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Commentary

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Dynamic Manipulation Generates Touch Information That Can Modify Vision

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This report constitutes a critical expansion of a recent study on tool use (Carlson, Alvarez, Wu, & Verstraten, 2010), published in this journal. Carlson et al. explored the classic question of how, during manipulation, an external object may seem to become an extension of one's body. They demonstrated that objects manipulated with the hand can become one with the body, but objects manipulated with a tool cannot. They interpreted this as evidence that such integration is limited to first-order extensions.

However, close inspection of the experimental conditions reveals that Carlson et al. overlooked how dynamic manipulation of an object affects the prehensile system. They used just one tool: a pair of grippers fixed to, and supported by, a table. In this arrangement, the table absorbs most of the forces associated with object manipulation. By contrast, when a freely maneuverable handheld tool is used, the forces are transmitted through the tool and interact with the arm and body, much as they do during direct manual manipulation.

The notion that, without vision, object properties such as the length of a handheld rod can be perceived during dynamic manipulation has been well established. This system of touch perception is known as *dynamic touch*—perception based on information from effort-related muscle and tendon deformations (Carello & Turvey, 2000; Gibson, 1966; Turvey, 1996; Turvey & Carello, 2011). However, little is known about the perception of a target object when it is manipulated with a handheld tool. We concluded that the approach used by Carlson et al. would be a useful way to test such perception empirically, and we extended their conditions to include one with a freely maneuverable tool. Moreover, we predicted that the target object would be perceived with and without a tool, but only when the prehensile limb was maneuvering freely.

The Present Study

As did Carlson et al., we elicited positive afterimages in dark-adapted participants by exposing them to a bright flash of light. Such afterimages persist for about 12 s, but the afterimage of a body part or target object fades quickly when observers move it away from its position in the afterimage (Carlson et al., 2010; Davies, 1973; Gregory, Wallace, & Campbell, 1959; Hogendoorn, Kammers, Carlson, & Verstraten, 2009). Fading is a result of the discrepancy between vision and touch in perceiving the position of the limb or the target object.

We had participants form positive afterimages of their hand while they held a ball either with a bare hand or with a tool; they then released the ball. If target objects can indeed be perceived through dynamic touch, participants should have experienced rapid fading of the ball in the afterimage whether they used a bare hand or a handheld tool to release it. Further, fading in these two conditions should have been equivalent. However, this dynamic-touch account would not predict rapid fading if the ball were dropped from a table-supported tool, because the ball's release in this condition would not affect the dynamics of the prehensile limb.

In our experiment, participants held a ball on each side of the body. In the bare-hand condition, they held the balls in their hands; in the handheld-gripper condition, they held the balls with a pair of handheld grippers; and in the table-supported-gripper condition, they held the balls with a pair of table-supported grippers. On each trial, when an afterimage of their hands was sustained, observers dropped the ball on one side of their body (using their *release hand*) and continued holding the ball on the other side (using their *clutch hand*). Shortly after the release, observers reported the quality of each ball in the afterimage, using a 3-point scale (+1 = *increased quality*, 0 = *no change*, and −1 = *decreased quality*). The

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proportion of "fade" responses (ratings of decreased quality) was calculated for each condition for each observer.[1]

Results

We collected data from 21 observers (10 females, 11 males), who provided informed consent and who had either normal or corrected vision. Each of them completed four trials per condition. Figure 1 summarizes the mean proportion of ball-fading responses for the release hand and the clutch hand in each of the three conditions. The afterimages of the ball faded more often in the release hand than in the clutch hand, $F(1, 20) = 119.6$, $p < .000001$, and fading occurred more often in the bare-hand and handheld-gripper conditions than in the table-supported-gripper condition, $F(2, 20) = 18.8$, $p < .000001$.

These data show that fading was elicited during ball release, but only when the prehensile limb was maneuvering freely. This notion was confirmed by a significant interaction effect between hand and condition, $F(2, 40) = 29.6$, $p < .000001$. The afterimage of the ball held in the release hand faded more frequently when the ball was dropped from a bare hand or from the handheld gripper than when it was dropped from the table-supported gripper, $F(2, 40) = 34.9$, $p < .000001$, whereas there was no difference in fading across conditions for the ball that remained in the clutch hand, $F(2, 40) = 1.1$, $p = .34$. Critically, the fading of the ball held in the release hand did not differ between the bare-hand and the handheld-gripper conditions, $t(21) = 0.4$, $p = .68$.

Our findings provide clear evidence that equivalent information about the position of an object is obtained whether one manipulates the object directly or with a freely maneuverable tool, but that the same information is not obtained when one uses a tool that is supported externally by a table. Further, directly touching the target object with the hand (rather than with a tool) does not aid in obtaining such information, despite the differences in cutaneous and haptic touch perception. These findings cannot be attributed to the observers' understanding of the causal relationship between the hand movement and ball release, because then fading should have occurred in all three conditions. Rather, our findings reveal that touch information is obtained when the forces from object manipulation interact with the dynamics of the prehensile limb.

Conclusions

Consequently, we can revise the interpretation suggested by Carlson et al.: During dynamic manipulation, a target object no longer exists independently from the prehensile system, so the brain cannot take on the role of integrating the object into a representation of the body. Instead, the brain's activity is most likely related to its control of the dynamic manipulation of the target object. This involves perception and action, and we have shown that the relevant information is obtained through dynamic touch.

In our experiment, object perception obtained through dynamic touch modified vision, producing rapid fading of

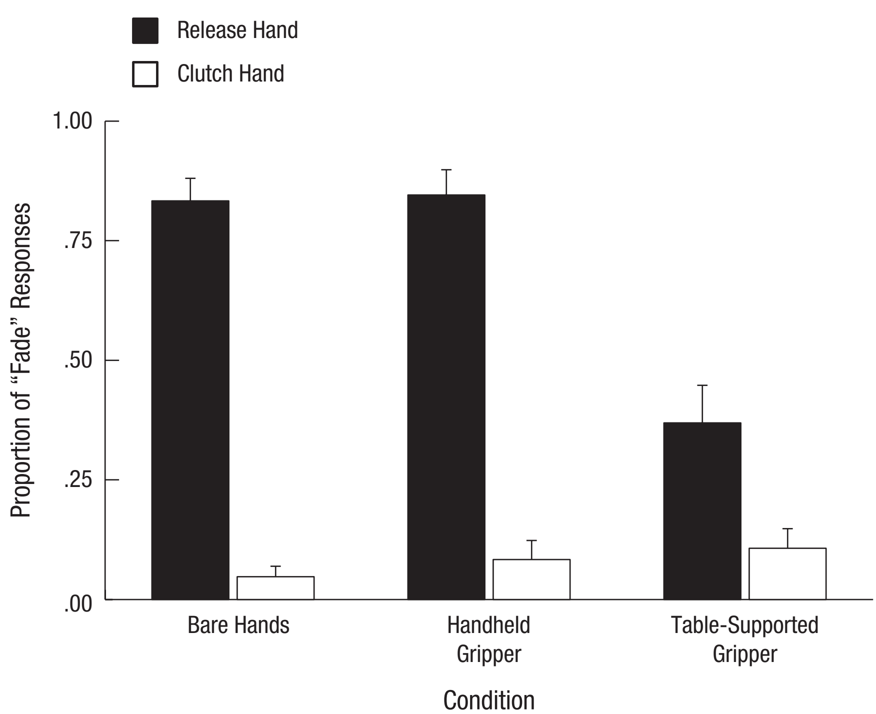

Fig. 1. Proportion of responses indicating fading of the ball in the release and clutch hands as a function of condition. Each bar represents the averaged results for 21 naive observers. Error bars represent 1 *SD*.

positive afterimages of the target object. Dynamic touch may drive neural plasticity during tool use: Iriki, Tanaka, and Iwamura (1996) found that neurons in primates' intraparietal cortex expanded their receptive fields to include a rake that the primates had used to reach for food.

Finally, we do not claim that feeling a target object with a tool is identical to feeling it with the hand, and we recognize that holding a tool constrains severely the hand's capacity for cutaneous and haptic touch. However, we argue that holding a tool does not constrain the prehensile system's capacity for dynamic touch.

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Declaration of Conflicting Interests

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

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Note

1. For more detailed information on the experimental method, see Carlson et al., 2010. We replicated their methods and verified some critical details through personal communication.

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