hitting space" as well as for the space near the palm vs. the forearm. Further, this same facilitation could be extended beyond the hand to the end of a rake, but only after participants had used the rake. In addition, an analogous functional topography of the spatial prioritization was also observed for targets appearing near prongs of the rake relative to the back bar of the rake. Thus, the spatial prioritization observed in these studies appears to be functionally related to the affordances presented by the presence of the hand or after functional interaction with a tool.

This prioritization of function based on a body part's location has also been demonstrated in brain damaged populations [51] [52] [53]. Buxbaum and Coslett [51] report a patient with a distinct form of optic ataxia in which he had difficulty fixating or attending to locations where he was not reaching. His attention seemed to be captured by his hand position and was directed by his reaching action. Coslett and Lie [52]found that tactile extinction in two patients with right parietal damage was alleviated in the contralesional hand when the ipsilesional hand was positioned proximal to it. Finally, Schendel and Robertson [53] report a patient with a left hemianopsia whose left hemifield vision loss was attenuated when his left hand was held up, proximal to the target locations. This facilitation was dependant on the proximity of the hand to the target locations, suggesting an enhancement of visual processing for stimuli appearing in the space surrounding the hand.

Together, these studies suggest that spatial attention incorporates multimodal inputs and the functional properties of the hands to change the distribution of attention across peripersonal visual space. Further, objects used to manipulate space outside of normal reach are easily and rapidly assimilated into body space. Additional neural systems are likely to contribute to perceptual processing when the body is relevant to attentional allocation. This work is consistent with the biased competition model [8] and extends that purely visual model to include multimodal systems.

2.3 Effects of Effector Action on Spatial Attention.

In the section above, we presented research indicating that static hand position can influence the prioritization of functional space near the hand. Here we consider how action changes the prioritization of space. Executing an action is a dynamic process. A static hand does not interact with visual spatial cues to change regions in spatial salience, or what has been considered in spatial attention literature as shifts in attention [7]. Maybe an active hand can change or shift the location of this prioritization.

To investigate this hypothesis, we examined whether performing an action (i.e., brief hand grasp) would cue and shift attention to where the action just occurred, or inhibit attention from returning there [54]. Participants performed a target detection task in a modified spatial cuing paradigm. Their hands were held next to target locations and shielded from view. For each trial, the fixation cross would change color to indicate which hand participants should move (i.e., perform a brief hand grasp) and a target would appear in either the left or the right box location. The hand grasp acted as a lateral cue, and was nonpredictive with respect to where the target would appear. Thus, if action cued attention, then a validity effect would be found for targets appearing on the same side as the action; the hand action would function as a spatial cue to prioritize processing near the location of the action. Alternatively, action may inhibit the shifting of attention or lead to inhibition in activation regions near the action; some research has indicates inhibition of return in that participants were slower to respond to targets appearing on the same side as the action, presumably because the participant has already responded to what was salient in that space [4] [55]. Results from our study indicated that the hand grasps functioned as spatial cues, shifting attention or changing prioritization of processing to the proximal target location– targets appearing near the completed action were detected faster than targets near the stationary hand. Further, this effect was not observed in a condition in which participants only imagined performing the hand grasp upon viewing the color change, confirming that the color was not operating as a symbolic spatial cue and suggesting that actually performing the action was necessary to shift attention.

In summary, our own bodies influence attention both by the spatial location and functional range of an acting effector and by the effector's actions. Without action, body part location prioritizes space by speeding responses to targets appearing in the functional range of the effector. Actions performed by that effector tend to override the existing amplification of the signal from the region near the body part and shifts attention to the functional spatial range of the action. Thus, the topography of spatial attention appears to be defined by body part location, but action changes its dynamics-what becomes relevant is your purpose for the action and the actual function of the action. The difference between the effects of hand presence and hand action on spatial attention mechanisms may reflect contributions from different neural networks to visuospatial processing.

3 How Do Other People's Bodies Influence Attention?

The studies reported above emphasize that our own bodies can play an important role in spatial attention. However, attention can also be directed by what other people are doing. Other people's actions provide important sources of information about their intentions, emotional states, and, importantly for us, their future actions [56] [57]. They may also provide cues to the locations of subsequent events and help us plan appropriate reactions to those events. To humans, objects in peripersonal space are important not only because they may grasp you but also that you may grasp with them.

The directional action component of gaze, head turn, and pointing may be critical for attention shifts. Gazing is one type of action we can observe in others. In typical studies of spatial attention and gaze direction, participants viewed a face in which the eyes looked to the left or right; participants responded faster to targets consistent with gaze direction [58] [59]. In addition, other types of actions may be socially relevant for directing attention toward some future event of interest. For example, Langton and Bruce [60] examined whether pointing cues direct attention. In a covert attention paradigm, central cues of a person pointing with his hand were presented; participants responded more quickly to targets corresponding with the pointed direction. Nonetheless, not all body postures direct attention. When left and right-facing heads and trunks were used as cues, head cues shifted attention, but trunks did not [61]. These studies suggest that attention is directed by bodies in action that contain directional information about impending changes in the environment and our need to respond to it, but little work had addressed this issue. To investigate how the actions of others direct attention, we compared different types of actions in a covert-orienting task with non-predictive central cues [62]. The cues were static images of human figures in mid-action (e.g., throwing or running) or standing in a neutral, hands-at-sides pose. They either faced to the left or the right of the screen. Results indicated that only action cues produced validity effects, that is, relatively faster responses to targets appearing on the side consistent with the direction of the action. Attention appeared to be shifted in the direction of the implied action. Further, the action cues produced the faster responses than the standing cues, implying that action cues may have primed motor responses. Additional work is needed to determine the specifics of what aspects of action are cuing different spatial attention mechanisms.

4 Spatial Attention and Future-oriented Behavior

We have argued that spatial attention plays an important role for performing functional actions in the environment. However, selective attention is also important for preparing for upcoming action as well. In fact, in the real-time flow of natural behavior, we presume attentional processing is most often oriented toward upcoming action or events. By prioritizing activation based on both bottom-up and top-down inputs, attention should be critical to such preparation. Action sequences cannot be mostly reactive to specific environmental features because responses will be too late-some form of prospective control is necessary. Alternatively, action sequences cannot be planned too far in advance since not all relevant contextual information for planning action can be known in advance. Thus, selective attention processes help the performer to determine what information is most relevant at different points in time during a flow of action [63]. It is an integral part of the continual perception-action cycle with the goals of action influencing perceptual selection and information gleaned from the environment influencing subsequent planning for action [64].

In the previous sections, the reported research examines spatial attention at specific moments but does not capture the dynamic cycling between perception and action that is characteristic of real-world performance. Bryan and Harter [65] were some of the first researchers to recognize the role of prospective control in skilled performance. They studied telegraph operators and found that as operators became increasingly skilled, they used predictable patterns in word and phrase structures to more efficiently organize on-going actions. Later, researchers recognized that in order for behavior to be effective and fluid, action must be based on anticipated future states of the environment and of the self [66] [67]. More recently, Roberts and Ondrejko [63] examined how skilled actors utilize perceptual selection to anticipate future states and plan upcoming action accordingly. Using an especially designed video game they simultaneously recorded task actions and eye movements while participants played the game. Players controlled the orientation of a ship that could shoot at multiple moving targets. The goal was to hit as many targets as possible and not allow the targets to intercept the ship. At any point in time the screen contained many moving objects, some of which were better targets than others, depending on their trajectories, velocities, and upcoming locations relative to the ship. Thus, the game, as in many everyday contexts, presented the actor with a cluttered environment where some locations provide more information than others, depending on one's current and upcoming goals and actions. In the game, finding the next target among many possibilities, determining the current orientation of the ship, moving the ship to a new orientation, and deciding when to release the shot to time an interception successfully, all required different kinds of information that were available at different locations. Thus, there was inherent competition about where to look when, because of the variety of visual stimuli and by the mix of the flow of task goals and specific situations the game presented at any one point in time (e.g., the sudden appearance of a fast moving obstacle coming toward the ship).

The findings revealed tight correspondences between current and upcoming task actions and the timing and location of players' eye movements. Players precisely relocated their foveas to areas of the screen that monitored on-going activity, but more interestingly, to locations that provided detailed spatial or location information that was relevant for guiding specific upcoming actions. For example, performers were able to shift between looking at the target and looking at the ship when setting up for the next shot. Players did not foveate on more than one or two potential targets even when there were many possibilities. Players used peripheral information to make the selection of the new target and usually made a saccade to the new target less than 1 sec after the previous target was shot. Analyses of the trajectories and future locations of all possible targets indicated that performers most often looked at the one or two ”best” possible targets in terms of the ease of making an intercept and/or likelihood of an eventual crash with the ship. Remarkably, peripheral selection must have occurred in many cases well before the previous shot even reached the target. Selective attention, then, biased visual information gathering that was then was used to regulate ongoing action and prepare for upcoming action. Selective attention occurred in the service of the players' goals but also was constrained by particulars of the changing visual landscape the game.

This work emphasizes the role of selective attention in perception-action cycling and fits well with the biased competition model of Desimone and colleagues [8]. Multiple potential targets in the world compete for resources that result in specific action selection. In the video game, action selection occurred in terms of eye movement to specific targets and subsequent finger responses to control the ship. This type of real-time research examining selection and action sequences for future-oriented actions should provide additional insight into the body's role in selective attention.

5 Conclusions

Every day humans perform actions in the world. They create change in the environment and respond to changes produced by others. The research discussed in this chapter argues that it is critical to consider the conditions under which spatial attention is deployed as well as what we are using it for. Our bodies, our actions and the actions of others all influence the dynamic distribution of spatial attention. We have shown that attention is not merely a visual phenomenon and that its effects appear to be related to the body's capacity for performing functional actions. Given that most tasks involve our body and lead to physical output, our actions have implications for others and vice versa. Thus, any theory of spatial attention is incomplete if is does not emphasize the importance of sensorimotor experience and the interaction of the body with the world. Spatial attention is a dynamic system that is influenced by our own bodies and actions. It may be directed by visual cues but it does not end with the response. Active attention integrates interactions between the motor system, its cuing effects, and multiple shifts of attention. In conclusion, current theories of spatial attention must account for the every changing influences from the body and its actions that produce functional interactions with the world.

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