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Calibration to tool use during visually-guided reaching

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ABSTRACT

In studying human perception and performance researchers must understand how the body schema is modified to accurately represent one's capabilities when tools are used, as humans use tools that alter their capabilities frequently. The present work tested the idea that calibration is responsible for modifying an embodied action schema during tool use. We investigated calibration in the context of manual activity in near space through a behavioral measure. Participants made blind reaches to various visual distances in pre- and post-test phases using a short tool that did not extend their reach. During an intervening calibration phase they received visual feedback about the accuracy of their reaches, with half of the participants reaching with a tool that extended their reach by 30 cm. Results indicated both groups showed calibration appropriate to the type of tool that they used during the calibration phase, and this calibration carried over to reaches made in the post-test. These results inform discussions on the proposed embodied action schema and have applications to virtual reality, specifically the development of self-avatars.

1. Introduction

Perception of whether or not something is reachable is an indicator of how people scale distances within their immediate surroundings (Bourgeois & Coello, 2012; Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989; Gabbard, Ammar, & Lee, 2006; Heft, 1993; Mark et al., 1997). The purpose of the present work is to investigate an actor's ability to calibrate to the introduction of a hand-held tool that increases reaching capabilities, and how calibration persists after the tool has been removed. While previous research has investigated similar questions, the majority of evidence for calibration and the lingering effects of calibration is based off judgment based measures. In addition to a few of the issues inherent in using judgment based measures (e.g., Pagano & Isenhower, 2008), there is a lack of evidence regarding how action based measures, such as errors exhibited while reaching to targets, are affected during calibration to a tool and the extent to which this calibration carries over once the tool has been removed. The present work wishes to expand upon this issue.

When investigating the perception-action system, it is important to acknowledge that features of the environment and the action capabilities of an actor are both dynamic; they each continually change over short and long time scales. Over longer time scales, action capabilities generally change due to developmental changes in size, strength, coordination, practice, etc. Over shorter time scales the action capabilities can be changed by fatigue, injury, or the incorporation of a hand-held tool. The result of this dynamic relationship between actor and environment is that the affordances available to a person are continuously changing.

The process by which the perception of affordances becomes properly scaled to the dynamic relationship between environmental features and action capabilities is known as calibration (Bingham & Pagano, 1998; Fajen, 2005; Mon-Williams & Bingham, 2007; Rieser, Pick, Ashmead, & Garing, 1995; Withagen & Michaels, 2004, 2007). Research has shown that calibration occurs during practice performing a given behavior (e.g. Bourgeois & Coello, 2012; Franchak, van der Zalm, & Adolph, 2010; Wagman, 2012) or during practice performing a related behavior (Stoffregen, Yang, Giveans, Flanagan, & Bardy, 2009). Evidence suggests that rather than being in a "calibrated" state, with changes in perception or action capabilities requiring that the system adjust or "re-calibrate," the perception-action system is in a constant state of continuous (re)calibration. The removal of feedback regarding the outcomes of ones' actions is itself a perturbation, and without continuous calibration the system drifts, becoming progressively more inaccurate (Bingham & Pagano, 1998; Ebrahimi, Babu, Pagano, & Joerg, 2016; Vindras & Viviani, 1998; Wann & Ibrahim, 1992; Wickelgren, McConnell, & Bingham, 2000).

One example of a task that requires calibration is determining what is within reach of the body and then executing an accurate reach. This

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task is vital to human existence, as people continually interact with hand-held tools and graspable objects on a daily basis. Calibration is critical because many sources of visual information provide only relative units of measurement and calibration within the context of self-produced explorations provides a definite (i.e. absolute) scaling to the mapping from perceptual input to action (see Bingham & Pagano, 1998; Fajen, 2005). Calibration also provides a means by which different sources of information, (i.e. cues), each necessarily being in a different unit of measure, become combined to guide action (Coats, Pan, & Bingham, 2014).

Additionally, once a tool or object is grasped the capabilities of an actor may change if the tool alters the extent of reachable space. Many tools increase the area in our environment that we can access, to the point that objects which were previously unreachable now become reachable. Recent research has shown that the use of a tool which extends one's reach causes an extension of perceived reachable space, and this perceived extension persists even after the tool is no longer in use and the user has reverted to reaching without the tool (Bourgeois, Farnè, & Coello, 2014; Maravita & Iriki, 2004). It has been hypothesized that the tool becomes incorporated into the body schema, altering the perceived length of the arm (Sposito, Bolognini, Vallar, & Maravita, 2012) and thus altering the perceived boundary of reachable space (Maravita & Iriki, 2004).

The body serves as a perceptual ruler, and thus the units for the perception of size and distance are not external metrics, like inches or centimeters, but are units intrinsic to the scale of one's own body and its action capabilities (e.g., Bingham & Pagano, 1998; Cutting, 1986; Gibson, 1979; Proffitt & Linkenauger, 2013). Proffitt and Linkenauger (2013), for example, discuss how the units for the perception of size and distance are internal metrics such as the size of the hand, maximum reaching distance, and other units of our own body (see also Fajen, 2005; Lessard, Linkenauger, & Proffitt, 2009; Stefanucci & Guess, 2009). This means that size of the surrounding environment is influenced by the perceived size of one's own body (Creem-Regehr, Payne, Rand, & Hansen, 2014; Proffitt & Linkenauger, 2013; van der Hoort, Guterstam, & Ehrsson, 2011). Specifically, the perceived sizes of real objects are scaled relative to the perceived size of one's dominant hand, such that the perceived size of one's hand is a metric that is used to scale the perceived sizes of objects (Linkenauger et al., 2014). Importantly, this effect may go beyond the simple use of the visible body as a familiar size cue. It may involve the recalibration of perception such that the rescaling of the environment persists even when the body is subsequently taken out of view (van der Hoort & Ehrsson, 2014).

Perceptual information is scaled by metrics based on the size of the body, its abilities, and the scale of the actions taken to generate the optic flow used to reveal the perceptual information (Bingham & Pagano, 1998; Bingham & Stassen, 1993; Mantel, Stoffregen, Campbell, & Bardy, 2015; Pagano, Grutzmacher, & Jenkins, 2001). For example, if an actor intends to reach for an object in near space, then the actor's arm length becomes the relevant action boundary to scale the environment, and the distance the head moves to reveal the visual distance to the target determines the units for the perception of distance (Bingham & Pagano, 1998; Bingham & Stassen, 1993; Mantel et al., 2015). Thus, for objects within the action boundary defined by arm length, the environmental information becomes scaled as a proportion of that action boundary. Proffitt and Linkenauger (2013) argue that in this way anthropometric and action boundaries function as perceptual rulers, by scaling the abilities of an actor's body to their surrounding environment.

Previous research has shown that manipulating the action boundary for reaching can influence apparent distances to reachable targets. For example, if participants' reaching ability is augmented by a hand-held tool then targets that were previously out of reach are reported as being closer (Osiurak, Morgado, & Palluel-Germain, 2012; Witt & Proffitt, 2008; Witt, Proffitt, & Epstein, 2005). It appears that when participants reach with a tool, their perceptual ruler is extended to include distances that could be reached by the tool, and thus objects appear to be closer to the actor (Proffitt & Linkenauger, 2013). Further experiments that manipulated hand size and grasping ability obtained similar results (Haggard & Jundi, 2009; Linkenauger, Ramenzoni, & Proffitt, 2010).

Research investigating the effect of tool use on the perception of reachable space has also incorporated action-related perceptual tasks into their experimental methodology (e.g., Bourgeois et al., 2014). It has been hypothesized that using a tool modifies represented arm-length due to an incorporation effect, and reachability judgments depend on a motor-related perceptual system that takes into account off-line modifications of represented body-segments (Berti & Frassinetti, 2000; Cardinali et al., 2009, 2012; Maravita & Iriki, 2004).

Bourgeois et al. (2014) used a horizontal screen to present participants with visual targets at simulated distances that were from 15 to 85 cm farther than their actual maximum reaching ability. Tools consisting of wooden rakes were used to provide a functional extension of arm length by either 0 cm or 60 cm, respectively. As part of the experiment, participants were presented with a two-alternative forced choice reachability judgment task, before and after having used a tool, to indicate if a target was reachable or not. Type of tool use was varied between groups. Following the first block of reachability judgments, participants were tasked with making 50 reach-and-retrieve movements towards an object, which were randomly presented at different locations so as to cover the participant's entire reach space. Participants completed another two-alternative forced choice reachability judgment task after having used the tool (i.e. the post-test). The results indicated that using a functional tool resulted in an extension of perceived reachable space. The tool was functional in the sense that it extended the actor's reaching capability. Alternatively, simply holding a tool that did not functionally increase the reach had no effect on perceived reachable space. Further, tool use also extended perceived reachable space with the hand alone. Bourgeois et al. (2014) concluded that the tool becomes motorically integrated into the body schema, and this integration has perceptual consequences that outlast the period of tool-use.

The authors interpreted these results to suggest that the modified arm-length representation in the body schema resulting from tool use affects the perception of reachable space for both reaches with and without the tool. This modified arm-length representation brings about certain benefits and costs, namely that tool-use increases the accuracy of perceptual estimates, while still using the tool to reach, but decreases the accuracy of perceptual estimates of what is reachable with the hand alone, respectively. Overall, Bourgeois et al. advocate the theoretical stance "…that reaching judgments depend on a motor-related perceptual system, which takes into account off-line modifications of represented body-segments" (2014, pg. 93).

One shortcoming of the work by Bourgeois et al. (2014) is its methodological reliance on categorical judgments alone. A growing body of work from our own laboratory and elsewhere has demonstrated the benefits of implicit action measures for assessing perception (Bridgeman, 1991; Heft, 1993; Milner & Goodale, 2006; Napieralski et al., 2011; Pagano & Bingham, 1998; Pagano & Isenhower, 2008). We have found that when participants are asked to look at a target and then from that single view make two separate responses simultaneously, a verbal report of perceived distance and a rapid manual reach to the target distance, the verbal reports are less accurate than the reaches, more variable than the reaches (both within and between participants), reflect relative rather than absolute judgments, respond less well to calibration, and are more open to distortions from cognitive influences (Napieralski et al., 2011; Pagano et al., 2001; Pagano & Bingham, 1998; Pagano & Isenhower, 2008). It is important to note that many manual responses are similar to verbal reports if they cause the participant to take a cognitive stance (Heft, 1993), if they utilize relative instead of absolute judgments, or if they involve delayed responses (Pagano et al., 2001). It seems that the most accurate way to investigate the perception of one's immediate action space is to use implicit action measures