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The World Within Reach: Effects of Hand Posture and Tool Use on Visual Cognition

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Abstract

Our mental processing of the visual world is not independent of our physical actions within it. Placing objects near one's hands and interacting with objects using tools can enhance visual perception, bias and prolong the allocation of attention, and distort memory in systematic ways. This suggests that the world within our reach is cognitively different from the world beyond reach. In this review, we examine the evidence supporting this conclusion, focusing on the cognitive and neural mechanisms that underlie these effects, the parameters that may control their emergence, and their potential practical applications.

Keywords

perception, attention, memory, hand posture, tool use, embodied cognition

Intuition and introspection suggest that people represent the world on the basis of objective, veridical observations, but a growing body of research instead suggests that people's perceptions depend critically on their interactions with the environment. In this paper, we summarize recent investigations from our labs and others that have considered the consequences of purposeful observer-environment interaction on multiple aspects of cognition. We begin with interactions involving hand posture and conclude with interactions involving tool use. Whether one takes an object in the hands or manipulates an object with a tool, profound changes in perception, attention, and memory are observed.

Reaching Out With the Hands

Activities as simple as grasping a pint of beer require a complex integration of visual, tactile, proprioceptive, and spatial representations that is not necessary when objects are positioned farther away. Objects we reach for therefore impose processing demands and behavioral consequences that are not applicable to objects farther from the body.

Effects on perception

Several approaches have been taken to investigate the ways in which one's hand position influences one's perception of the environment. In patients with damage to the visual cortex, the corresponding loss of vision can be attenuated by manipulating the position of the hand. Following a stroke in the right occipital lobe, Patient W. M.'s ability to see objects in the left visual field was severely impaired (a condition called *hemianopsia*), but placing his left arm in his "blind" field of view nearly doubled his ability to detect objects near his left hand (Schendel & Robertson, 2004). In neurologically normal observers, placing the hand near objects affects early preattentive perceptual processes, such as the segregation of objects from backgrounds (Cosman & Vecera, 2010), and reduces perceptual biases created by visual illusions (Vishton et al., 2007). Furthermore, when objects are viewed through magnifying goggles, they appear to shrink back to near-normal size when one's hand is placed next to them (Linkenauger, Ramenzoni, & Proffitt, 2010). These processing changes may arise through a shift from the perception-oriented parvocellular pathway toward the action-oriented magnocellular pathway when objects appear near the hands. Indeed, visual discriminations requiring magnocellular mechanisms improve, whereas those dependent upon parvocellular processing are impaired, when visual stimuli are placed near the hands (Goodhew, Gozli, Ferber, & Pratt, in press; Gozli, West, & Pratt, in press; Weidler & Abrams, 2012).

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Effects on attentional control

Hand position also affects attentional control. Following a stroke in the right parietal lobe, patients can lose the ability to attend to an object in the left visual field when another object is simultaneously present in the right visual field. This phenomenon is known as *visual extinction*, and it can be alleviated by placing the patient's hand near the leftward stimulus, which suggests that attention is redistributed toward the hands (di Pellegrino & Frassinetti, 2000). In neurologically intact individuals, shifts in hand position are accompanied by corresponding shifts in attentional priority: In detection tasks, targets appearing near the hand are detected more quickly than targets appearing farther away, even when explicit cues indicate the most likely locations of all upcoming targets (Reed, Betz, Garza, & Roberts, 2010; Reed, Grubb, & Steele, 2006).

The effects of hand posture on attentional processing are not strictly limited to objects within one's grasp, however. Peripheral distractor objects that normally influence response times while observers are processing a central target escape selection when the observers' hands (but not other types of barriers) are placed between the target and the distractor items (Davoli & Brockmole, 2012; Fig. 1a). Attentional enhancements within the space between the hands, then, are accompanied by diminished processing farther afield, which suggests that the hands facilitate the focusing of attention by defining regions of space upon which the spotlight of attention should shine most brightly.

Hand posture also influences shifts in attention allocation. Using search, cueing, and attentional-blink paradigms, we have shown that the disengagement of attention from items near the hands is inhibited, which results in prolonged processing of such items (Abrams, Davoli, Du, Knapp, & Paull, 2008; see also Davoli & Abrams, 2009). Shifts of attention between global and local aspects of objects between the hands are also relatively slow and inflexible (Davoli, Brockmole, Du, & Abrams, 2012). This resistance seems to reflect an attentional mechanism that compels observers to more fully evaluate objects that are near their hands by inhibiting changes in attentional scope.

Effects on memory and higher-order cognition

The quality of learning, memory, and higher-order cognitive processes are inextricably linked to perception and attention (see Brockmole, Davoli, & Cronin, 2012, for a review) and are therefore also affected by hand posture. For example, holding one's hands near a display increases the number of presented items that can be held in visual working memory (Tseng & Bridgeman, 2011). Hand proximity is not universally beneficial to memory, however. When it comes to long-term memory, the effects of hand proximity are context specific (Davoli, Brockmole, & Goujon, 2012). When learning entails simply studying and memorizing a variety of visual stimuli, no differences emerge between memory for stimuli near the hands and memory for stimuli far from the hands. However, when learning specifically entails abstracting commonalities across many similar items (e.g., structurally identical geometric patterns that differ in color), substantially slowed rates of learning are observed for items near the hands. This pattern suggests a bias toward detail-oriented processing for objects near the hands (Fig. 1b).

In addition to representations of individual objects, representations of the global environment are affected by people's interactions with objects. We recently asked participants to study real-world environments containing many objects (Thomas, Davoli, & Brockmole, in press). Participants either examined each object visually or picked up and held each object (Fig. 1c). Subsequently, they either drew a scale map of the environment or built a life-sized full-scale replica. In both cases, participants who had handled the objects recalled environments as smaller and interobject distances as shorter than did those who had only viewed the objects. Thus, discrete interactions with multiple objects can lead to global changes in one's representation of space.

Finally, aspects of semantic processing are affected by hand posture (Davoli, Du, Montana, Garverick, & Abrams, 2010). When we asked people to rate the sensibleness of sensible and nonsensical versions of written sentences (e.g., "Tim carried his suitcase to the car" vs. "Tim typed his suitcase to the car"), those who held their hands near the sentences were relatively *worse* at classifying the nonsensical versions correctly. Furthermore, Stroop interference (i.e., the slowed reaction times that occur when people must identify the print color of a written word denoting a different color—e.g., the word *red* written in blue ink) is reduced when words are presented near the hands. Both of these types of effects indicate that for items near the hands, semantic processing is impoverished, an effect consistent with increased focus on visual detail.

Reaching With Tools

The changes in the cognitive processing of objects near the hands may be adaptive, given that such objects are immediate candidates for action (Abrams et al., 2008; Graziano & Cooke, 2006). The objects of our desire are not always within our hand's reach, however. In many cases, interactions with objects are mediated by tool use, which also has consequences for cognition.

Effects on perception

After reaching for an object beyond arm's reach with a stick, observers estimate its distance to be shorter than they do if they reach for it without the stick (Witt, Proffitt, & Epstein, 2005). This pattern suggests that "reachability" is one metric according to which perception is calibrated. Tools such as sticks allow for direct physical contact with objects just out of reach, but more and more of our interactions with the environment in the modern world are achieved remotely and across great distances. Although the representation of reachable

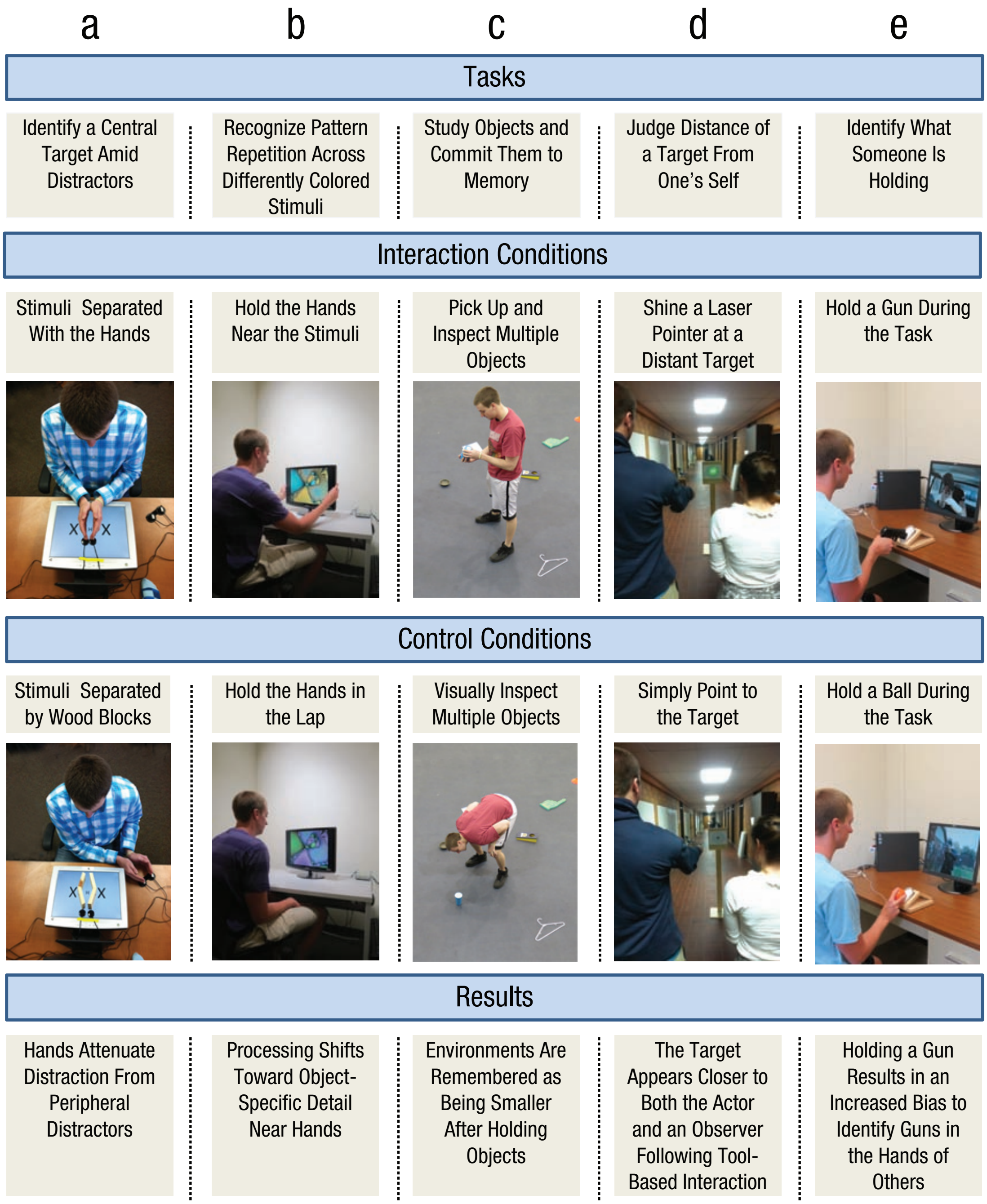

Fig. 1. Alterations of multiple aspects of visual cognition by hand position and tool use. For each pair of images showing an interaction condition and a control condition, the differences in how the actor is interacting with the environment may seem physically minor, yet they have a profound impact on how people (a) attend to, (b) learn about, (c) remember, (d) perceive, and (e) identify information.

space is flexible, it is likely limited. Nevertheless, some recent research has indicated that direct and remote interactions have analogous effects on perception. For example, illuminating targets 30 meters away with a laser pointer leads observers to judge them to be closer than targets that are merely pointed at with an inert baton (Davoli, Brockmole, & Witt, 2012; Fig. 1d). Hence, distortions of perception that arise from interactions with objects reflect people's capacity to interact with those objects even from far away (see also Lee, Lee, Carello, & Turvey, 2012; Witt & Sugovic, 2010).

Tool use also affects higher-order perceptual phenomena such as object categorization. The Theory of Event Coding

(Hommel, Musseler, Aschersleben, & Prinz, 2001), for example, argues that perception and action planning share a common code (i.e., they arise from a common representational medium). Consequently, objects incorporated into one's action representation can have consequences for perceptual processing. This point was dramatically demonstrated when observers were asked to hold either a gun or a neutral object (e.g., a ball) and to determine whether actors in photographs were holding a gun or a benign object as quickly as possible (Witt & Brockmole, 2012). When wielding a gun themselves, perceivers were more likely to classify the objects held by the pictured actors as guns than when they were holding the ball (Fig. 1e). Such results suggest that tool use modulates perception at multiple levels, ranging from visuospatial properties to the interpretation of object identity.

Effects on attention

Attentional processing normally observed for the space immediately around the hands is extended to more distal areas of space through tool use. This includes attentional prioritization of the functional end of a tool (Farne, Iriki, & Ladavas, 2005) similar to that observed for objects near the hand (Reed et al., 2010). In addition, patients who neglect (Berti & Frassinetti, 2000) or extinguish (Maravita, Husain, Clarke, & Driver, 2001) stimuli in *peripersonal*, or near-body, space exhibit a transfer of that deficit to *extrapersonal* stimuli that are located farther away but are rendered reachable by tool use. The opposite relationship also holds: Patient W. M.'s hemianopsia was alleviated both near his hand and near the end of a reach-extending tool in the lesion-affected left visual field (Schendel & Robertson, 2004).

Effects on memory

The formation of an action plan can cause changes in perception that are maintained for several minutes beyond the completion of the planned action (Vishton et al., 2007), an effect suggesting that the perceptual distortions described above may also persist in memory. To test this, we had participants view pictures displayed at various distances up to 22 meters away (Davoli, Brockmole, & Witt, 2012). While they did this, some participants interacted with each scene by illuminating it with a laser pointer, whereas others merely pointed at each scene with an inert baton. Later, participants completed a surprise memory test in which they marked the location of each picture on a scale model of the viewing environment. The participants who had used a laser pointer recalled smaller distances between the targets than did the participants who had merely pointed. Perceptual distortions that arise from tool use are not transient, but instead persist in memory after an interaction has terminated.

Observed Reaching

As social animals, people often act in the presence of others, and their spatial attention can be directed by action-based social cues, including eye gaze, head gaze, pointing, and implied body motion (see Birmingham, Ristic, & Kingstone, 2012, for review). Furthermore, when performing collaborative tasks, people coordinate their attention with that of a partner both spontaneously (e.g., Richardson, Dale, & Kirkham, 2007; Welsh et al., 2007) and obligatorily (Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, 2010). To determine if representations of collaborating observers share a common perceptual basis, we recently asked whether the spatial compression of distance exhibited by tool users is also present among participants observing tool use (Bloesch, Davoli, Roth, Brockmole, & Abrams, 2012). Observers watched as their partners either reached (unsuccessfully) toward an out-of-reach target with their arms or reached (successfully) to the target with a reach-extending tool (Fig. 1d). Observers' estimates of the distance between themselves and the target reflected the spatial-compression effects found in actors. As another example, both actors and observers estimate the speed of a moving target to be faster when using a smaller tool with which interception of the target is more difficult to achieve (Witt, Sugovic, & Taylor, 2012). These findings suggest that socially contextualized tool-based tasks engender a "common ground," or shared representation, among viewers that reflects their awareness of what other people perceive.

General Discussion

The constellation of effects we have described here indicates that the mechanisms underlying perception, attention, and memory are not independent of the relationship between perceivers and their environment. Holding one's hands near an object alters perceptual sensitivity, prolongs and biases the allocation of attention, leads to detail-specific memory, and inhibits semantic processing of the object. Using a tool to reach for objects causes them to be perceived as closer and to become attentionally prioritized. These distortions are encoded into spatial representations of objects and their interrelations. Representation of the hands and of tools seems to be so critical to cognition that merely imagining the manipulation of one's hands (Davoli & Abrams, 2009), imagining direct (Witt & Proffitt, 2008) or remote (Davoli, Brockmole, & Witt, 2012) tool-based interactions, and observing others' interactions with objects are sufficient to alter visual processing in the same manner as actual performance.

Adaptive purpose

The effects described above are unlikely to be the result of random evolutionary occurrences. Enhanced perception, focused attention, and detail-oriented processing of objects would allow for the heightened processing and discrimination of objects' properties, which may in turn assist observers in determining appropriate responses to nearby objects. Additionally, imagining or watching someone perform an action not only provides information about the goal of the action, but also indicates to the observer what might be necessary for that interaction to be successful. Thus, we learn about the world not only through our own physical experiences, but also through the experiences of others.

Underlying mechanisms

Broadly, the behavioral changes we have discussed in this article are consistent with, and likely correspond to, several known characteristics of neuronal representation. To facilitate action, the primate brain contains neurons that have both visual and tactile receptive fields. Specific sets of these bimodal neurons respond to stimuli located within several centimeters of the hand (see Graziano, 2001). The responses of these neurons therefore change as objects approach or retreat from the hands, leading in turn to alterations in unimodal (i.e., visual) experience. As one might predict from such neuronal activity, the influence of hand position on cognition is dynamically adjusted in real time as the hands move through space, yielding a graded rather than an all-or-none effect (Adam, Bovend'Eert, van Dooren, Fischer, & Pratt, in press). The receptive fields of neurons coding the space surrounding the body also expand to include the space that can be reached by a tool, and this expansion persists even after the tool has been discarded (Iriki, Tanaka, & Iwamura, 1996). Hence, objects initially coded as being in extrapersonal space can be brought into peripersonal space and then retained as such in memory. Finally, some brain areas are active during both performance and observation of goal-directed actions (e.g., Rizzolatti & Craighero, 2004).

Behavioral studies have, however, outpaced those examining the neurological underpinnings of the effects of hand position and tool use on cognition, and other neural mechanisms will surely come to light (cf., Qian, Al-Aidroos, West, Abrams, & Pratt, 2012). Efforts to this end will clarify the extent to which the analogous behavioral changes thus far observed across manipulations of the hand, interactions involving the use of tools, and observations of action arise from common or independent mechanisms.

Kinematic parameters

Although factors such as hand visibility, gross body posture, and the manner in which participants are asked to respond to stimuli appear to be irrelevant to hand-posture effects (Abrams et al., 2008; Davoli & Abrams, 2009; Davoli et al., 2010; Reed et al., 2006; Tseng & Bridgeman, 2011), the roles of other potentially important kinematic, behavioral, and contextual factors have not been fully assessed. For example, effects may differ depending on whether one manipulates the placement of one hand or of both hands (Tseng & Bridgeman, 2011) or on whether objects are placed on the palm side or the back side of the hand (Reed et al., 2010; Schultheis, Carlson, & Abrams, 2010). Likewise, different perceptual changes are associated with one's ability to grasp (Linkenauger et al., 2010) and to use tools to modify one's reach (Witt et al., 2005). Resolving such discrepancies constitutes an important avenue for future research (see Proffitt & Linkenauger, in press).

Practical applications

Finally, recent findings related to hand position and tool use are likely to also have practical implications for behavior in modern society. Little work has been done in this area, but alterations in cognitive processing near the hands, for example, may have important implications in applied fields such as integrative educational techniques involving haptics (e.g., Minogue & Jones, 2006), the use of hand-held devices in dual-task scenarios (e.g., texting while driving; Drews, Yazdani, Godfrey, Cooper, & Strayer, 2009), and multisensory interventions for people with intellectual and developmental disabilities (e.g., Lotan, Gold, & Yalon-Chamovitz, 2009). Thus, our knowledge of observer-environment interactions achieved through reaching and tool use can be incorporated into theories of visual cognition and also real-world applications.

Recommended Reading

Brockmole, J. R., Davoli, C. C., & Cronin, D. A. (2012). (See References). A comprehensive review that places effects of hand posture and tool use within a broader discussion of the many ways in which attention and memory interact to determine visual experience.

Davoli, C. C., & Abrams, R. A. (2009). (See References). Original research demonstrating effects of imagined hand manipulation on visual processing, a topic not thoroughly discussed in this paper.

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Witt, J. K., & Brockmole, J. R. (2012). (See References). A discussion and empirical evaluation of multiple possible mechanisms by which tool use can affect object recognition.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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