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BRIEF REPORT

Enhanced cognitive control near the hands

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Abstract Recent research has shown that objects near the hands receive preferential visual processing. However, it is not known whether proximity to the hands can affect executive functions. Here we show, using two popular paradigms, that people exhibit enhanced cognitive control for stimuli that are near their hands: We observed reduced interference from incongruent flankers in a visual attention task, and reduced costs when switching to an alternative task in a task-switching paradigm. The results reveal a remarkable influence of posture on cognitive function and have implications for assessing the potential benefits of working on handheld devices.

Keywords Hand posture · Cognitive control · Embodied cognition · Visual attention · Task switching

When people hold their hands near visible objects, the objects receive preferential processing that can lead to biased spatial selection (Reed, Grubb, & Steele, 2006), delayed disengagement of visual attention (Abrams, Davoli, Du, Knapp, & Paull, 2008), increased visual working memory capacity (Tseng & Bridgeman, 2011), and a preference for focusing on item-specific details (Davoli et al., 2012a, b). The effects are thought to reflect the fact that objects near the hands are important—they could be candidates for action, or perhaps obstacles to be avoided—and thus should be evaluated thoroughly (see Brockmole, Davoli, Abrams, & Witt, 2013, for a review). Little is known, however, about the mental mechanisms that might underlie the changes in perception near the hands. Here we explore the possibility that cognitive control (executive) mechanisms are engaged more fully when evaluating stimuli near the hands.

Cognitive control is believed to be mediated by a distributed network of brain mechanisms that exert control by modulating brain areas responsible for the evaluation of stimuli and the control of action (e.g., Banich, 2009). Enhanced cognitive control would permit the allocation of limited resources and the acquisition of appropriate task-relevant information for interacting with objects near the hands. Such an enhancement could be critically important, because objects near the body are often hazards that must be dealt with efficiently (Graziano & Cooke, 2006).

A recent study by Davoli, Du, Montana, Garverick, & Abrams (2010) may provide some insight into the question. The participants in that study performed a Stroop task with the stimuli either near to or far from the hands. The Stroop task is commonly used as a measure of cognitive control (e.g., Jostmann & Koole, 2007; Koch, Holland, Hengstler, & van Knipperberg, 2009). Davoli et al. (2010) found reduced interference in the Stroop task when participants held their hands near the stimuli, consistent with a greater magnitude of cognitive control near the hands. However, in part due to results from another experiment in their study illustrating that semantic processing may be poorer near the hands, Davoli et al. (2010) interpreted the finding as reflecting impaired semantic processing near the hands—not enhanced cognitive control. Given that reduced Stroop interference could simply result from impaired semantic processing, it is unclear whether their results are evidence for any changes in cognitive control near the hands.

Our goal in the present study was to clarify whether in fact there are changes in cognitive control for stimuli near the hands. Current accounts of cognitive control postulate multiple facets of executive control, including maintenance of the present task instructions in working memory, shifting between tasks, monitoring stimuli for conflicting information, allocation of attention to relevant stimulus attributes, and inhibition of prepotent or task-irrelevant responses (e.g., Banich, 2009; Cohen, Braver, & O'Reilly, 1996; Miyake et al., 2000). Enhancement of any of these functions when a person is faced with a critical situation involving objects in near-hand space would be helpful.

There is good reason to believe that cognitive control might be enhanced by hand proximity. In particular, several researchers have proposed that proximity to the hands engages mechanisms involved in the selection and control of appropriate goal-directed actions (e.g., Abrams et al., 2008; Gozli,

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West, & Pratt, 2012). According to these ideas, objects near the hands are candidates for action (objects far from the hand cannot be acted upon immediately), and enhanced evaluation of them would be beneficial—either to facilitate interaction (such as with a tool) or to avoid injury (such as with an obstacle). Because cognitive-control mechanisms aid in the selection of appropriate actions and the suppression of inappropriate ones (e.g., Banich, 2009), enhanced cognitive control could facilitate these behaviors.

In the present study, we employed two popular paradigms that have been used to assess control abilities. In one, a variation of the Eriksen flanker task (Eriksen & Eriksen, 1974), participants were required to identify a centrally presented target letter and to ignore peripheral flanking letters that were sometimes mapped onto a different response than the target. Executive control would be necessary either to inhibit processing of the flanking letters or to suppress response competition activated by incompatible flankers (e.g., Gratton, Coles, & Donchin, 1992). In the other, a task-switching paradigm, participants were required to frequently switch between two simple tasks (e.g., Meiran, 1996). On switch trials, executive control is necessary to retrieve new task rules and response codes into working memory and to shift attention to task-relevant aspects of the stimuli, among other things (e.g., Monsell, 2003).

Importantly, neither task that we used required participants to process the meaning of the stimuli. Thus, any effects of hand proximity could not be due to impaired semantic processing, the interpretation that Davoli et al. (2010) had offered for their results. To anticipate the results, we found reduced flanker interference and reduced switch costs when the hands were near the stimuli, indicating increased cognitive control for stimuli near the hands.

Experiment 1

Participants performed a modified version of a flanker task (e.g., Eriksen & Eriksen, 1974) in which they were required to identify a centrally presented target letter and to ignore flanking distractor letters. If cognitive control is improved near the hands, interference from incongruent flankers should be reduced when the hands are near the stimuli.

Method

Participants Ten undergraduates participated for course credit.

Apparatus and procedure The participants viewed the CRT display binocularly from a distance of 35 cm (fixed by a chinrest). In the hands-near blocks, participants placed their hands on 6-cm-diameter buttons attached to the center of each side of a 40-cm-wide monitor; their elbows rested on foam pads. In *hands-far* blocks, participants placed their hands on the same two buttons, now attached 40 cm apart on a board on participants' laps.[1] The sequence of events on each trial is shown in the left panel of Fig. 1. Each trial began with the presentation of a fixation cross (1.6º × 1.6º) for 500 ms, followed by a five-letter string composed of various combinations of the letters H, K, C, and S (subtending approximately 1.6º × 6.5º). Participants were instructed to indicate as quickly as possible (while remaining accurate) the identity of the middle letter in the string. If it was an H or K, they were to press the left response button, and if it was C or S, they should press the right button. The letter string remained visible for 1 s or until the participant responded, and was followed by a 1-s blank intertrial interval. *Congruent* trials consisted of the target letter flanked by the identical letter or by the other letter requiring the same response (e.g., HHHHH or KKHKK); *incongruent* trials consisted of target letters flanked by either of the letters from the other response set (e.g., CCHCC or SSHSS). If participants responded incorrectly or did not respond within 1 s, an error message was shown for 5 s.

Design Participants performed 16 practice trials, followed by four blocks of 48 test trials each, with breaks between blocks. Within each block, each of the four letters appeared as a target equally often, and each letter appeared as a flanker equally often with each target letter, in a random order. Thus one-half of the trials within each block were congruent. At the end of the second test block, the experimenter moved the response buttons in order to accommodate the alternative postural condition. All participants performed two test blocks with the hands near and two with the hands far from the stimuli (the starting hand position was counterbalanced across participants).

Results

Differences in interference across conditions in a flanker task may be manifest as reaction time (RT) differences, accuracy

[1] It is worth noting that one could manipulate the proximity of the hands to stimuli in a number of different ways. For example, participants could leave their arms raised in both the hands-near and hands-far conditions, but separate their hands by spreading their arms in the hands-far condition. Alternatively, participants could maintain a constant separation between their hands, but move them away from the stimuli in either the horizontal or the vertical plane. The last option is the one that we chose, in part because it is the approach that has been used most often. Note that each choice necessarily introduces a factor related to the geometric relations between the stimuli and the hands that is confounded with the manipulation. Further research may be needed to determine the extent to which those factors contribute to the effect.

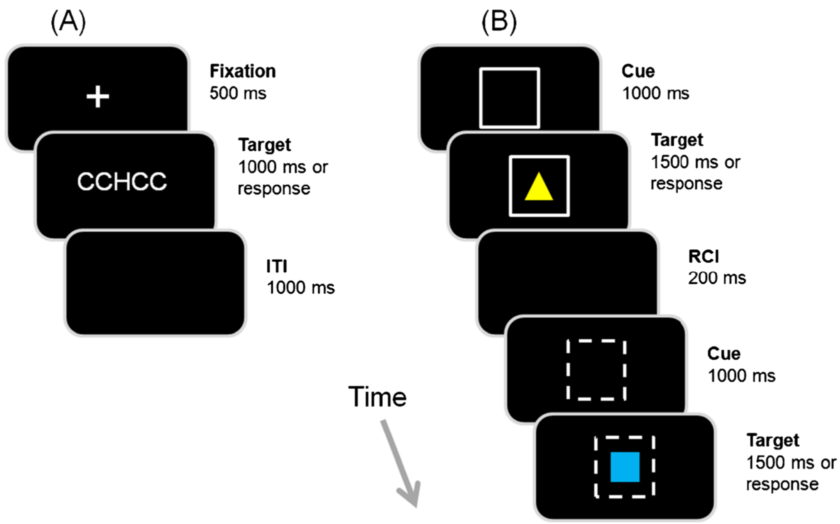

Fig. 1 Sequences of events in the experiments. (A) One trial of the flanker task from Experiment 1. (B) Two trials from the task-switching paradigm used in Experiment 2. See the text for additional explanations. ITI, intertrial interval; RCI, response–cue interval

differences, or both (e.g., Eriksen & Eriksen, 1974). Response accuracy is shown in Fig. 2 as a function of trial type, separately for the two hand positions. As expected, accuracy was greater on congruent trials, indicating processing of the to-be-ignored flankers, $F(1, 9)= 47.22$, $p < .001$, $\eta^2_p = .84$. We found no main effect of hand position, $F(1, 9) = 3.02$, $p = .116$, but importantly, hand position and trial type interacted: Flanker congruency had a much smaller impact when the hands were near the display than when they were far, $F(1, 9) = 7.67$, $p = .022$, $\eta^2_p = .46$. Indeed, when the hands were near the display, the effects of flanker congruency

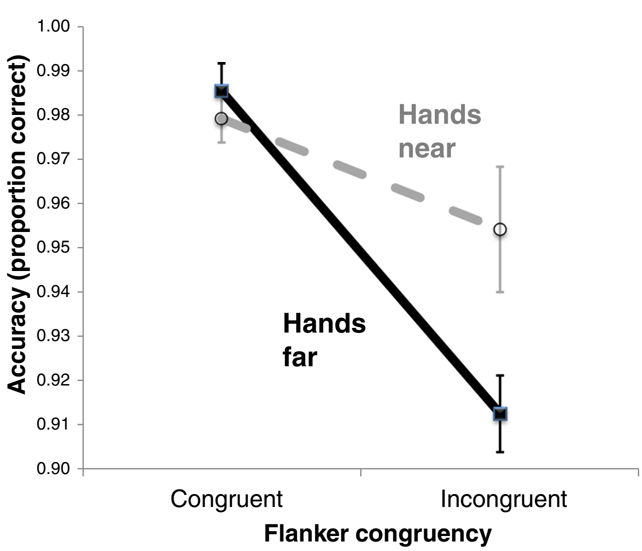

Fig. 2 Accuracy in the flanker task, shown separately for congruent and incongruent flankers and for the two hand postures, from Experiment 1. Participants were less affected by the to-be-ignored flankers when their hands were near the stimuli. Error bars depict standard errors of the means.

were eliminated, $t(9) = 1.69$, $p = .126$, but when the hands were far away, we observed a large effect of congruency, $t(9) = 13.02$, $p < .001$.

Note that this experiment contained two types of congruent trials: One-half of the congruent trials contained a target that was not a physical match of the flankers (e.g., KKHKK), whereas the other congruent trials contained a target that was an exact physical match of the flankers (e.g., KKKKK). Because none of the incongruent trials contained an exact physical match, it is possible that participants used a different strategy to respond on the physical-match trials, inflating accuracy on congruent trials and contaminating the computation of flanker congruency. To examine this possibility, we reanalyzed the data after eliminating the physical-match congruent trials, and we found exactly the same pattern as before: No main effect of position was apparent, $F(1, 9) = 4.19$, $p = .071$; participants were more accurate on congruent (hands near = .996, hands far = .996) than on incongruent (hands near = .954, hands far = .913) trials, $F(1, 9) = 60.00$, $p < .001$, $\eta^2_p = .87$; and, critically, hand position and trial type interacted, $F(1, 9) = 5.81$, $p = .039$, $\eta^2_p = .39$.

RTs were longer on incongruent trials (mean of median RT: hands near = 483 ms, hands far = 480 ms) than on congruent trials (hands near = 438 ms, hands far = 429 ms), $F(1, 9) = 74.06$, $p < .001$, $\eta^2_p = .89$, consistent with the effects of congruency on accuracy. But we found no main effect of hand position, $F(1, 9) = 1.36$, $p = .273$, nor did position and congruency interact, $F < 1$.

Discussion

When participants held their hands near the items being evaluated, they were protected from the decrease in accuracy on incongruent trials that occurred when the hands were far away. Thus, the results show enhanced cognitive control for stimuli near the hands. Our results on the surface appear similar to those reported by Davoli & Brockmole (2012), who also studied a flanker task near the hands. However, in their study, the hands were sometimes interposed between the target and the flankers. They found that interposed hands suppressed processing of the flankers more effectively than did other interposed objects—such as blocks of wood. In contrast, our results show that proximity to the hands permits enhanced cognitive control, even when the to-be-attended targets and to-be-ignored flankers are all between the hands.

Despite our conclusions regarding cognitive control, it is possible that the effect that we observed reflects enhanced visuospatial filtering near the hands, via some unspecified attentional mechanism, and not greater cognitive control per se. One reason to suspect this is that several researchers have reported changes in aspects of visual attention for stimuli near the hands (e.g., Abrams et al., 2008; Cosman & Vecera, 2010; Davoli, Brockmole, Du, & Abrams, 2012a; Reed et al., 2006). In explaining their results, each of these researchers invoked explanations involving attentional mechanisms, yet none appealed to any sort of change in executive control abilities. Importantly, in each of these cases, the changes caused by hand proximity could all be explained by changes in the *spatial* allocation of attention. To rule out the possibility that reduced flanker interference can be attributed to changes specifically in visuospatial attention (as opposed to improved executive control processes), we conducted an additional experiment using a measure of cognitive control that is not influenced by visuospatial filtering.

Experiment 2

Task-switching paradigms are widely used to assess cognitive control (e.g., Monsell, 2003). In a typical experiment, participants are asked to evaluate one of two different attributes of the stimulus on each trial. The relevant attribute switches periodically, and participants usually suffer a performance cost on a trial after a switch (in terms of either increased RTs or increased errors), as compared to a trial on which the relevant attribute is repeated from the subsequent trial. The magnitude of the switch cost reveals the extent to which participants are able to exert executive control. If the reduced flanker interference in Experiment 1 arose because hand proximity improved cognitive control, then switch costs should also be reduced near the hands. In a new experiment, participants switched between two simple tasks (identifying either the color or the shape of a colored object) while their hands were either near to or far from the display.

Method

Participants A group of 30 undergraduates participated for course credit.[2]

Stimuli, apparatus, and procedure The apparatus was identical to that used in the previous experiment, and the two hand postures were also the same. The sequence of events for two trials is shown in the right panel of Fig. 1. Each trial began with a box cue presented for 1,000 ms. The border of the box (solid or dashed) indicated whether the participant should respond by identifying the subsequent target's shape or color (cue assignments were counterbalanced across participants). Next, a colored shape target (a blue square, a yellow square, a blue triangle, or a yellow triangle) appeared for 1,500 ms or until response. Participants identified the cued dimension of the target (color or shape) and responded as quickly as possible by pressing one of two response buttons. Errors or late responses were followed by a 5-s delay; the next cue appeared 200 ms after a response or error message. Cue boxes subtended approximately 25º × 25º, and the targets subtended approximately 12º × 12º.

Design Participants performed 12 untimed and 24 speeded practice trials, followed by eight test blocks, each consisting of an initial buffer trial followed by 48 test trials. Task order varied randomly across trials, with the constraint that equal numbers of switch trials (when the task on the present trial differed from that on the preceding trial) and repeat trials (when the task on the present trial matched that on the preceding trial) must occur in each block. The target on each trial was selected randomly from the four possibilities. Participants had a break at the end of every block. The experimenter moved the response buttons to accommodate the alternate hand position after the fourth block; starting hand position was counterbalanced across participants.

Results

Two participants were replaced: One whose RTs were more than two standard deviations above the mean, and one who did not follow instructions. Error trials and trials following an error were not included in the latency analyses (cf. Altmann, 2007). The means of median RTs are shown in Fig. 3 as a function of trial type, plotted separately for the two postures. As expected, RTs were greater on switch than on repeat trials

[2] We increased the number of participants in this experiment relative to the first in order to match the sample sizes used in comparable prior research on flanker (Eriksen & Eriksen, 1974) and task-switching (Meiran, 1996) paradigms.

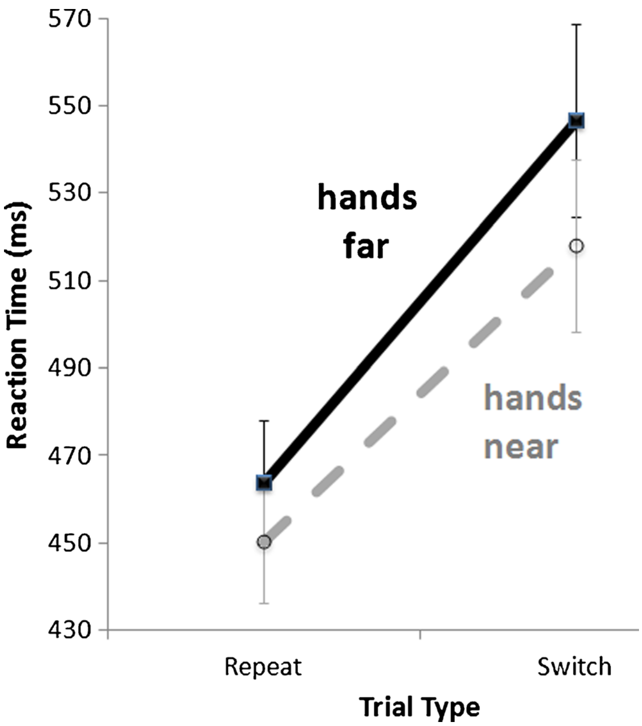

Fig. 3 Reaction times in the task-switching paradigm, as a function of trial type for the two hand postures, from Experiment2. Participants exhibited reduced switch costs (the difference between switch and repeat trials) when their hands were near the stimuli. Error bars depict standard errors of the means.

$F(1, 27) = 64.11$, $p < .001$, $\eta^2_p = .70$, replicating the common switch cost finding (e.g., Monsell, 2003). Overall, participants were slightly faster when their hands were near the stimuli (484 ms) rather than far away (505 ms), $F(1, 27) = 3.69$, $p = .065$. Most importantly, hand posture interacted with trial type: Switch costs were smaller when the hands were near the stimuli (67.7 ms) than when the hands were far away (82.8 ms), $F(1, 27) = 5.13$, $p = .032$, $\eta^2_p = .16$. More specifically, although RTs did not differ for repeat trials across hand postures, $t(27) = 1.32$, $p = .197$, participants responded faster on switch trials when their hands were near the stimuli than when the hands were far away, $t(27) = 2.27$, $p = .031$. Accuracy data revealed greater accuracy only for repeat (near = .956, far = .957) relative to switch (near = .929, far = .928) trials, $F(1, 27) = 30.47$, $p < .001$, $\eta^2_p = .53$; we observed no main effect of hand position, nor did hand position interact with trial type, Fs < 1.[3]

Discussion

The present data indicating reduced switch costs when stimuli are near the hands provide additional evidence that cognitive control is enhanced for stimuli near the hands. More specifically, in this experiment, having the hands near the stimuli reduced the *residual switch cost* (e.g., Rogers & Monsell, 1995), because participants had 1,000 ms of preparation time between the appearance of the cue (which indicated which task would be performed) and that of the target. When more than ~600 ms are provided (e.g., Rogers & Monsell, 1995), participants are able to fully engage in all of the preparation possible prior to target onset. Thus, our switch costs indicate a residual cost—those mental processes that must occur after target onset on switch trials, regardless of the amount of preparation time (e.g., Monsell, 2003). Finally, it is important to note that these reduced switch costs cannot be attributed to enhanced visuospatial attention (as might have been possible in the flanker paradigm used in Exp. 1) because both the relevant and irrelevant attributes of the stimuli were in the same locations. Thus, the results indicate greater cognitive control employed for stimuli near the hands.

General discussion

In two experiments, we have shown that people exhibit greater cognitive control when evaluating objects near their hands. The benefits of this change were reduced interference from to-be-ignored distractors in a flanker task, and reduced RT costs for switching to an alternative instruction in a task-switching paradigm. Presumably, the enhancement occurred because objects near the hands are important—they may be candidates for action, and the consequences of responding to them inappropriately might be great.

The present results clarify and extend findings reported by Davoli et al. (2010). They found reduced interference in a Stroop task when the stimuli were near the hands—consistent with the present findings of enhanced cognitive control for stimuli near the hands. However, reduced Stroop interference is also consistent with an impairment in semantic processing, and given that results from another experiment had indicated that semantic processing was impaired near the hands, the latter interpretation was favored by Davoli et al. (2010). The tasks used in the present experiments, however, did not require semantic processing. Hence, the effects reported here can more unambiguously be attributed to changes in cognitive control. The present results, combined with those from the Davoli et al. (2010) study, suggest that in addition to an impairment in semantic processing, cognitive control is enhanced for stimuli near the hands.

We have ample a priori reason to believe that cognitive control might be enhanced for stimuli near the hands. The executive control system serves to facilitate intended actions, often while overcoming interference from distraction (e.g., vel Grajewska,

[3] We also conducted a pilot experiment with a very similar design. In that experiment, the task cue varied in a predictable AABB sequence, and eight participants served in each hand posture condition. As in Experiment 2, RTs were longer on switch than on repeat trials, $F(1, 14) = 239.75$, $p < .001$, $\eta_p^2 = .95$. In addition, we again found an interaction between position and trial type: Switch costs were reduced when participants had their hands near (81.5 ms) rather than far from (120.8 ms) the stimuli, $F(1, 14) = 8.08$, $p = .013$, $\eta_p^2 = .37$.

Sim, Hoenig, Herrnberger, & Kiefer, 2011). Researchers have postulated that changes in cognition for stimuli near the hands occur because objects within reach are immediate candidates for action (e.g., Abrams et al., 2008; Gozli et al., 2012). Therefore, if the purpose of the executive control system is to facilitate appropriate goal-directed action, and stimuli near the hands are more likely candidates for action, such stimuli would benefit from enhanced executive control. Indeed, when proximity to the hands affords the easy production of an action, it becomes critical to exert control in order to prevent the production of inappropriate actions.

What can be concluded about the nature of the modulation of cognitive control near the hands? Executive control is typically conceived of as involving a distributed network of brain areas that include the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex. Activity in these regions is believed to help maintain the current task instructions, establish an attentional set for preferential processing of relevant stimulus attributes, and monitor behavior for the occurrence of a conflict in the stimuli or an error in the response (Banich, 2009; Banich et al., 2000; Cohen et al., 1996). In addition to this anterior attention network, a network of areas more posterior in the brain is also involved in attentional selection (Posner & Peterson, 1990). Either the anterior or the posterior attention network may play a role in the selection of information appropriate for effective behavior. In some cases, selection takes place early in the processing stream, such as when to-be-ignored information is effectively filtered out and mostly desired information is attended (e.g., deFockert, Rees, Frith, & Lavie, 2001). In the flanker task, for example, that would involve suppressing the intake of information from the flankers. In other cases, selection takes place late in processing—after to-be-ignored information has been processed, but before the (incorrect) response based on that information is emitted (e.g., Coles, Gratton, Bashore, Erikson, & Donchin, 1985). For example, sometimes it is not possible to completely ignore the flankers in a flanker task, and it later becomes necessary to resolve the competition between the multiple potential responses that may have been activated.

How might hand proximity affect some of these mechanisms? On the one hand, there is some reason to believe that hand proximity might be involved in early selection, such as that which is thought to be guided by activity in the anterior attention network. In particular, the DLPFC mechanism has often been identified as being involved in maintaining task instructions (Cohen et al., 1996), and indeed, this mechanism is thought to establish the top-down set for the correct task. More consistent maintenance of the task instructions would thus be expected to lead to better performance, and this might be one way in which hand nearness exerts its effect. Also, this top-down control has been shown to rely heavily on sufficient working memory capacity, with greater capacity leading to greater early filtering of distractors (deFockert et al., 2001; Lavie & deFockert, 2006). Thus, results showing enhancement of certain types of memory near the hands (e.g., Davoli et al., 2012a, b; Tseng & Bridgeman, 2011) are consistent with a role of hand proximity in establishing and maintaining the task set.

However, some researchers have suggested that hand proximity affects behavior through the activity of bimodal visual–tactile neurons with hand-centered visual receptive fields (e.g., Adam, Bovend'Eerdt, van Dooren, Fischer, & Pratt, 2012). If that is correct, it is unclear how much of the effect should be attributed to top-down influences. Instead, proximity to the hands may affect cognitive control via more posterior attentional mechanisms, and possibly via selection that is later in the processing stream. In particular, hand nearness has been shown to bias processing in favor of the magnocellular visual pathway (Abrams & Weidler, 2013; Gozli et al., 2012). One explanation of this bias is that magnocellular mechanisms are more heavily involved in the guidance of limb movements, and hence biased processing along this action-oriented pathway would be beneficial when candidate objects are available for action near the hands (Gozli et al., 2012). Because the magnocellular pathway projects strongly to the parietal cortex (Livingstone & Hubel, 1987; Maunsell, Nealey, & DePriest, 1990), it would be well suited to influencing posterior attentional mechanisms. Consistent with this possibility are data from Omtzigt, Hendriks, & Kolk (2002) indicating that the magnocellular pathway plays a key role in the allocation of attention in tasks with distracting peripheral flankers.

We may also gain some insight into the way in which hand proximity affects cognitive control by considering the fact that the switch costs that we measured in Experiment2 were specifically *residual* costs. That is, they reflect the cost of switching tasks even when the participant is given a relatively long time to prepare for the trial, after having received the cue. According to Meiran's (2000; see also Meiran et al., 2008) model of task switching, the residual costs reflect the time needed to activate the appropriate stimulus–response (S–R) translation rule for the task (e.g., press the left key if the stimulus is blue, the right key if it is yellow), but they do not include the time that would be needed to reconfigure attentional selection mechanisms to direct attention to the (new) relevant stimulus attribute (i.e., color instead of shape). If these ideas are correct, our results suggest that hand proximity affects the activation of the correct S–R translation rule. Other models of task switching attribute residual costs to different processes. For example, De Jong (2000; Lindsen & de Jong, 2010) has suggested that residual costs arise from a subset of switch trials during which no advance preparation has taken place (and, hence, RTs are unusually long), mixed with a subset during which the participant was able to completely prepare for the new task prior to stimulus presentation. If this view is correct, our results suggest that proximity to the hands may reduce the proportion of unprepared trials. However, because we did not also study brief cue–target intervals, it is not possible for us to investigate these claims with the present data. Finally, some explanations of residual costs attribute them to interference of one sort or another (see Kiesel et al., 2010, for a review). If that is the case, our results suggest that hand proximity may reduce such interference. Clearly, further research will be needed before it will be possible to precisely pinpoint the manner in which hand proximity affects task switching.

Our conclusions regarding the effects of hand proximity on cognitive control require executive mechanisms to be reasonably flexible in order to adapt to changes in the presence of objects near the hands. Consistent with that possibility, considerable evidence has suggested flexibility in cognitive-control mechanisms. For example, the presence of a response-incongruent distractor on one trial will lead to greater suppression of distractors on the next trial (Gratton et al., 1992). Likewise, when a high number of incompatible trials are expected, people exert greater cognitive control, as evidenced by a reduced RT cost on those incompatible trials (e.g., Gratton et al., 1992) and by changes in brain activity indicative of greater executive control (Carter et al., 2000). Most importantly, research has shown that the magnitude of cognitive control exerted can be location-specific. That is, when participants expect a high level of conflict from stimuli in one location and a low level from stimuli in a second location, they are able to flexibly allocate executive control to varying degrees in the two locations simultaneously (Corballis & Gratton, 2003; vel Grajewska et al., 2011). Such location-specific allocation of cognitive control is similar to what we have reported in the present article: In our case, the location that receives the greater degree of control is the space near the hands.

Combined with earlier results (Davoli et al., 2010), evidence has indicated that hand proximity improves performance in the Stroop task, the flanker task, and a task-switching paradigm. In addition, although a range of executive abilities have been suggested to play roles in cognitive control, these three tasks may have a common basis. In particular, Friedman & Miyake (2004) had participants complete a battery of tasks including flanker, Stroop, and task switching. Flanker- and Stroop-based forms of interference were both strongly related to a single factor, which in turn predicted the magnitude of residual switch costs. Given the common mechanisms underlying these three tasks, it is not surprising that a single manipulation of hand proximity would affect each of them.

In addition, our findings that proximity to the hands more fully engages executive control mechanisms may help explain some previously reported changes for stimuli near the hands. For example, Abrams et al. (2008) reported a larger attentional blink for stimuli near the hands. Taatgen, Juvina, Schipper, Borst, & Martens (2009) have shown that increased cognitive control can produce a greater attentional blink, so it is possible that the influence of hand proximity is due to increased cognitive control. Also, Tseng & Bridgeman (2011) reported enhanced visual short-term memory near the hands (in a change detection task). Such an effect fits with the present findings if an executive control mechanism plays a role in maintaining or retrieving information from working memory, as has been proposed in some models (e.g., Baddeley, 1986). Indeed, working memory is often considered to be a key component of cognitive control (e.g., Lavie, Hirst, de Fockert, & Viding, 2004), and enhanced working memory would be expected to facilitate such control. Finally, several researchers have suggested an important role for cognitive control in the guidance of visual attention (e.g., Huettig, Olivers, & Hartsuiker, 2011; Lavie & deFockert, 2006), consistent with findings that have shown effects of hand proximity during visual search and cuing (Abrams et al., 2008; Davoli & Abrams, 2009; Reed et al., 2006).

Finally, our results may have important implications for behaviors that are becoming increasingly common in modern life: People are performing more and more tasks on handheld devices that present high quantities of rapidly changing visual information. The requirement that the hands be nearby such devices may enhance a person's ability to focus on task-appropriate information and may allow for completing tasks more efficiently—perhaps accounting in part for the tremendous popularity of handheld devices. Nevertheless, some evidence has also suggested reduced semantic processing near the hands (Davoli et al., 2010), so the benefit may depend on the nature of the material being manipulated. Eventually, obtaining a more detailed understanding of the specific changes near the hands may permit the development of handheld devices that maximize their advantages.

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