The dissociation between perception and action in the Ebbinghaus illusion: Nonillusory effects of pictorial cues on grasp

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According to a recently proposed distinction [1] between vision for perception and vision for action, visually guided movements should be largely immune to the perceptually compelling changes in size produced by pictorial illusions. Tests of this prediction that use the Ebbinghaus illusion have revealed only small effects of the illusion on grasp scaling as compared to its effect on perception [2–4]. Nevertheless, some have argued that the small effect on grasp implies that there is a single representation of size for both perception and action [5]. Recent findings, however, suggest that the 2-D pictorial elements, such as those comprising illusory backgrounds, can sometimes be treated as obstacles and thereby influence the programming of grasp [6]. The arrangement of the 2-D elements commonly used in previous studies examining the Ebbinghaus illusion could therefore give rise to an effect on grasp scaling that is independent of its effect on perceptual judgements, even though the two effects are in the same direction. We present evidence demonstrating that when the gap between the target and the illusion-making elements in the Ebbinghaus illusion is equidistant across different perceptual conditions (Figure 1a), the apparent effect of the illusion on grasp scaling is eliminated.

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Results

Effects of the illusory displays on estimations and grasp scaling

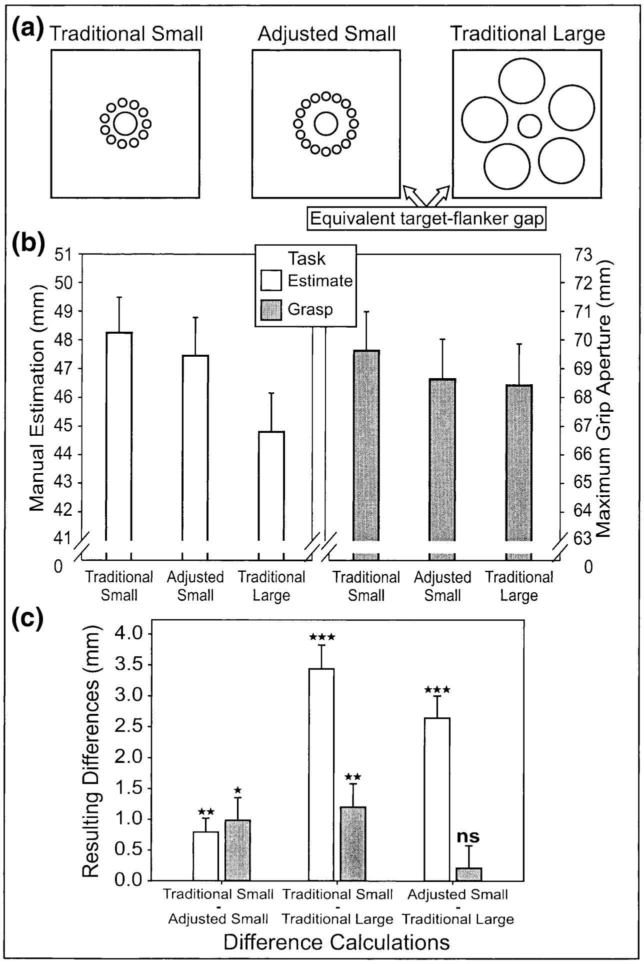
A clear dissociation between perceptual judgements and grasp scaling was established by the examination of the pattern of results across the three illusory displays illustrated in Figure 1a, in which both the size of the surrounding elements and their proximity to the target were manipulated. The effect of the displays on perceived size was consistent with the well-known properties of relative-size contrast illusions; targets surrounded by smaller objects appear to be larger than identical targets surrounded by larger objects. Grasp scaling, in contrast, appeared to be affected primarily by the physical proximity of the 2-D illusory elements to the target, irrespective of the size of the surrounding elements. Thus, the three illusory displays affected both perception and action, but they did so in quite different ways.

An analysis of variance (ANOVA) examining the within-subject variables of task, display, and disk size produced a significant interaction between the task and illusory display [$F(2, 32) = 20.86, p < .001$]. In other words, the effect of the illusory displays differed across the two tasks. Separate ANOVAs carried out on the two tasks revealed significant effects of the three illusory displays on both manual estimations [$F(2, 32) = 56.57, p < .001$] and grasp scaling [$F(2, 32) = 7.24, p < .01$; Figure 1b]. Comparisons between displays within each task are illustrated in Figure 1c. In the manual-estimation task, targets surrounded by small circles were perceived to be larger than targets surrounded by large circles. This was true even when the distance between the target disk and the surrounding elements was equated for the large- and small-circle annuli. In contrast, when subjects grasped these same targets, there was virtually no difference in grasp scaling with small- and large-circle displays provided that there was the same finger-width gap between the target disks and the surrounding annuli. Effects on grasp scaling became apparent only when the size of the gap differed across displays. Thus, the hand opened wider for disks placed on the traditional small-circle annulus (where there was almost no gap between the target disk and the surrounding annulus) than it did for disks placed either on the large-circle annulus or the adjusted small-circle annulus (where there was a finger-width gap between the target disk and the surrounding circles).

Effects of target disk size on estimations and grasp scaling

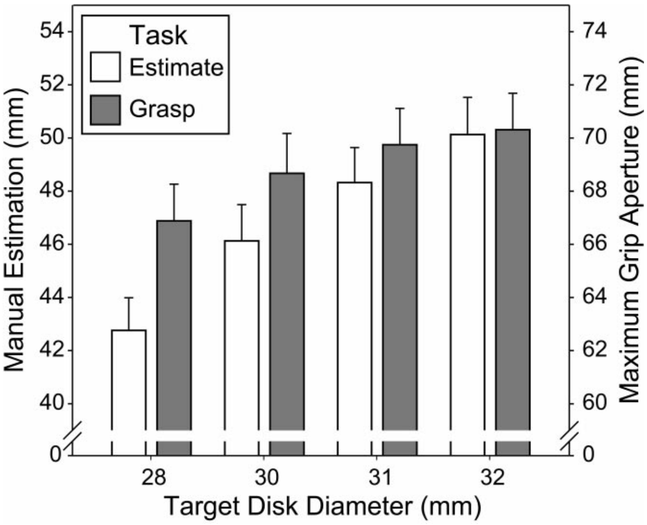
It is unlikely that the different effects of the illusory displays on manual estimation and grasp scaling were due to differences in the accuracy of the two modes of responding; both measures increased systematically with increases in target width (Figure 2). Nevertheless, there was a significant interaction between task and target size [$F(3, 48) = 14.00, p < .001$]. On average, a 1 mm increment in target diameter resulted in a 1.85 mm (SE = 0.43)

Figure 1



(a) A schematic representation of the three illusory displays. Note that the inner diameter of the adjusted small-circle annulus was matched to that of the traditional large-circle annulus. In the experiments the central targets were three-dimensional plastic disks, while the surrounding elements were two-dimensional. **(b)** The mean values for the manual-estimation task (left) and the grasping task (right) with the three illusory displays. Results are averaged across disk sizes since the effect of disk size on manual estimations and on grasp scaling did not interact with illusion condition ($p > .05$ in both cases). **(c)** The difference scores resulting from each of the possible within-task comparisons between the three displays. For the manual-estimation task, the long-established effect of the illusory displays was seen; targets surrounded by smaller circles appeared to be larger than targets surrounded by larger circles. Significant differences were seen for comparisons between the traditional small-circle annulus and the traditional large-circle annulus [$t(17) = 8.92$, $p < .001$] and between the adjusted small-circle annulus and the traditional large-circle annulus [$t(17) = 7.40$, $p < .001$]. In addition, the traditional small-circle annulus resulted in larger estimates than did the adjusted small-circle annulus [$t(17) = 3.48$, $p < .01$], and this effect is consistent with well-known properties of the illusion. For the grasping task, significant differences in grasp aperture were seen only when displays with different gap distances between the target and surrounding annulus were compared. Grasp scaling was significantly greater for targets placed on the traditional small-circle annulus (where there was almost no gap between the target disk and the surrounding annulus) as compared to grasp scaling for targets placed either on the large-circle annulus [$t(17) = 3.17$, $p < .01$] or the adjusted small-circle annulus [$t(17) = 2.72$, $p < .05$]. For the comparison between the adjusted small circle-annulus and the large-circle annulus, in which the distances between the target disks and the surrounding annulus were equated, no difference was seen [$t(17) = 0.58$, $p > .05$]. The error bars in (b) and (c) represent standard error. A single asterisk indicates that $p < .05$; a double asterisk indicates that $p < .01$; and a triple asterisk indicates that $p < .001$.

Figure 2



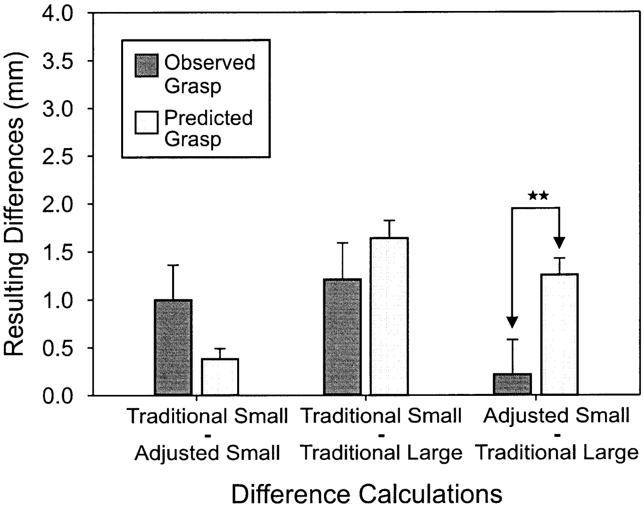
Perceptual estimations and grasp scaling across target disk sizes. It should be noted that measurements calculated between the markers placed on the thumb and index finger included the width of the thumb and finger, the actual gap between the thumb and finger was approximately 20 mm smaller than the measured distance. Both estimation and grasp size increased as a function of target width [$F(3, 48) = 83.66$, $p < .001$ and $F(3, 48) = 26.06$, $p < .001$, respectively]. For manual estimation, paired t-tests comparing estimations of adjacent disk sizes revealed significant differences [$t(17) \geq 4.95$, $p < .001$ for all comparisons]. For maximum grasp aperture, paired t-tests comparing grasp scaling for adjacent disk sizes revealed significant differences [$t(17) \geq 2.93$, $p < .01$] except for the comparison between the 30 mm and 31 mm disks [$t(17) = 1.56$, $p > .05$]. The error bars depict standard errors of the means.

increment in manual estimation but only a 0.88 mm (SE = 0.46) increment in grasp scaling.

Predicted effects of the illusory displays on grasp scaling: Controlling for differences in response functions

Although there was a clear dissociation between the pattern of effects seen for estimations and grasp scaling across the illusory displays, it is important to establish that the difference in the magnitude of the effects across the two tasks was not simply due to the fact that the two tasks had different response functions. After all, increments in the real size of the target disk produced corresponding increases in grasp aperture that were only half the magni-

Figure 3



Observed and predicted differences in grasp scaling across displays. Bars depict the differences between the mean absolute values for each of the three displays. Predicted changes in grasp scaling were calculated from the observed changes in perception, with control for differences in the response functions of the two tasks (as described in the text). The observed difference in grasp scaling between the adjusted small-circle annulus and the large-circle annulus was significantly smaller than the difference predicted given that grasp scaling and size estimations shared a unitary representation of size [$t(17) = 2.91$, $p < .01$]. As would be predicted, the observed difference in grasp scaling between the traditional small-circle annulus and the adjusted small-circle annulus was actually larger than the predicted difference; however, this comparison did not reach significance [$t(17) = 1.58$, $p > .05$]. Error bars depict standard errors of the differences. Double asterisks indicate that $p < .01$.

tude of those shown in manual estimation. Similarly, one might argue that the effect of the size of the annulus circles on grasp aperture would also be half of that shown for manual estimates. In other words, the small effects of the displays on grasp scaling could reflect the same perceptual effect seen in manual estimation, albeit one that was simply more attenuated. To test this possibility, we calculated the changes that would be expected if the effect on grasp scaling were due to an attenuated perceptual effect by taking into account the observed differences in the response functions of the two tasks for real changes in disk size. For example, for a 1.00 mm change in manual estimation, we would expect a 0.48 mm change in grasp scaling; $0.88/1.85 = 0.48$. Using this formula, we could use the observed changes in perceived size across the illusory displays to calculate the magnitude of changes in grasp scaling that would be predicted if perception and action were driven by a unitary representation of size. Thus, the 2.64 mm difference in manual estimations between the adjusted small-circle annulus and the large-circle annulus (with equivalent finger-sized gaps) should have produced a corresponding 1.26 mm change in grasp scaling; $2.64 \times 0.48 = 1.26$. As shown in Figure 3, however, we observed a difference of only 0.21 mm. In short, there are clear differences between the actual effects of the displays on grasp scaling and the predicted effects from changes in perceived size.

Discussion

It has previously been suggested that the small effects on grasp induced by the Ebbinghaus illusion show that the programming of skilled actions is not completely impervious to perceptual effects [2–4]. More recently, Franz et al. [5] have taken a stronger view in suggesting that these small changes in grasp imply that there is a single representation of size that drives both perception and action. The present experiment, however, shows that this is clearly not the case. By manipulating the distance between the target and the surrounding annuli in an Ebbinghaus display, we show that the effects on grasp are not related to changes in perceived size. Instead, the distance between the target object and the surrounding annulus appears to be the critical variable.

Franz et al. [5] proposed that the dissociation between perception and action that was demonstrated in previous experiments using the Ebbinghaus illusion [2–3] resulted from differences in the attentional demands across tasks. They tested this idea by presenting half of the Ebbinghaus illusion on each trial — that is, a single target surrounded by either the large- or the small-circle annulus — in an effort to ensure that both the grasp and the perceptual judgements were directed toward a single target and its surrounding illusory context. As Franz et al. clearly showed, the magnitude of the perceptual effect is greatly reduced with the single annulus display as compared to the effect typically observed with the traditional two-annulus display. The reduced perceptual effect with the single-annulus display was similar in magnitude to the effect seen in grasp scaling with either the single- or the two-annulus display. This result led the authors to conclude that the same internal representation of target size was used for both perceptual judgements and the programming of grasp. In the Franz et al. experiments, however, the distance between the target disk and edge of the circles making up the large-circle annulus was larger than the distance between the target disk and the edge of the circles making up the small-circle annulus. In fact, the dimensions of the annuli used by Franz et al. were essentially the same as the large-circle and traditional small-circle annuli that we used in the present experiment. Thus, the differential effects of the large- and small-circle annuli on grasp that Franz et al. reported were most likely due to the difference in the size of the gaps between the target disk and the surrounding annuli in these two displays. Indeed, the magnitudes of the effects on grasp in all of the experiments that have employed the traditional Ebbinghaus large-circle configurations have been remarkably consistent; they have ranged from approximately 1.0

mm to 1.5 mm, and in all of these cases the gap between the target disk and the surrounding annuli varied in the same way between the large- and small-circle displays [2, 3, 5]. In a study by Pavani et al. [4], the size of the gap between the target disk and the surrounding annulus comprised of large circles was larger than that used in the present study, but the average difference between the maximum hand opening for targets placed on the large- and small-circle annuli was still around 1.0 mm.

Why should the grasp be at all sensitive to the distance between the target and the surrounding annulus? It could be the case that the circles in the surrounding annulus are being treated as potential obstacles. Previous experiments have shown that maximum hand opening is reduced when there is a finger-width gap between a target and the surrounding elements as compared to the case in which the target is presented on its own [3] or the case where the gap between the target and the surrounding annuli is too small for the fingers to fit [6]. There is evidence from other studies that 2-D "non-obstacles" can influence the trajectory of visually guided movements. For example, Welsh, Elliot, and Weeks [8] showed that movement trajectories to 2-D targets presented on a computer screen were affected by the presence of 2-D distractors. Howard and Tipper [7] found that reach-to-grasp movements directed toward a 3-D target were altered by the presence of a light-emitting diode (LED) embedded in the surface of the display. It is perhaps not surprising, then, that the 2-D illusory elements in our experiment altered the posture of the fingers as subjects formed their grasp.

Conclusion

The present experiment provides compelling evidence that the size-contrast illusion elicited by the Ebbinghaus display does not affect grasp scaling. The critical variable for grasp scaling appears to be the distance between the target disk and the edge of the surrounding annulus, not the size of the circles making up the annulus.

Materials and methods

Subjects

Nine female and nine male undergraduate students participated in the experiment. All subjects were right handed [9] and had normal or corrected-to-normal vision. Participants were reimbursed for their time.

Stimuli

Each of the three displays illustrated in Figure 1a were mounted in the center of a 20.5 cm × 20.5 cm piece of cardboard. The traditional small-circle annulus had an inner diameter of 38 mm and consisted of 11 circles, each of which was 10 mm in diameter. The adjusted small-circle annulus had an inner diameter of 54 mm and consisted of 16 circles, each of which was 10 mm in diameter. The traditional large-circle annulus had an inner diameter of 54 mm and consisted of 5 circles, each of which was 54 mm in diameter. In each trial participants were presented with one of the illusory annuli and a plastic target disk (either 28, 30, 31, or 32 mm in diameter and 3 mm thick) centered within the annulus. A black line, 1 mm wide, was affixed to the top of the target disks to clearly mark their circumference. Subjects were seated on a chair raised to the height of the testing table so that they had a "bird's eye view" of the display. The display was positioned so that the target disk was 35 cm from the start button and along the midline of the subject.

Procedure

Each subject performed two tasks, the "manual estimation" task and the "grasping" task. Task order was counterbalanced across subjects. Both tasks were performed under open-loop conditions, in which the subject could not see the hand, display, or target. The viewing period was controlled by the use of PLATO goggles (Translucent Technologies). The lenses of these goggles are liquid-crystal shutters that remain opaque until they receive a signal via a switch controlled by the experimenter. The change in state from opaque to clear or vice versa takes approximately 2 ms. A circular overhead fluorescent light positioned 1 min above the stimulus provided illumination to the stimulus and the surrounding table surface.

Finger and hand position in both tasks was recorded by the use of a three-camera Optotrak system (Northern Digital) that detects infrared signals emitted by markers. The markers were fastened to the subject's index finger, thumb, and wrist with small pieces of cloth tape. In both tasks, subjects were required to initiate their response as soon as the target was visible. On an estimation trial, subjects began with the heel of their hand resting on the start button and their thumb and index finger pinched together. The beginning of each trial was signaled by the experimenter, who then pushed a hand-held button that caused the lenses of the goggles to clear, allowing the subject to view the display. As soon as they saw the target, subjects were required to slide their hand off the button toward their body. The release of the button activated a switch that changed the lenses of the goggles from clear to opaque. At this point, the subjects manually estimated the size of the disk by separating their thumb and index finger until they felt the gap accurately matched the width of the near-far axis of the target disk they had just seen. They held this position until an audio signal sounded 2.5 s after the start of the trial. Thus, this sequence had to be completed in 2.5 s. Subjects were given sufficient practice prior to the start of the estimation task to ensure that they could easily complete the sequence in the allotted time. After each estimation, subjects were required to reach out and pick up the disk to ensure that they received the same amount of haptic feedback about the real size of the disks as they did when performing the grasping task. The grasping movements following estimations were performed without a view of the hand or the target and were not recorded (although subjects were not made aware of this fact).

The sequence for the grasping trials was similar to that for the estimation trials. Subjects began with their thumb and index finger pinched together, pushing down on the start button. Again, the experimenter signaled the beginning of each trial and pushed the control button, and the display came into view. Subjects immediately reached out to grasp the target disk along the near-far axis. They were instructed to use a "natural" movement as they reached out to grasp the disk and not to reach as quickly as they could. As in the estimation task, the goggles became opaque as soon as the button was released. Subjects were instructed to hold on to the disk until they heard the audio signal. Subjects were given sufficient practice to ensure that they could easily complete the sequence within 2.5 s.

The average viewing time for each task was estimated by the calculation of movement onset, which corresponds to the time between the lenses clearing and the subject releasing the start button. On average, movement onset occurred at 915 ms (SE = 33 ms) during the estimation task and at 720 ms (SE = 24 ms) during the grasping task. The small difference in viewing time is unlikely to be critical since similar results on grasp scaling were obtained when the viewing time was unrestricted (1).

Subjects completed one set of trials for each of the two tasks. A trial set consisted of 60 individual trials; 5 trials for each of the 12 conditions (3 displays × 4 disks) were presented in random order. The mean of the five trials given for each condition was taken as the subjects' score and entered into the analysis. Rest periods were given halfway through each trial set and between the two sets of trials.

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