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Minireview

Take the matter into your own hands: A brief review of the effect of nearby-hands on visual processing

Philip Tseng^{a,*}, Bruce Bridgeman^b, Chi-Hung Juan^{a,*}^a Institute of Cognitive Neuroscience, National Central University, Jhongli City, 320, Taiwan^b Department of Psychology, University of California, Santa Cruz, CA, 95064, USA

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ABSTRACT

An exciting new line of research that investigates the impact of one's own hands on visual perception and attention has flourished in the past several years. Specifically, several studies have demonstrated that the nearness of one's hands can modulate visual perception, visual attention, and even visual memory. These studies together shed new light on how the brain prioritizes certain information to be processed first. This review first outlines the recent progress that has been made to uncover various characteristics of the nearby-hand effect, including how they may be transferred to a familiar tool. We then summarize the findings into four specific characteristics of the nearby-hand effect, and conclude with a possible neural mechanism that may account for all the findings.

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1. Introduction

The term “nearby-hand” refers to one's own hands or limbs being held immediately adjacent to a visual stimulus (e.g., hands placed right next to a computer monitor), as compared to a distant placement (e.g., on one's lap). Ever since the seminal papers by Reed, Grubb, and Steele (2006) and Abrams et al. (2008) that demonstrate how nearby-hands can alter performance in some classic experimental paradigms, the field has seen a surge of studies that began to investigate this interestingly peculiar phenomenon. In Reed, Grubb, and Steele's study (2006), participants rested both hands near the computer display while performing a Posner orienting task. It was found that the closer the hands were to the display, the faster the participants' reaction time (RT) would become, regardless of cue validity. Subsequently, Abrams et al. (2008) used the same setup and found slower visual search, decreased inhibition of return, and increased attentional blink when one's hands were in proximity.

But how can nearby-hands produce faster attentional orienting, yet at the same time yield slower visual search and increased attentional blink? These seemingly contradictory results are resolved by the fact that the latter paradigms involved serial visual (visual search) and temporal (attentional blink) elements, but the former ones did not. That is, from an attentional perspective, nearby-hands produced a stronger attentional engagement and slower

disengagement that is nonselective of the content, thereby pouring more attentional resources toward each individual object, target and distractors alike, hence the accuracy-over-speed tradeoff. To this end, Tseng and Bridgeman (2011; also see Bridgeman & Tseng, 2011) subsequently used a change detection paradigm that provides accuracy measures of the nearby-hand effect and found improved accuracy coupled with slower RT. Therefore, nearby-hands seem to shorten RT when participants are cued to attend to certain locations, but to increase RT when participants have to serially look for a target or evaluate an object among various distractors, due to a slower disengagement of attention. Indeed, a series of important studies by Davoli and colleagues that found slower switching between global and local attention (Davoli et al., 2012), slower semantic judgment speed (Davoli et al., 2010), and slower contextual learning (Davoli, Brockmole, & Goujon, 2012) further clarified how slower RT may arise near the hands (see Brockmole et al., *in press*, for a review), because often times more resources are unnecessarily and unintentionally devoted to detailed information such as nonsensible sentence/words (semantic judgment) and background colors (contextual cuing).

One important aspect of the nearby-hand phenomenon is the distance between the hands and the stimuli of interest. That is, how close is close enough for the visual system to exhibit the nearby-hand effect? To begin, the simplest condition would be zero distance. This was demonstrated by Brown, Morrissey, and Goodale (2009), who showed that pointing movements made to visual targets projected onto the palm of the hand are more precise and accurate. Other paradigms that progressively manipulated either the locations of the stimuli on the screen while keeping the hands still (Reed et al., 2010), or vice versa (Tseng & Bridgeman, 2011), all

* Corresponding authors. Address: National Central University, No. 300, Jhonda Rd., Jhongli City, Taoyuan County, Taiwan, ROC.

E-mail addresses: tsengphilip@gmail.com (P. Tseng), chijuan@cc.ncu.edu.tw (C.-H. Juan).

report a graded function of the nearby-hand effect. Therefore, as the hands are placed further and further away from the stimuli, the nearby-hand effect also decreases as a function of such distance. Interestingly, some studies report that such nearby-hand effect can be lateralized towards either the left or the right hand. For example, in an orienting task, Reed et al. (2006, 2010; see also Simon-Dack et al., 2009) found stronger hand effect for targets appearing near the left hand. In other identification paradigms, the effect seems to be stronger near the right hand in right-handed individuals (Lloyd, Azanon, & Poliakoff, 2010; Tseng & Bridgeman, 2011). Therefore, there seems to be a qualitative difference between the left and the right hand (Le Bigot & Grosjean, 2012). This lateralization may have been induced by different experimental paradigms, task demands, or even the participant's own preferences, all of which remains to be investigated.

2. The functional aspect of hands and tools

As previously mentioned, even between the left and right hand there exists a sizable differentiation. This can possibly be explained with a functional account. To emphasize this functional aspect, the Brown, Morrissey, and Goodale (2009) study found that faster target detection was observed only when stimuli were projected onto the palm, but not the back of the hand. Similarly, Davoli and Brockmole (2012) also elegantly showed that hands, with palms facing inward, can “shield” attention from distractors outside the palm areas. These may be due to the fact that the back of the hand is less functional, and thus less represented in the cortex. It is worth noting that the same logic also applies to tools, which have been shown to induce the same nearby-hand effect under certain conditions. For example, using a Posner orienting task, Reed et al. (2010) found that when a rake is pointed inward, participants' RT become faster, presumably because the rake is useful only when it is pointing towards the attended space. This tool-use effect, however, is not always automatic, as an increasing number of studies are suggesting that only familiar tools can induce the nearby-hand facilitation. For one, participants who received training with a rake also showed faster detection RT when stimuli were projected on the rake, but only when the stimuli were projected on the upper side of the rake that they had been trained to use (Kao & Goodale, 2009). In addition, trainings that did not allow the participants to master the tool also do not work (Brown, Doole, & Malfait, 2011; Gozli & Brown, 2011). Thus, having the ability to handle a tool is not enough to induce the nearby-hand effect, but expertise or at least some working knowledge in controlling the tools is required for the visual system to treat them as if they were extensions of one's own hands. These results coincide well with a series of studies by Proffitt and Witt (see Witt, 2011, and Brockmole et al., in press; for two excellent reviews), who show that tool-use can alter depth and distance perception at early perceptual stages, which is approximately where the nearby-hand effect takes place, as evidenced by the effect of nearby-hands on figure-ground segregation (Cosman & Vecera, 2010).

Taking all of the aforementioned studies together reveals several specific characteristics of the nearby-hand effect: (1) the effect enhances attentional engagement and slows down disengagement, (2) the effect is graded as a function of the distance between the hand(s) and the stimuli, (3) if a tool is used, the tool must be familiar to the user, and (4) the hands and tools need to be oriented in a way that is functionally relevant to the position of the stimuli, or the attended space.

3. A possible neural mechanism

The four characteristics of the nearby-hand effect provide helpful clues to its underlying neural mechanisms. The bimodal visuo-

tactile neurons located in the parietal cortex and premotor cortex have been suspected as the neural underpinnings of the effect due to their roles in body ownership (Ehrsson, 2011), and, most important, their hand-centered receptive fields that move along with the hand (Reed, Grubb, & Steele, 2006). This speculation is supported by a recent neuroimaging study, where parietal and premotor cortex show selective BOLD response to stimuli within 100 cm of the hand, but not beyond (Brozzoli et al., 2011). This specific characteristic is consistent with the graded nature of the nearby-hand effect, and also explains why although familiar tools may be used to augment the peripersonal space, laser pointer beams that reach as far as 300 cm cannot (Longo & Lourenco, 2006; Tseng, Tuennemann, et al., 2010), presumably because a reasonable maximum distance between the hand/tool and the stimulus is necessary to activate the neural mechanisms behind such nearby-hand enhancement, which is consistent with the graded effect noted above. Note that a subtle difference between the two brain areas lies in the fact that neurons in the premotor cortex show greater response to hand movements, whereas the parietal cortex shows higher selectivity to the static position of the hand in visual space (e.g., Graziano & Botvinick, 2002). Since we now know that the nearby-hand effect can also be induced with moving hands (as recently demonstrated by Adam et al. (2012)), it is reasonable to assume a joint effort between both the parietal and the premotor cortex.

Among the brain regions that are involved in the nearby-hand effect, here we argue for a central role for the parietal cortex in mediating the effect due to its overlapping involvement in *spatial attention, tool-use, multisensory integration, and action*. As previously mentioned, the parietal cortex maintains a real-time representation of the position of the hand with visual and proprioceptive signals (Bolognini & Maravita, 2007). It also projects to many other brain regions, including the premotor cortex and the motor cortex, for planning of possible actions (Graziano & Botvinick, 2002). Therefore, processes of the nearby-hand effect should occur earlier in the parietal lobe before going the premotor cortex for potential motor commands. In terms of spatial attention, the parietal cortex's role has been quite well-documented (Rushworth & Taylor, 2006), and excitatory brain stimulation over this area can actually improve spatial attention and visual memory (Heimrath et al., 2012; Tseng et al., 2012; Tseng, Hsu, et al., 2010). Therefore, it is compatible with the effect of hands on attentional engagement and disengagement, as raised in point 1 above. Notably, the parietal cortex seems to be active for visuospatial attention only in near space (<50 cm), as TMS over the right parietal cortex exacerbates spatial pseudo-neglect, the natural tendency of healthy individuals to perceive the left side of an evenly-bisected line as slightly longer than the right (Bjoertomt, Cowey, & Walsh, 2002). Likewise, TMS over the parietal cortex also disrupts visuospatial search only within the peripersonal space (Lane et al., 2011). In terms of tool-use, neurons in the parietal cortex responds to objects within the peripersonal space, but such space is not limited by one's hand length as it can be rapidly augmented via tools (Brown, Doole, & Malfait, 2011). Indeed, monkey studies have shown that intraparietal visuotactile neurons do respond to tool-use, but only if the monkey becomes skillful in wielding the tool (Iriki, Tanaka, & Iwamura, 1996; for a review, see Maravita, Spence, & Driver, 2003). As such, these findings from the parietal cortex are supportive of points 3 and 4 above in the previous section, and interestingly, they seem to be quite consistent with the functional account (i.e., direction of the rake) that is proposed by Reed et al. (2010). In terms of multi-sensory integration, the parietal cortex has been demonstrated to perform multi-modal alignment between the sensorimotor and visual (Serenio & Huang, 2006) or proprioceptive (Azanon et al., 2010) maps. For example, using synchronized visual and tactile strokes to elicit the feeling of

owning a fake arm (i.e., the rubber hand illusion) can be traced to activities in the parietal cortex (Graziano, Cooke, & Taylor, 2000), and this illusion can be attenuated in strength via TMS over the same area (Kammers et al., 2009). This is because parietal neurons exhibit increased N1 (Kennett et al., 2001; Simon-Dack et al., 2009) and P300 (Longo, Musil, & Haggard, 2012) amplitudes when visual and tactile events coincide with each other, even if the two events are done mischievously to create false visuo-tactile integration. Lastly, the parietal cortex is closely associated with action, in an attentional sense. It has been shown to encode behaviorally relevant features (e.g., color) when they are relevant to the intended actions (e.g., Freedman & Assad, 2011; Toth & Assad, 2002), which is also consistent with the behavioral findings as described in point 4 above. In addition, beyond a static coding for actions or action-related features, activities in the parietal cortex represent these actions differently depending on the context or intention of the actor (Fogassi et al., 2005). This may shed light on the aforementioned context-dependent nature of the nearby-hand effect, though further investigation is clearly needed.

It is important to note, though, that the parietal cortex should not be taken as the only neural locus of the nearby-hand effect. This is because many studies have already found a strong hand-eye coupling in monkeys and humans (e.g., Fisk & Goodale, 1985; Neggers & Bekkering, 2000, 2001; Bekkering & Neggers, 2002; for a review, see Carey, 2000), suggesting that visual information is shared early between the eyes and the hands. For example, Neggers and Bekkering (2000) used a double-step saccade-pointing paradigm and demonstrated that a second saccade cannot be initiated until the current ongoing hand movement is completed, presumably to keep active fixation at the pointing target. This early sharing of information is likely to have taken place at the superior colliculus level in a feed-forward projection, with other areas such as frontal eye fields and parietal cortex coming into play in a later timeframe (Kalla et al., 2008). Interestingly, a patient study by Carey, Coleman, and Della Sala (1997) reported that Ms. D, a patient with bilateral parietal degeneration, could not decouple her hand movements from the eyes such that her hands could not reach anywhere else besides her foveated region. This interesting case suggests that the parietal cortex, too, plays a critical role in mediating the hand-eye coupling, and again reaffirms the notion of a common mechanism or network behind saccade/motor planning, spatial attention, and body image.

Together, neurophysiological evidence suggests active involvements from the superior colliculus, the parietal cortex, and the premotor cortex as a possible network of neural mechanisms underlying the nearby-hand effect. Here we have also emphasized the critical involvement of the parietal cortex due to its multiple roles in spatial attention, body/tool schema, multisensory integration, and behaviorally-relevant perceptual decisions. It is likely that these multifaceted functions of the parietal cortex across many domains (see Graziano & Cooke, 2006, for a helpful discussion on this idea) may be originating from one domain-general cognitive function, which consequently gives rise to the nearby-hand effect.

4. Conclusion

The present review focused on some of the recent findings from the nearby-hand literature. Much progress has been made, but more outstanding questions remain unresolved. For example, can nearby-hands facilitate cross-modal attention? Also, it would be interesting to know whether illusory limbs (e.g., rubber hand illusion) that are temporarily incorporated into one's body image can also enhance one's visual attention. Lastly, are there any individual differences in this effect, and what about the left handers? Addressing these questions would further our understanding of

this interesting phenomenon, as well as the link between body image, peripersonal space, and visual cognition.

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