Research Report

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insensitive to the robust perceptual illusion that a target disk surrounded by smaller circles is larger than the same disk surrounded by larger circles (Ebbinghaus Illusion)—despite the fact that grip opening is exquisitely sensitive to real changes in the size of the target disk. Peak grasping aperture is refractory to this size contrast illusion even when the hand and target are occluded during the action (Haffenden and Goodale, 1998), indicating that on-line visual feedback during grasping is not required to 'correct' an initial perceptual bias induced by the illusion.

A number of recent findings, however, have challenged the notion that perceptual illusions do not affect the control of object-directed actions. These challenges fall into several categories including: non-replication (Franz et al., 2003), the contention that early studies did not adequately match action and perception tasks for various input, attention, and output demands (Bruno, 2001; Smeets and Brenner, 2001; Vishton, 1999), or the idea that action tasks involve multiple stages of processing from purely perceptual to more 'automatic' visuomotor control (Glover, 2004; Glover and Dixon, 2001). Some of the competing accounts (Glover, 2004; Smeets and Brenner, 2001) are difficult to separate from the original two-streams proposal. In addition, some of the contradictory findings (Glover and Dixon, 2001) can be explained by appealing to the fact that illusions can arise at different stages in visual processing (Dyde and Milner, 2002). According to this argument, illusions that arise in early visual areas, such as primary visual cortex, will have an effect on action, whereas illusions that arise at higher stages of visual processing in the ventral stream will not. Nevertheless, becauseillorely iave

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In the first part of the experiment, there were 96 trials, 48 towards the illusory and 48 towards the normal face, 24 towards the cheek, and 24 towards the forehead. That is, there were 8 trials at each of the three distances for each target position. Participants were given 6 practice trials before beginning the experiment, 3 with the hollow (illusory) face and 3 with the normal face.

Deliberate pointing: Participants were instructed to point directly to the location where they perceived the target. On other trials, they were instructed to point the same corresponding distance below the face (to avoid the possibility of tactile feedback, particularly in the case of the normal face). These slow pointing movements were also recorded with the OPTO *RAK*. In the first part of the experiment, there were 96 trials, 48 towards the display, and 48 below the display. The

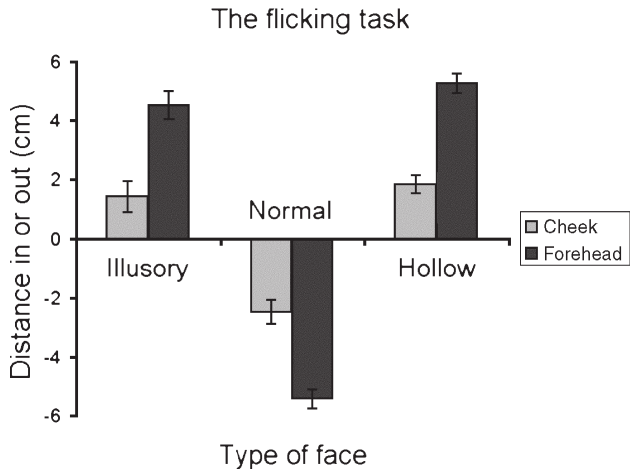

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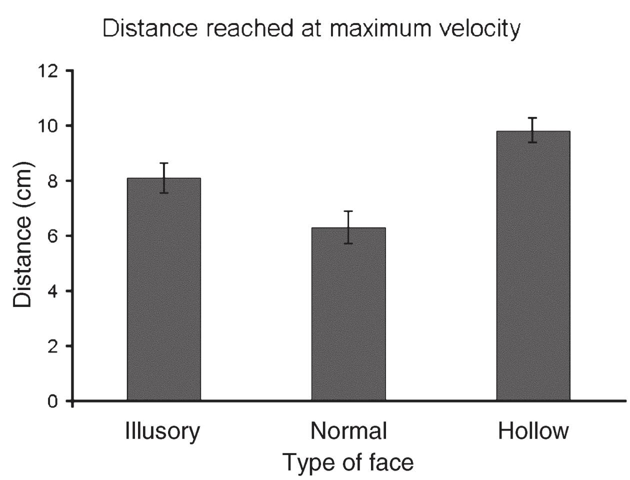
Fig. 4 shows that, early in the flicking movement, at the point of maximum velocity, the horizontal (axis) distance covered on the way to the target was greater for both the hollow face looking hollow and the hollow-face illusion than it was for the normal face ($F(2,14) = 37.7$, $P < 0.001$ and Fisher–Hayter, $P < 0.01$).

It should be noted, however, that the distance reached on trials with the hollow face looking hollow was slightly greater than it was for the illusory face (Fisher–Hayter, $P < 0.05$), which again probably reflects the absence of the de-focusing lens and the brighter viewing conditions that were required to make the hollow face appear hollow (Jiang et al., 1991). But even in this condition, participants failed to hit the target on approximately 30% of the trials.

Fig. 5, which shows the paths of the flicking movements (seen from the side), also makes the point that participants were programming their responses differently for the normal and illusorily depth-reversed faces. Note that the trajectories for these two conditions separated right from the start of the movements. Indeed, the average trajectory for movements made to the illusory face was much more similar to the average trajectory for the hollow face looking hollow than it was to the average trajectory for the normal face.



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3.3. Slow pointing

There were clear differences in the movement onset times for pointing with the three different displays ($F(2,14) = 7.4$, $P < 0.001$). The mean onset time for pointing movements to the illusory (hollow) face (737 ms, SE =63 ms) was significantly longer (Fisher–Hayter, $P < 0.05$) than the mean onset time for movements to the normal face (692 ms, SE = 53 ms), and both were significantly longer (Fisher–Hayter, $P < 0.01$) than the onset time for pointing movements to the hollow face looking hollow (612 ms, SE = 44 ms). Movement times did not differ across the three conditions. The average duration of the pointing movements (1660 ms, SE = 155 ms), however, was more than three times longer than the average duration of the flicking movements (471 ms; SE = 30 ms).

As Fig. 6 shows, the final positions of the pointing movements made to the illusory (hollow) face, like those made to the normal face, were in front of the reference plate. In contrast, the final positions of the pointing movements made to the hollow face looking hollow were located beyond the reference plate ($F(2,14) = 203$, $P < 0.0001$). The final positions of the pointing movements made to the illusory face were somewhat closer to the reference plate as compared to the final positions of movements made to the normal face (Fisher–Hayter, $P < 0.01$) and also did not reflect the perceived relative

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positions of the forehead and cheek targets. Nevertheless, as
Fig. 7

evidence from a study in progress (Króliczak, Heard, Goodale, and Gregory, in prep.) that, when participants view the displays monocularly, the end points of their flicking movements fall considerably short of the real position of the target on trials with the illusory face, although the participants knew that they were looking at an illusion. All of these suggest that the participants in the present experiment were using veridical cues to drive their accurate flicking movements. One cue that was certainly available is vergence, which has been shown to be the major source of information for reaching (Mon-Williams and Dijkerman, 1999). Moreover, there is evidence that transient shifts in vergence are mediated by a system that employs a single low-pass sensitive channel (Edwards et al., 1998), a system that would continue to operate when a de-focusing lens was placed over one eye.

The pronounced dissociation we found between perceptual report and rapid target-directed movements conflicts with the conclusion from an earlier study (Hartung et al., 2005), which used pointing as a visuomotor response. Given that pointing movements were directed to the perceived, not the real position of features on an illusory face, these authors concluded that the cues used by perceptual and visuomotor systems must be similar. We also found that, when participants pointed to the targets on the illusory face, they tended to point to the perceived, not the real position of those targets. But this is perhaps not surprising since, as we suggested earlier, there is evidence that pointing can often be influenced by cognitive factors (Bridgeman et al., 1997). This suggests that pointing and other more deliberate and slow movements do not have to engage the ‘automatic’ visuomotor mechanisms in the dorsal stream but instead can be mediated by ‘perceptual’ processing in the ventral stream (Rossetti et al., 2005). Indeed, although the movement times are not reported in the earlier study, the lack of difference between pointing and psychophysical measures (Hartung et al., 2005) may mean that their participants also adopted slow hand movements when pointing to the hollow-face illusion.

To conclude: the strong stable cognitive illusion of reversed depth did not substantially disturb rapid “flicking” behavior, which is a fast and simple goal-directed motor task. This demonstrates that visual information for perception and action can, under certain conditions, be dissociated. The visuomotor system can use bottom–up sensory inputs (e.g., vergence) to guide behavior to veridical locations of targets in