CHAPTER FIVE

Embodied Seeing: The Space Near the Hands

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Contents

Abstract

Recent research has revealed a special role of the hands in guiding vision. We process differently elements in the space around our hands and objects that are near the target of a hand movement. In this chapter we review several different but interrelated domains of research that have approached questions about the role of the hands from somewhat distinct perspectives. We organize our discussion by considering changes in vision during three different phases of a hand movement: (1) when a hand movement is not being

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contemplated yet is possible in the future, (2) when a hand movement is being planned or produced, and (3) after a hand movement has been completed. Consideration of these phases together reveals important connections between the different areas of research and may lead to enhanced understanding of the underlying processes.

1. INTRODUCTION

We use our hands to build shelter, to harvest food, and to help others. For these reasons, the space near the hands is special. The importance of the near-hand space arises, in part, because of the potential that hands possess to interact with the objects around us. And the space near the hands is also important because nearby objects may pose dangers that must be assessed. For these reasons, the mental mechanisms that process the space around the hands have become especially tuned to the important purposes served by the hands.

In this chapter we review recent research that illuminates the role of the hands, the special space near the hands, and the unique effect that the hands have on perception and cognition. We do so by considering the temporal relation between a person and a hypothetical movement of their hands. To organize our discussion, we separately consider a hand movement to be either in the future, the present, or the past. By **future** we describe the situation in which there is a potential, afforded by the current environment and one's current capabilities, to produce one of many possible hand movements. Differences in the movements that are possible lead to numerous changes in perception and cognition. **Present** refers to effects that have been observed on perception and cognition that are consequences of the planning and preparation of hand movements. And **past** refers to aftereffects that have been reported, which follow a movement that has just been completed. We consider each of these time frames in turn.

One of our goals is to consider together for the first time work from three distinct but interrelated literature that have typically been considered separately. Such a treatment reveals connections between the literature that may lead to new insights into the mechanisms involved in controlling action and perception.

2. FUTURE HAND MOVEMENTS

Whether we are or are not moving our hands at the moment, we are always in a state in which future actions are possible. Thus, the mechanisms involved in evaluating the world must be tuned to the potential future actions that the environment affords. Much of Gibson's (1979) theoretical thinking is based on precisely that idea. He believed that our perceptual experience is guided by the opportunities for action that are made possible by the environment. Other recent accounts of perception have also emphasized the importance of potential actions. For example, the action-specific account of perception maintains that our perceptions are scaled by our own abilities to produce actions (e.g., Witt, 2011). In the case of the hand, the connection among affordances, capabilities, and perception is presently becoming clear: what one can do with one's hands can have far-reaching implications for what is perceived, and for the cognitive processes that operate on the perceptual input.

2.1 Attentional Enhancement Near the Hand

One of the earliest results to reveal a dramatic effect of the hands on perception was reported by Schendel and Robertson (2004). They studied a patient who had brain damage that produced partial blindness in the left visual field. When the patient extended his left hand to be near the visual display, the blindness was reduced. Importantly, merely extending the hand was not sufficient: if the display was beyond reach, the extended hand provided no benefit. Thus, the proximity of the hand to the stimuli is what enhanced perception of those stimuli.

Other researchers have extended Schendel and Robertson (2004) findings with participants who do not have brain damage. For example, Reed, Grubb, and Steele (2006; see also Dufour & Touzalin (2008)) had participants extend one hand or the other toward a visual display, much like Schendel and Robertson (2004) patient. Participants were quicker to detect stimuli presented on the side of the display near the extended hand—revealing an attentional advantage for objects near the hand. Reed et al. suggested that objects near the hand are in the hand's grasping space, and hence would benefit from enhanced allocation of attention. One way in which that might be accomplished is through the activity of multimodal neurons that are known to play a role in integrating information from vision and proprioception (Graziano & Gross, 1995). And indeed, the effect of a nearby hand appears to be somewhat limited in spatial extent, matching the spatial limits of the multimodal neurons (Reed et al., 2006).

2.2 Inhibited Disengagement of Attention

Some of the benefits of an extended hand could reflect an attentional bias toward the visual hemifield nearest to the extended hand. More recently, researchers have studied effects of hand-nearness that cannot be caused by a spatial bias toward one side or another (see Bush and Vecera (2014)). The results reveal a multitude of changes in nonspatial aspects of the processing that occurs near the hands. In these studies, participants typically adopt the postures shown in Figure 1: they evaluate stimuli that are either near to both of their hands or far from both of their hands.

Abrams, Davoli, Du, Knapp, and Paull (2008) had participants make decisions about stimuli after adopting one of the two postures shown in Figure 1. Evaluation of stimuli near the hands differed from that for stimuli far away from the hands in important ways. For example, in one experiment participants searched through displays looking for specified target letters. As is typically the case in such tasks, increasing the number of elements in the display increased the time needed to find the target. However, the increase was greater for stimuli that were near the hands, as shown in Figure 2. The slower visual search rates might initially seem to confer a disadvantage to stimuli near the hands, but Abrams et al. argued that the slower rates would ensure a more thorough evaluation of such stimuli, perhaps due to their great importance (compared to stimuli that are not near the hands).

In subsequent experiments, Abrams et al. (2008) contrasted two possible explanations for the slower visual search near the hands: (1) slow movements of attention from item to item during the search and (2) inhibited disengagement of attention from each item during the search. The former would not appear to present any advantage at all—slow movements of attention from one item to the next would have minimal benefit. But the latter, inhibited disengagement of attention, might indeed lead to more thorough evaluation of stimuli near the hands. To distinguish between these two possibilities,

Figure 1 Postures used in experiments to study effects of hand-nearness. Many differences have been reported when the stimuli under consideration are near the hands, as in the right panel.

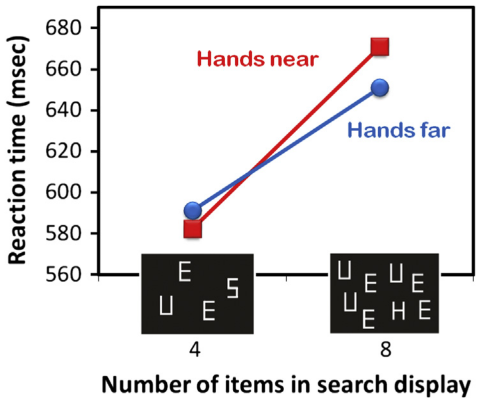

Figure 2 Visual search times for displays near to and far from the hands as a function of display size, from Abrams et al. (2008). Search rate (the increment in reaction time for an additional search element) was slower for stimuli that were near the hands.

Abrams et al. used an *inhibition of return* paradigm. In the experiment, participants were first cued by a flash to a location to the left or right of fixation. Then, either immediately or after a brief delay, they responded to the onset of a target, also either to the left or the right. Visual attention was attracted by the initial cue, resulting in a benefit to detect targets at the cued location when the time between cue and target was brief. And the proximity of the hands did not alter that benefit. But when the time interval between cue and target was longer, attention presumably returned to fixation before target presentation, resulting in a cost to return attention to the initially cued location if the target appeared there—the so-called inhibition of return of attention. Abrams et al. found that this cost, the inhibition of return, was reduced when the stimuli were near the hands. This suggests that attention had remained at the cued location for a longer duration when near the hands, resulting in a reduced cost of returning there later. An advantage of the prolonged dwell of attention is that it could force a more thorough evaluation of stimuli that are near the hands.

Several other studies have provided support for the idea that disengagement of spatial attention, and of other forms of processing, is inhibited in the space near the hands. In one study participants were shown stimuli that consisted of small shapes arranged to make a large shape, like those shown in Figure 3 (Davoli, Brockmole, Du, & Abrams, 2012). Subjects saw two such shapes in succession on each trial and were asked to judge either the small (local) element or the large (global) element of the two stimuli. Importantly, some trials required the same judgment for both stimuli, whereas

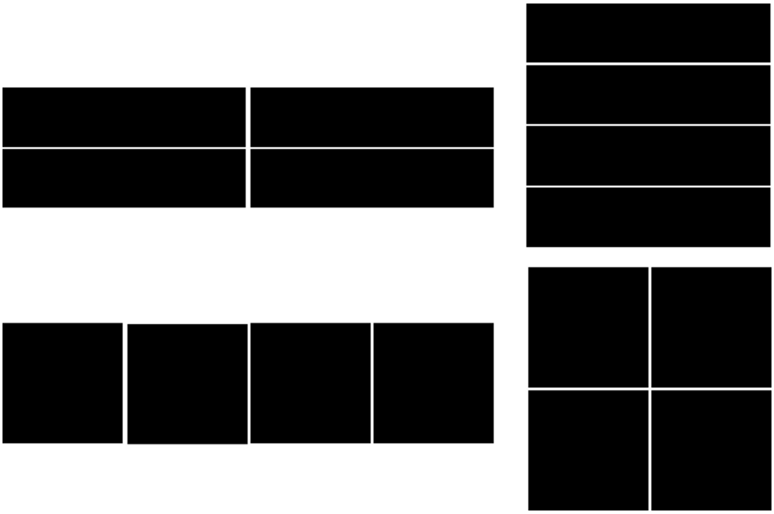

Figure 3 Stimuli like those used by Davoli, Brockmole, Du, et al. (2012). Participants identified either the local shape or the global shape of two stimuli presented successively on each trial. For example, in the upper right stimulus the local shape is a rectangle and the global shape is a square.

others required the subject to switch from one judgment to the other. When a consistent judgment was required (e.g., local—local) participants were equally good at the task when the stimuli were either near to or far from their hands. However, when the judgment switched between stimuli (e.g., local—global) participants were slower to make the second judgment when the stimuli were near their hands. The result suggests that switches in not only spatial attention, but also in attention to higher-level aspects of the visual configuration, are delayed near the hands.

Vatterott and Vecera (2013) have also reported results supporting delayed disengagement of attention from objects near the hands. In their experiment, which was designed specifically to test the disengagement account, participants searched for a uniquely-shaped target in a display that also sometimes contained a uniquely-colored distracter. Participants held one hand near one side of the display. Targets that appeared near the hand reaped no benefit from the hand's proximity, suggesting that the hands do not facilitate certain tasks by, for example, speeding engagement of attention on nearby objects (similar to the results and conclusions of Abrams et al., 2008). However, distracters that were near the hand were more disruptive than those that were far away, consistent with an impaired ability to disengage from them before resuming the search for the target.

Additional insight into attentional disengagement near the hands comes from a study of eye movements. Eye movements are known to be tightly linked to hand movements (Abrams, Meyer, & Kornblum, 1990) and to movements of attention (Deubel & Schneider, 1996), and recently we have shown that they may also depend on the proximity of the hands to the stimuli. Suh and Abrams (2013) had participants move their eyes either toward a peripheral target (pro-saccade) or away from one (anti-saccade), after the target suddenly appeared. The anti-saccades require that the participant inhibit the prepotent response to the sudden onset, disengage attention from it, and look the other way. Suh and Abrams found an increased reaction time cost for anti-saccades (the difference between initiation times for anti-saccades compared to pro-saccades) near the hands—consistent with a delayed disengagement of attention from the imperative stimulus which is required for anti-saccade but not for pro-saccades. In a second experiment, Suh and Abrams used a centrally-presented stimulus to signal the saccade target location. Participants there were slower to initiate saccades when their hands were near the display, presumably due to delayed disengagement from the central signal. Taken together the results suggest that delayed disengagement of attention near the hands affects the eye movements that people make. One advantage of such an occurrence is that it would tend to facilitate the maintenance of fixation upon an object of interest when it is near the hands.

2.3 Enhanced Cognitive Control

Other studies have revealed changes in processing for near-hand stimuli that may also stem from inhibited disengagement of attention, but for which there is also an alternative explanation. Weidler and Abrams (2014b) examined two tasks that measured executive (or cognitive) control. The first task studied was a flanker task in which participants were required to identify a centrally-presented target letter while ignoring sometimes-conflicting flanking distractor letters. The task requires maintenance of spatial attention at the central location and suppression of the flanking stimuli, and thus would be expected to benefit from a mechanism that inhibits disengagement of attention. As predicted, the flankers caused less interference when the stimuli were in the near-hand space, presumably due to the same underlying mechanism as the one responsible for the slower visual search rates (Abrams et al., 2008), the delayed shifting between local and global scopes of attention (Davoli, Brockmole, Du, et al., 2012), and the enhanced adverse effect of near-hand distractors during search (Vatterott & Vecera, 2013).

Although the flanker results from Weidler and Abrams (2014b) can be easily explained by inhibited attentional disengagement, an alternative possibility exists: the reduced flanker interference may instead arise from enhanced executive or cognitive control for stimuli near the hands. Such an effect might reflect a more central origin of the influence of the hands—participants may be better at maintaining the task instructions when stimuli are near their hands—and not merely better at visuospatial filtering. This possibility is confirmed by the second experiment reported by Weidler and Abrams, which employed a task-switching paradigm, as illustrated in Figure 4. In the experiment, the outline of a box *cue* (either solid or dashed) informed participants of the requisite judgment: either the color or the shape of an upcoming colored shape. The judgment sometimes switched from one trial to the next (as illustrated in the figure), and sometimes it remained the same. Importantly, performance of the task would benefit from effective maintenance of the task instructions in memory, but not from enhanced visuospatial filtering. Indeed, Weidler and Abrams observed enhanced performance for stimuli near the hands: the reaction-time cost incurred when the task switched from one trial to the next was reduced near the hands. The results reveal greater executive control devoted to the analysis of stimuli near the hands—a result that cannot reflect merely enhanced attentional focusing or visuospatial filtering—but instead one that seems likely to reflect a more central, cognitive mechanism

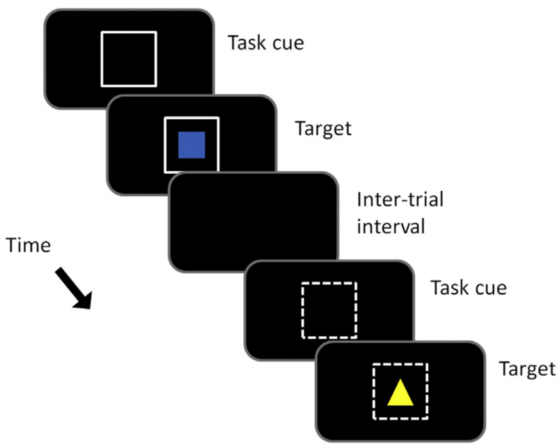

Figure 4 Sequence of events on two trials from Weidler and Abrams (2014b). The task cue indicates whether participants should identify the shape or the color of the target, and can sometimes change from one trial to the next, as in the example here.

such as one involved in maintenance of task instructions in working memory. Results reported by Davoli, Du, Garverick, Montana, & Abrams (2010), who found reduced Stroop interference near the hand, permit a similar conclusion.

It is worth noting that the improved task-switching performance in the near-hand space seems inconsistent with the results described earlier involving switches between local and global scopes of attention (Davoli, Brockmole, Du, et al., 2012). Both paradigms measured the ability of participants to rapidly switch from one task to another: either to change the focus between color and shape in the case of the task-switching paradigm, or to change the focus between local and global scopes of analysis in the local/global task. Yet, while participants were better at switching between color and shape when the stimuli were in the near-hand space, they were poorer at switching between local and global analyses. Two explanations for the apparent conflict seem possible: first, the switching required by the two tasks was clearly different. It may indeed be the case that visuospatial attentional switching (i.e., attentional disengagement) is inhibited in the near-hand space, as reflected by many results reviewed earlier, including those from the local/global task. At the same time, switching of task instructions at a higher, cognitive level, as required in the task-switching paradigm, could be facilitated near the hands. Because the two tasks require different switching, there need be no inherent conflict.

The other explanation for the apparent discrepancy between the local/global results and the task-switching results involves the timing of the switching that is being measured in each task. In both tasks participants knew in advance that a switch would be needed. In the local/global experiment, the judgment for the first stimulus on each trial and that for the second stimulus on each trial were specified for an entire block of trials. In the task-switching paradigm, the relevant dimension for a trial was presented 1 s in advance of the stimulus. But, despite the advance knowledge of the requisite switch in both cases, the recorded reaction times included different components of the switching in the two experiments. In the local/global task, there was a very brief interval between the response to the first stimulus and the presentation of the second (the response–stimulus interval varied from 0 to 232 ms). As a result, the reaction times, at least for the briefest response–stimulus intervals, measured all of the processes involved in reconfiguring the task set for the new required judgment. On the other hand, because participants had one full second to prepare for the stimulus prior to its presentation on every trial in the task-switching paradigm, those reaction times reflect only the processes that cannot be reconfigured in advance of the stimulus—what are referred to as the *residual* switch costs (Monsell, 2003). Thus, the aspect of switching being measured in the two experiments may be different. The important conclusion is that people appear to be slower to make changes in visuospatial attention for stimuli near the hands, although they are faster to alter the allocation of cognitive resources to such stimuli.

2.4 Figure–Ground Segregation

Numerous other tasks have been shown to be influenced by the proximity of the hands. The breadth of these phenomena reveal the importance of the hands in marshaling the perceptual, cognitive, and motoric resources needed to deal effectively with one's environment. For example, Cosman and Vecera (2010) examined the segregation of objects from the background. They presented participants with stimuli that contained ambiguous figure and ground regions. Resolving such ambiguity is an important prerequisite to successful interaction with an object, and is thought to occur early in visual processing. Cosman and Vecera found that regions near an outstretched hand were more likely to be perceived as figure than regions that were far from a hand, showing that the nearness of a hand can have an important effect on precisely the sorts of visual processing that would be needed for effective interaction with objects in one's environment.

2.5 Visual Processing Channels

Abrams et al. (2008) suggested that one of the benefits of altered vision near the hands would be to enhance the acquisition of information needed to interact manually with nearby objects. Gozli, West, and Pratt (2012) tested that idea by examining participants' sensitivity to brief temporal and small spatial interruptions in stimuli near the hands. They reasoned that an enhancement that would influence hand movements might be expected to emphasize processing on the magnocellular visual channel as opposed to the parvocellular channel. This is because the dorsal visual pathway is heavily involved in controlling movement (Goodale & Milner, 1992), and this pathway receives its predominant input from the magnocellular channel (Livingstone & Hubel, 1988; Maunsell, Nealey, & DePriest, 1990). Magnocellular mechanisms are more sensitive to movement, but less sensitive to fine spatial detail (Callaway, 1998). Consistent with the prediction, Gozli et al. found that participants exhibited enhanced sensitivity to temporal interruptions, but impaired sensitivity to spatial gaps, when the stimuli under scrutiny were near their hands.

Abrams and Weidler (2014) performed several additional tests of the possibility that processing near the hands is biased toward magnocellular visual mechanisms. In one experiment they examined differences in contrast sensitivity for stimuli near the hands. In particular, it is known that magnocellular mechanisms selectively process low spatial frequency information at the expense of high spatial frequency information (Callaway, 1998). If indeed magnocellular processing is emphasized near the hands, then a relative advantage would be expected for low spatial frequency stimuli when in the near-hand space. The procedure on one trial of their experiment is shown in Figure 5. Participants were required to determine the orientation of a briefly-presented sine-wave grating (a *Gabor patch*) that was either vertical or tilted a few degrees to the left or right of vertical. Abrams and Weidler varied the spatial frequency of the grating, as well as the proximity of the participant's hands to the display (they used the postures shown in Figure 1). The results are shown in Figure 6, in which the discriminative sensitivity to the stimuli (A′)—the ability to distinguish tilted gratings from vertical ones—is shown as a function of the spatial frequency and nearness of the hands. As can be seen, participants enjoyed improved discrimination of low spatial frequency stimuli near the hands, at the expense of high spatial frequency stimuli.

The pattern of results reported by Abrams and Weidler (2014) is exactly what would be expected if magnocellular processing was emphasized for stimuli in the near-hand space. In addition to the enhanced sensitivity to low spatial frequency, the impaired sensitivity to high spatial frequency is

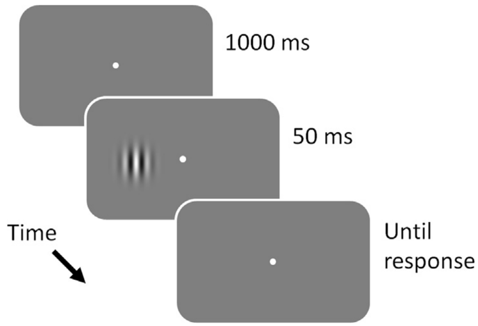

Figure 5 Sequence of events on a trial from Abrams and Weidler (2014). Participants determined whether the Gabor patch was vertical or slightly tilted.

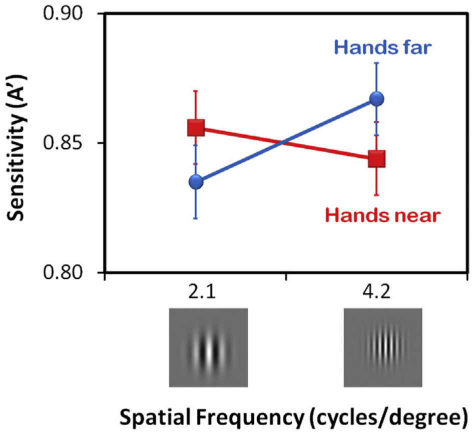

Figure 6 Results from Abrams and Weidler (2014). Discrimination for low spatial frequencies was enhanced near the hands, whereas that for high spatial frequencies was impaired.

consistent with the known tradeoff between magnocellular and parvocellular mechanisms (Bocanegra & Zeelenberg, 2009). To further examine the possibility of magnocellular involvement in enhancing vision near the hands, Abrams and Weidler exploited a less well-known feature of the magnocellular channel: its activity is suppressed in the presence of long wavelength (i.e., red) illumination (Wiesel & Hubel, 1966). If the changes in visual processing near the hands arise from biased activity on the magnocellular channel, then such changes should be reduced or eliminated under red illumination. Abrams and Weidler tested this prediction in two experiments. In the first, they repeated the experiment just described, but with a display that contained a red background throughout the experiment. As predicted, under red illumination, there was no change in sensitivity when the hands were placed close to the display. This result helps to bolster the earlier conclusion that the changes observed in contrast sensitivity near the hands reflect enhanced processing by magnocellular mechanisms.

In a second experiment, Abrams and Weidler (2014) repeated the visual search experiment by Abrams et al. (2008) described earlier (Figure 2). They reasoned that, if the reduced visual search rate near the hands stemmed from enhanced activity of the magnocellular channel, then the effect of hand proximity on search rate should be reduced or eliminated under red illumination. As predicted, in their experiment they replicated the original result when they used a green background on the display screen, but the visual search rate was unaffected by the proximity of the hands when the background on the screen was red. The results are not only illuminating with respect to the differences in processing that occur in the near-hand space, but they also may contribute to an understanding of visual perception more generally. In particular, the results of Abrams and Weidler suggest that the magnocellular channel plays a critical role in regulating attentional disengagement and visual search rate.

Why might magnocellular processing be emphasized for the near-hand space? One reason, as noted earlier, is that the dorsal stream, which is involved in controlling movement, receives heavy input from the magnocellular channel. Emphasizing magnocellular processing would thus be expected to facilitate the use of information for movement production. It is also possible that enhanced magnocellular processing would favor some of the neural mechanisms that are thought to be involved in the processing of visual information near the hands. In particular, it has been suggested (e.g., Abrams et al., 2008; Reed et al., 2006) that vision near the hands is mediated in part by the activity of multi-modal neurons that have visual receptive fields that move with the hand (Graziano & Gross, 1995). Thus, objects near the hands would fall into the receptive fields of these neurons, and would benefit from their processing, whereas objects far from the hands would not. Importantly, these multimodal neurons have been found in the ventral intraparietal area, which is on the magnocellular channel.

2.6 Emotional Stimuli

It is also the case that emotional stimuli can lead to enhanced activity on the magnocellular channel (Bocanegra & Zeelenberg, 2009, 2011). This occurs because emotion activates the amygdala that receives input and projects to the visual cortex primarily via magnocellular connections (Amaral, Behniea, & Kelly, 2003). The connection between emotional processing and the magnocellular channel raises the possibility that effects of hand-nearness may be mediated in part by some of the same mechanisms that process emotion. Indeed, given the importance of processing objects near the hands for purposes such as self-defense or tool use, it could be argued that the presence of a near-hand object is itself an emotional event—one that requires immediate and efficient evaluation in order to respond in an appropriate way.

To test the possibility that objects in the near-hand space benefit from enhanced activity in brain mechanisms involved in the processing of emotion, Weidler and Abrams (2013) had participants search for letters embedded in pictures of natural scenes. The pictures were either neutral,

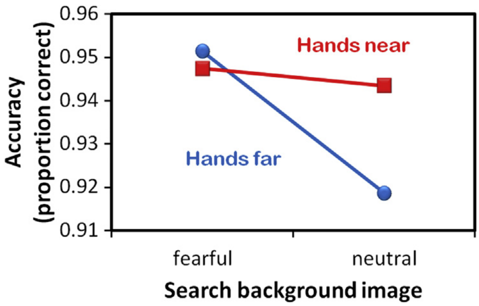

Figure 7 Results from Weidler and Abrams (2013). Accuracy was enhanced when the background contained an emotional (fearful) image, or when the hands were near the display.

such as a scene from a typical office, or they were emotionally evocative, such as a snake on the verge of striking. Results are shown in Figure 7. The time to find the target stimuli did not vary across conditions, but the accuracy did: participants were better at finding stimuli on the emotional images. The emotional activation presumably recruited additional visual processing resources. Importantly, that result was only observed when the hands were far from the display. When the hands were near the display, both emotional and neutral stimuli led to highly accurate searches. One interpretation of that result is that proximity to the hands enhances processing of the target and at the same time permits the participant to suppress processing of the background. However, there is evidence that people do indeed process details of the background (at the expense of processing the general gist; Davoli, Brockmole, & Goujon, 2012). Alternatively, the pattern of results suggests that proximity to the hands recruits some of the same mechanisms that are recruited by emotionally evocative stimuli, endowing even neutral stimuli with some of the advantages typically conferred only to emotional stimuli. It is tempting to conclude that this occurs because objects near the hands are typically important, demanding additional mechanisms for their effective processing.

2.7 Summary

Numerous perceptual and cognitive changes affect the processing of stimuli near the hands. For stimuli in the near-hand space people are slower to disengage spatial attention and to switch between local and global scopes of analysis. They are better at exerting cognitive control and at discriminating low spatial frequency information. They segment figure from ground more consistently, and emphasize processing on the magnocellular visual pathway. All of these changes occur in the absence of any explicit movement plan, but they presumably stem from the potential actions that are afforded by the proximity of the hands to the elements under scrutiny.

3. PRESENT HAND MOVEMENTS

Work reviewed in the preceding section shows that movement-related perceptual and cognitive changes may be engaged when the hands are near a visual stimulus, even in the absence of any explicit intention to produce a movement. This presumably occurs because of the potential actions that are afforded by the proximity of the hands. But we are often in a state in which a movement is being produced, or in which a planned movement is held in readiness. Such a state also leads to changes in perception and cognition—presumably changes that may facilitate the successful completion of the movement. We discuss this research next.

3.1 Spatial Effects

Several researchers have shown that plans to produce a movement lead to changes in the allocation of spatial attention. For example, Deubel, Schneider, and Paprotta (1998) had participants discriminate briefly flashed symbols that appeared near or far from the target of a planned pointing movement. Discrimination was best at the movement's target location, suggesting that visual attention had preferentially selected that location prior to movement due to the movement plan. Linnell, Humphreys, McIntyre, Laitinen, and Wing (2005) reported a similar result.

The plans for a hand movement can also change the spatial reference frame within which a visual scene is evaluated. Tipper, Lortie, and Bayliss (1992) had participants reach for targets among distractors from one of two postures—with the hand beginning either near their body (and thus the hand moved away), or with the hand beginning far away (requiring a movement toward the body). By assessing the impact of distracting visual stimuli, Tipper et al. found that the allocation of attention to the scene depended on the direction of the hand movement: Attention was biased by the direction of the action such that more attention was devoted to the space along the path of the movement than beyond it. Similar results were reported by Bloesch, Davoli, and Abrams (2013), who also showed that a change in the direction of a hand movement does not lead to similar changes in attention in older adults.

Taken together, the studies just reviewed show clear effects of planned hand movements on the spatial allocation of attention. Such changes would be beneficial due to the importance of acquiring high-quality visual information to accurately guide the upcoming movement to successful completion (Abrams et al., 1990). There are also numerous nonspatial changes that occur as a consequence of a prepared hand movement, and these are reviewed next.

3.2 Illusions

An important effect of a planned hand movement was demonstrated by Vishton et al. (2007). They had participants make judgments about the sizes of objects that were subject to the Ebbinghaus illusion. In the illusion, the perceived size of a central target (typically a circle or disk) depends on the sizes of surrounding context objects: smaller surrounding objects increase the perceived size of the target. It had previously been shown that grasping movements directed toward target stimuli subject to the illusion reveal a much smaller illusion magnitude (as measured by the positioning of the fingers during the grasp) than do verbal judgments of the target size (e.g., Aglioti, Desouze, & Goodale, 1995). Such results were used to argue that the motor system has privileged access to veridical visual information that is unavailable to the cognitive/perceptual system. In their experiment, Vishton et al. had participants provide verbal judgments about the target after having merely *prepared* a grasping movement. Importantly, the magnitude of the illusion was similarly reduced—revealing an important effect of movement preparation on visual perception.

3.3 Grasping, Pointing, and Reaching

A number of researchers have varied attributes of the movements that participants held in readiness. Craighero, Fadiga, Rizzolatti, and Umiltà (1999) had subjects prepare to grasp a handle that was tilted either to the left or to the right. The imperative stimulus was a visually-presented bar, also tilted either to the left or to the right. Importantly, the orientation of the stimulus was not informative regarding the correct response: participants were to produce the prepared movement regardless of the bar's orientation. Nevertheless, initiation times were faster when the stimulus bar orientation matched that of the movement to be produced. The inference is that preparation of a movement facilitated perception of objects with features that matched the parameters of the movement. It is easy to see how such an effect could facilitate successful production of a movement that was being prepared.

Consistent findings were reported by Wohlschläger (2000). He had participants rotate a knob either clockwise or counterclockwise while judging the direction of movement of an ambiguous rotating apparent-motion display. The direction of the hand movement strongly affected perception of the display: participants were biased to perceive visual motion that was congruent with their hand movements compared to motion that was incongruent. The same effect also occurred even in the absence of overt movement—when participants were merely preparing to produce a specific hand movement.

The results of Craighero et al. (1999) and Wohlschläger (2000) show that a planned movement may bias attention toward specific values of dimensions that are relevant to the movement. Other work has shown that a prepared hand movement may bias selection toward a particular dimension itself. For example, Bekkering and Neggers (2002; see also Hannus, Cornelissen, Lindemann, and Bekkering (2005)) had participants either point to or grasp a target object. Doing so required a search for the target among distractors that differed in either color or orientation. Grasping would be expected to require information about an object's orientation, whereas pointing would not require such information. Indeed, when participants searched for a target that they were required to grasp, they were less likely to look to a distractor with the wrong orientation compared to when they were preparing to merely point to the target. Thus, when preparing a grasp, the perceptual system prioritizes the processing of visual orientation information.

Fagioli, Hommel, and Schubotz (2007) also asked participants to prepare either a grasping or a pointing action to be directed to a nearby response board. The action was to be carried out upon detecting an unexpected ("deviant") event in a sequence of stimuli shown on a separate stimulus display. The deviant could either be a stimulus with an unexpected size or one in an unexpected location. As might be predicted, when preparing a grasping movement, participants were more sensitive to size deviants, because presumably object size is critical for grasping, whereas pointing preparation led to increased sensitivity to location deviants.

In related research, Wykowska, Schubö, and Hommel (2009) asked participants to search for size or brightness singletons among an array of like-size or like-brightness elements. Prior to the search, participants prepared either a pointing or a grasping motion and held it in readiness. Consistent with the findings of Fagioli et al. (2007), participants detected size singletons faster when they were preparing a grasping compared to a pointing movement. Thus, specific attributes of a planned movement can bias the perceptual system to acquire information that would facilitate the movement (see also Gutteling, Kenemans, and Neggers (2011)).

3.4 Natural Objects

Movement-biased perception has also been demonstrated for stimuli that are somewhat more natural than those that vary on basic features such as luminance or size singletons as used in the work just reviewed. In one example, Symes, Tucker, Ellis, Vainio, and Ottoboni (2008) asked participants to identify which single object was changing as two slides alternated in a classic change-blindness task. The slides contained images of small and large fruits and vegetables. On some trials participants were to indicate that they detected the change using a handle that required a power grip, whereas on other trials they were to respond using a pinch-like precision grip. Although the response was arbitrary, participants detected changes to large objects more quickly when they were using the power grip response, and changes to small objects more quickly when producing a precision response. The results suggest that movement preparation biased visual attention toward stimulus features that were congruent with the planned movement—hence changes in small objects are easier to detect when one is preparing a pinching movement.

Pavese and Buxbaum (2002) had participants in one experiment view objects such as coffee cups, cabinet handles, and doorbell buttons. Participants were to look for a designated target object, sometimes in the presence of distracting objects. On some trials participants were required to reach out to the target, whereas on other trials they pressed a nearby button to report the target's location. When the response required participants to reach out to the target, the time to initiate the movement was slower if a distractor with a handle was present, compared to a nearby distractor that did not contain a handle. A similar pattern was not observed when only a button press response was required. The results suggest that planning to put one's hands near an object causes one to be more sensitive to features of objects that permit handling—such as the presence of handles.

In related research, Bub, Masson, and Lin (2013) asked participants to name photographs of real-world objects (e.g., teapot and pan). Importantly, each of the objects had a handle, and participants held in readiness one of several movements (for later production) while they made their identifications. The time needed to identify the objects depended on the correspondence between the planned movement and the movement most appropriate for interaction with the object. If the hand to be used and the orientation of the planned movement matched the object-appropriate movement, identification was rapid. But if either the planned orientation or hand was not a match, identification was slowed. (If both the hand and orientation were a mismatch, identification was also fast, presumably because the attributes of the appropriate movement were easily accessible as they were not bound into the movement being held in readiness.) The results show not only that a planned movement can affect perception, but also that the plans for a future movement can influence the identification of visual objects. The effect on identification shows that the influence of movement preparation can extend beyond low-level perceptual attributes.

Yu, Abrams, and Zacks (2014) also had participants make judgments that required access to semantic information about their stimuli. In their study, subjects judged whether a pictured object was presented in its upright orientation or an inverted orientation, using one hand for each of the two responses. Each of the objects had a handle or typical grasping location, although this feature was not relevant to the judgment required. Nevertheless, when subjects were asked to imagine grasping the depicted stimuli (but only under those conditions) the judgments were faster when the response hand happened to be closest to the handle of the depicted object. It is important to note that the effect only occurred when participants were planning to grasp the object—no facilitation was observed when participants made the same judgments and the same responses in the absence of a prepared grasp. Thus, merely viewing an object did not facilitate object-appropriate movements, but the preparation of an appropriate movement facilitated access to semantic information about the object.

3.5 Perceived Distance is Affected by Extensions of the Hands

The ability to move one's hands to a target object can not only change perceptual sensitivity to attributes in the scene, as just discussed, but it can also affect the perceived distance to the object. Witt, Proffitt, and Epstein (2005) had participants estimate the distance to a nearby target. Distance-estimation trials were randomly interspersed among two types of hand-pointing trials. In some blocks, participants pointed only with their hand (which could not extend far enough to reach the target); in other blocks they pointed with a hand-held stylus (with which they were able to reach the target). In blocks in which the stylus was being used, the targets looked closer than in blocks without the stylus. The result is believed to reflect the way in which the perceptual system accounts for one's action capabilities: targets that are reachable are perceived to be closer than those that are out of reach (see also Witt (2011)). For present purposes, the result reveals an important effect of a planned hand movement on perception: The anticipated success of a movement alters perceptions regarding the movement target. Additionally, in the Witt et al. study, the changes were produced not by the hand itself, but by an artificial extension of the hand.

A recent study by Bloesch, Davoli, Roth, Brockmole, & Abrams (2012) has extended the Witt et al. (2005) results in an important way. In the Bloesch et al. study, as in the earlier one, participants were asked to judge the distance to a target object after either unsuccessful pointing (with an arm), or successful pointing (with a reach-extending stylus). However, in the Bloesch et al. study it was not the participants who did the pointing. Instead, the participants simply watched as another person pointed. The setup of the experiment is shown in Figure 8: participants sat adjacent to an actor, who sometimes wielded a stylus that allowed them to reach the target. The targets were all out of the participants' reach. Nevertheless,

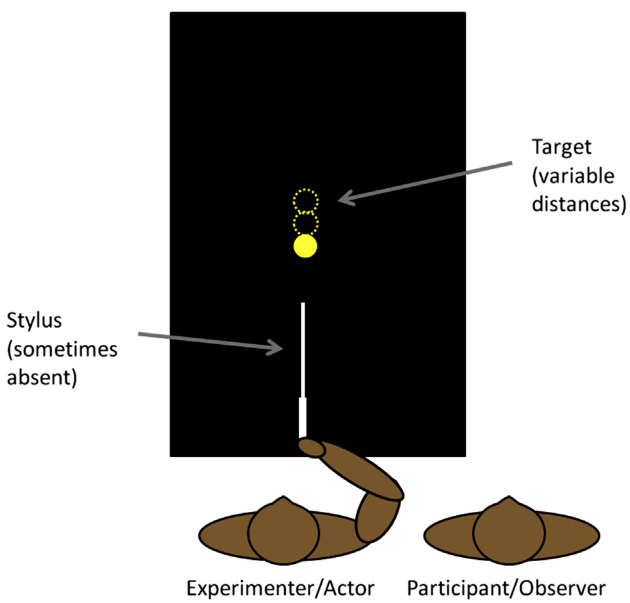

Figure 8 Arrangement used in pointing observation experiments of Bloesch et al. (2012). The observer assessed the distance to the target but never wielded the stylus.

the results were exactly the same as if the participant had wielded the tool themselves: when the actor was able to reach the target with the stylus, the target appeared closer (to the participant) than when the actor pointed without the stylus. The results show that an individual's perceptions are influenced not only by their own movements, but also by the movements and capabilities of others. It is speculative but tempting to conclude that the observer may have imagined making the same movements as the actor. In that case, the results show that imagining a movement may involve many of the same mechanisms that underlie an actual movement, an idea that has additional support (e.g., Davoli & Abrams, 2009).

When an observer's perceptions are influenced by an actor's capabilities does the observer view the scene as if in the actor's location, or do they account for the actor's capabilities and view the world from their own viewpoint? These represent two distinctly different possibilities: the former presumes that the observer must transform his or her spatial reference frame and imagine viewing the world from a different location in addition to imagining the actions performed. The latter presumes that the observer must convert the spatial coordinates of the performed actions into their own spatial reference frame. When the actor and observer are sitting side-by-side, as they were in the study by Bloesch et al. (2012), it is not possible to distinguish between these two possibilities. In order to distinguish between them, Abrams and Weidler (in press) repeated the earlier experiment but with an important twist: they had the actor and observer view the stimuli from opposite directions. The situation is shown in Figure 9. In the experiment, the participant watched from one side of the display while an actor reached for a target from the other side. The actor used either their unaided hand, which was not long enough to reach the target, or a stylus that did permit them to reach the target.

It is known that the use of a tool will cause the target to seem closer to the actor (e.g., Witt et al., 2005). If the participant viewed the scene as if from the actor's perspective, then when the tool is being used the participant should see the target as being closer. However, if the participant accounts for the actor's capabilities from the participant's own viewpoint, then use of the stylus should make the target appear to be farther away. The results reveal that the latter possibility occurred: observers perceived the target to be farther away when the actor used the tool. The result may be the first to show that the perceptual system scales the world to account not merely for one's own capabilities, but also for the capabilities of others. There are clear adaptive advantages to such behavior. If the capabilities of a rival render

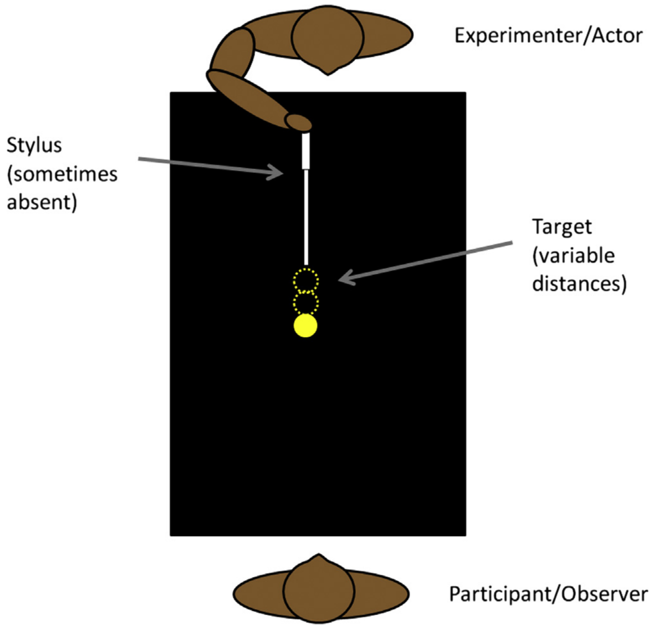

Figure 9 Arrangement used in pointing observation experiments of Abrams and Weidler (in press) . The observer assessed the distance to the target but never wielded the stylus.

a sought-after target more difficult to obtain, appropriate scaling of perception would allow one to more accurately assess the energy expenditure needed to acquire the goal.

It is worth noting that the neural mechanisms that have been shown to underlie some processes related to handheld tool use are the very same ones that are proposed to be involved in the effects of hand–nearness. In particular, Iriki, Tanaka, and Iwamura (1996) showed that the receptive fields of some cells that are sensitive to visual stimuli near the hand can expand to include a handheld tool. These cells may include bimodal cells that are sensitive to both tactile and visual stimuli on and near the hand that were mentioned earlier and are believed to play a role in the effects of hand-nearness (e.g., Reed et al., 2006).

3.6 Movement Effort Affects Perceived Distance

The action-specific account of perception (e.g., Witt, 2011) argues that perception is scaled to reflect a person's current capabilities. Hence, when a reach-extending tool is wielded, objects that can be reached appear closer than without the tool, as just noted. In addition to the use of a tool, other changes in a person's capabilities have been shown to alter perception. For example, Kirsch and Kunde (2013) manipulated the difficulty of producing a target-directed hand movement by changing the required force or amplitude, which was signaled prior to each movement. The required force was altered by adjusting the magnitude of a resistive force applied to the handle that participants were required to move. Before producing the hand movement, however, participants were required to judge the distance to the movement target. Kirsch and Kunde found that when more force was going to be needed for the hand movement, the target looked further away. Thus, not only do changes in the reachable distance affect the perceived distance (e.g., Witt et al., 2005), but the anticipated effort of a reaching movement does too. The findings are consistent with other results showing effects of locomotor effort on perception (e.g., Bhalla & Proffitt, 1999), but the difference is that in this case it is effort related specifically to a planned hand movement that alters perception.

3.7 Summary

Plans to make a hand movement lead to changes in perceptual processing. People direct their attention to the location of the planned movement, and they alter the allocation of attention depending on the path of the movement. Differences in the type of movement planned can differentially affect sensitivity to distinct visual features, and can even affect the identification of common objects. Wielding a tool that extends one's reach can affect the perceived distance to an object—even if someone else is holding the tool. And the anticipated effort to reach a goal can affect its perceived distance. These perceptual changes facilitate the effective production and accurate completion of the actions that are being planned.

4. PAST HAND MOVEMENTS

What are the consequences of having recently produced a movement? There is considerable evidence that the choice of a subsequent movement will be strongly biased by a movement just completed (e.g., Cohen & Rosenbaum, 2011; Dixon, McAnsh, & Read, 2012; Valyear & Frey, 2014). And it is also clear that completion of a movement may bind together attributes of the movement with attributes of the stimulus associated with it—and that may also affect subsequent responses (e.g., Hommel, 1998). These phenomena, while important, are beyond the present scope because we choose here to limit our discussion to the uniquely perceptual and attentional consequences of hand movements, to which we turn next.

4.1 The Action Effect

How is perception modified by a completed hand movement? Researchers have only recently have begun to explore this question, but it is clear that a prior movement can lead to important changes in perception that persist at least for a short time. Buttaccio and Hahn (2011) were the first to report such effects, and in a replication of their work Weidler and Abrams (2014a) confirmed and extended their findings. The key events on a trial in the Weidler and Abrams experiment are shown in Figure 10. Each trial consisted of two parts. In the first part, the *action task*, participants pushed a key when a colored circle appeared on designated (but not all) trials—regardless of the color of the circle. A short time (less than 1 s) later, in the second part, the *search task*, participants engaged in a visual search in which the search target was embedded within colored circles. Although the color of the circle from the action task was not informative with respect to the target location it nevertheless influenced search times. Results are shown in Figure 11: on trials on which subjects responded to the circle in the action task (the "Action" trials in the figure), they were faster to find the target (in the search task) if it happened to appear in the color to

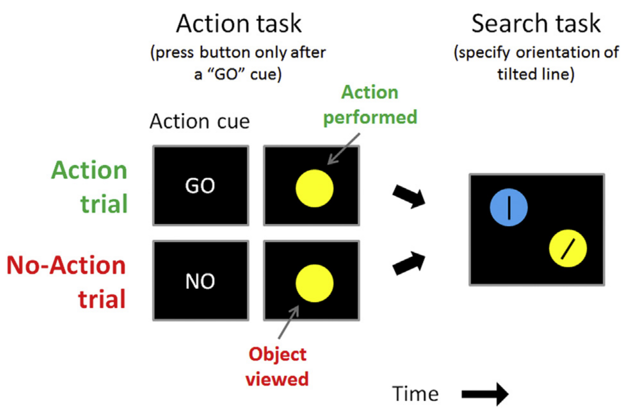

Figure 10 Key events on a trial of the experiment by Weidler and Abrams (2014a). Participants were told in advance to press a key on some trials (the *action* trials). The color of the object to which they acted varied, but was irrelevant in the task. They performed a visual search through colored objects, in which color was also irrelevant, a short time later.

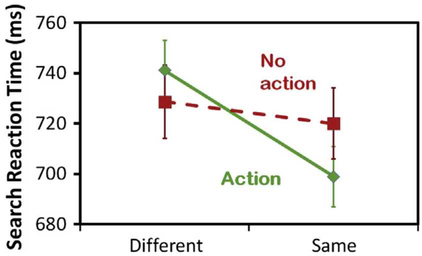

Figure 11 Results from Weidler and Abrams (2014a). Color was never relevant in the task yet the color of the earlier object affected search if an action had been made earlier.

which they had responded earlier. When subjects merely viewed but had not responded to the circle in the action task (the "No-action" trials), the color of the circle had no effect. Thus the production of a movement, although arbitrary, strengthened a representation of features of the object (also arbitrary) that was present during the movement, and prioritized attentional selection for a matching object a short time later.

The effect of prior action described by Buttaccio and Hahn (2011) and Weidler and Abrams (2014a), the action effect, was revealed by a visual search task in which participants were required to serially search through the display elements in order to find the target. The benefit of the prior action might thus occur at a later stage of visual processing such as that involved in evaluating the individual search stimulus identities, or the benefit of the prior action might occur at an earlier stage of analysis. In order to pinpoint the locus of the effect of prior action, Weidler and Abrams (submitted for publication) examined the effects of the action using a pop-out search task. A pop-out search is one in which the target is identified by a salient perceptual singleton (e.g., it is a uniquely shaped item). Such a search is believed to be accomplished at early ("parallel") stages of visual processing. The results were clear: even when the search target was a salient singleton, the search was facilitated by a previous action if the action had been directed toward an item with the same color as the target. Importantly, as in the earlier study, color was not informative with respect to the target location. The findings suggest that the effects of the prior action influence very early visual processes—processes that are engaged during the initial, parallel analysis of all elements in the scene. Nevertheless, the pattern of results is also consistent with the possibility that the effects of prior action are on late, post-perceptual processes such as response selection. More work will be needed to test that possibility.

In the experiments of Buttaccio and Hahn (2011) and Weidler and Abrams (2014a, submitted for publication) color was the only feature tested. What other features of an acted-on object have the ability to affect subsequent perception? To examine the question, Weidler and Abrams (unpublished results) varied the *shapes* of the action target in the action task and of the target and distracters in the search task. The shapes they used are shown in Figure 12. As in the earlier experiments, the shape in the action task was not informative regarding the location of the target in the search task (the search elements were vertical or oblique lines superimposed onto the shapes). Nevertheless, a similar pattern of results obtained: On trials on which participants made an action to a specific shape, they found the target more quickly if it appeared in the same shape in the search task. Merely viewing, but not acting on, a shape in the action task had no effect. Thus, arbitrary properties of acted-on objects, such as color and shape, are retained in memory and can influence subsequent perceptual processing. Such an occurrence might convey an adaptive advantage because it would automatically facilitate the detection of objects that were targets of a prior action, something that might be useful when engaged in activities such as hunting or foraging.

Why are arbitrary properties of an action-target prioritized in subsequent visual processing? As just noted, one possibility stems from the presumed evolutionary benefit of reinforcing behaviors that are appropriate and/or successful at the expense of behaviors that are inappropriate or unsuccessful. When viewed in this way, the action effect might be regarded as a special case of the value-based attention results reported by some researchers (e.g., Anderson, Laurent, & Yantis, 2011). Participants in the Anderson et al. experiments performed visual search tasks through colored stimuli, first in a training phase in which one color was more likely to be associated with a reward than other colors, and then subsequently in a transfer phase in which the reward was eliminated and color was irrelevant. Despite the irrelevance of the color in the transfer phase, participants nevertheless prioritized search

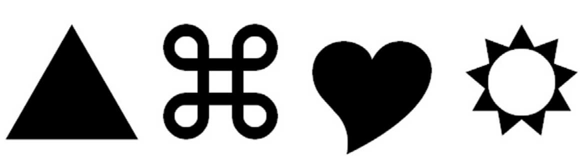

Figure 12 Shapes used in the experiment by Weidler and Abrams (unpublished results).

for that color—they were more impaired by distracters in a previously valuable color than one in a different color. The interpretation is that attentional selection was influenced by the previously valuable, but now irrelevant, color. Similarly, in the experiments by Weidler and Abrams (2014a), a previously "valuable" color (in that case a color to which an action had been performed) biased visual search. The congruence of the findings suggests that the two phenomena may arise from the same underlying mechanisms, and opens a possible avenue to an enhanced understanding of both.

4.2 Effects of Athletic Performance

Perception also appears to be affected by features of recently-completed movements involving handheld tools. In the study by Witt, Linkenauger, Bakdash, and Proffitt (2008) the "tool" was a golf club, and the features involved the extent to which the participants succeeded at putting a golf ball into a hole. In one experiment, Witt et al. had participants putt a golf ball under relatively easy (from a short distance away) or relatively difficult (from a longer distance) conditions. In the easy condition, participants had more putting success than in the difficult condition. Importantly, they also perceived the hole to be bigger. The perceived hole size was assessed by having the participant draw (using a graphics program) a circle that matched the perceived size of the hole—and they did so while simultaneously viewing the hole from a fixed distance, suggesting that the effect did not simply reflect a difference in their memory for the hole size.

Similar results were also obtained in a study that employed a variation of a pong-like video game (Witt & Sugovic, 2010). In the experiment, participants were to move a paddle in order to intercept a moving target. The task was made more or less difficult by varying the paddle size—bigger paddles make it easier to intercept the target. Participants were then asked to judge the speed of the target. Similar to the findings in the golf experiment, participants perceived the ball to be moving more slowly when they had greater success at intercepting it. Taken together, the results show that the success of an athletic movement can affect perception of the size of some of the objects involved in the activity.

4.3 Summary

A growing body of work is showing that perception can be affected by movements that have been recently produced. The movements can affect attentional prioritization of features of the objects that were present when the movement was produced. And prior movements might also affect the perception of attributes of objects such as their size or speed.

5. DEFENSIVE BEHAVIORS VERSUS MOVEMENT CONTROL

Throughout this chapter we have focused on the changes in cognition and perception that occur around the time of hand movements, emphasizing the manner in which the perceptual changes may serve the action system. We have said little about the nature of the actions that were contemplated or performed, or about what the purpose of those actions might be. In some cases, actions are needed to manipulate objects or tools in the environment. In other cases, however, actions are necessary for self-defense–and there is some reason to believe that the close links between action and perception may have evolved in part to facilitate such a purpose. For example, the multimodal neurons that have been suggested to underlie some of the effects of hand proximity (e.g., Reed et al., 2006) have been identified as playing an important role in self-defense (Graziano & Cooke, 2006). These neurons are sensitive not only to tactile stimulation on the skin (such as on the hands or face), but also to nearby objects that have not yet made contact with the body. Thus, they are believed to play a role in maintaining a protective zone around the body. It is possible that some of the near-hand changes that we have described here enable a person to more effectively deal with nearby objects not because they are tools to be wielded or food to be eaten, but instead because they may be obstacles to be avoided or impediments to be deflected.

6. CONCLUDING REMARKS

While it has been known for some time that the behavior of the hands depends upon the visual system (e.g., Abrams et al., 1990; Woodworth, 1899), it has only recently become clear that the visual system also depends upon the hands. As we have shown here, changes in visual perception occur when different hand actions are afforded by the environment and by one's current capabilities (Section 2), when they are planned and produced (Section 3), and after they have been made (Section 4). Understanding how these changes occur seems likely to lead to new insights into perception, cognition, and action.

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