Research Article

Planning to Reach for an Object Changes How the Reacher Perceives It

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ABSTRACT—*Three experiments assessed the influence of the Ebbinghaus illusion on size judgments that preceded verbal, grasp, or touch responses. Prior studies have found reduced effects of the illusion for the grip-scaling component of grasping, and these findings are commonly interpreted as evidence that different visual systems are employed for perceptual judgment and visually guided action. In the current experiments, the magnitude of the illusion was reduced by comparable amounts for grasping and for judgments that preceded grasping (Experiment 1). A similar effect was obtained prior to reaching to touch the targets (Experiment 2). The effect on verbal responses was apparent even when participants were simply instructed that a target touch task would follow the verbal task. After participants had completed a grasping task, the reduction in the magnitude of the illusion remained for a subsequent verbal-response judgment task (Experiment 3). Overall, the studies demonstrate strong connections between action planning and perception.*

Pictorial illusions are rare outside of perception labs, but they provide tools for exploring the nature of human visual processing. Over the past decade, the Ebbinghaus illusion has been used to identify stark differences between the visual processing that mediates perceptual judgments and that which mediates visually guided actions, such as grasping (Fig. 1; for a review, see Glover, 2004). Adult participants generally perceive the disk surrounded by small circles to be approximately 10% larger than the disk surrounded by large circles (Fig. 1a). The effect of the illusion on grip scaling is significantly smaller, however, exhibiting a magnitude of approximately 6% (e.g., Aglioti, DeSouza, & Goodale, 1995; Haffenden & Goodale, 1998; see Fig. 1b). Results such as these have been interpreted as evidence for two separate streams of visual processing in the human brain (Glover, 2004; Milner & Goodale, 1995).

This finding has been disputed, however, as different variations of the judgment and reaching tasks have yielded disparate results (Franz, 2001; Glover, 2004; Smeets, Brenner, de Grave, & Cuijpers, 2002; Vishton & Fabre, 2003; Vishton, Rea, Cutting, & Nuñez, 1999). Some researchers have argued that there may be no compelling evidence for the presence of two separate visual systems (Franz, 2001, 2003). The current study addressed this issue by assessing the Ebbinghaus illusion and reaching actions, but the debate has encompassed many illusions and visually mediated behaviors (Brenner & Smeets, 1996; Carey, 2001; Dassonville, Bridgeman, Bala, Thiem, & Sampanes, 2004; de Grave, Brenner, & Smeets, 2004; Dewar & Carey, 2006; Glover & Dixon, 2001; Lee & van Donkelaar, 2002; Proffitt, Creem, & Zosh, 2001; Westwood, McEachern, & Roy, 2001; Wraga, Creem, & Proffitt, 2000).

The differences in illusion magnitude that have been obtained could indicate the presence of two separate, task-specific visual subsystems. However, the same pattern of data could be produced by a single system with two different modes of processing that correspond to these different behaviors. For instance, when one chooses to engage in a reaching behavior, the visual system may alter the way in which it processes information, not just for the formation of grip, but for all visually mediated behaviors.

Evidence suggesting this possibility was provided by Witt, Proffitt, and Epstein (2005), who found that experience with reaching for targets while holding a 39-cm baton changed participants' distance perception. Targets that would have been out of reach, except for the baton, were judged to be 7 cm closer than they were in a control condition in which participants did not hold the baton. This reduction in distance judgments was not

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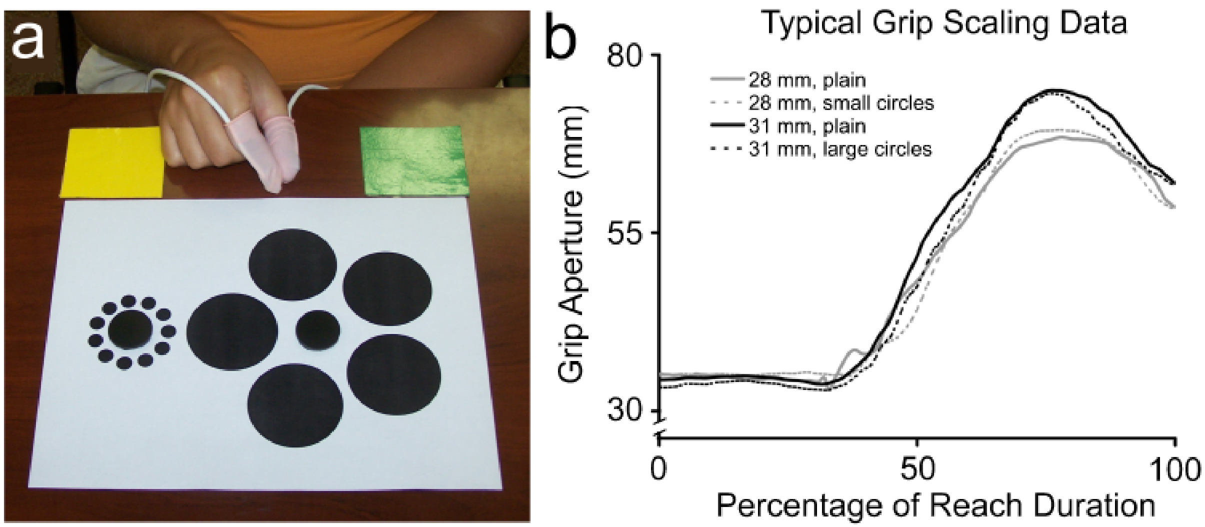

Fig. 1. The Ebbinghaus illusion as presented to participants in this study (a) and typical grip-scaling data (b). In the Ebbinghaus illusion, the two central disks are identical in size, but most participants judge the disk surrounded by small circles to be approximately 10% larger than the disk surrounded by large circles. For the grasp task in Experiment 1, we attached position sensors to the thumb and index finger of participants, as shown in (a). The graph shows typical results from the grasp task; grip aperture is plotted as a function of time. Data for four reaches are presented. The black and gray lines show grasps directed at disks 31 and 28 mm in diameter, respectively. The maximum grip aperture is highly correlated with the size of the targets. The presence of the illusion-inducing circles (see the dashed lines) influences the size of the grip aperture, but the effect is much smaller than in perceptual judgment tasks.

found when participants simply held the baton; thus, the intention to reach seems critical to the effect. Witt et al. interpreted this finding as consistent with Iriki, Tanaka, and Iwamura's (1996) finding that some cells in the macaque intraparietal sulcus are selectively activated by visual targets presented within reach. When the macaques were given curved handles that enabled them to reach farther, the receptive fields of these neurons changed to match the extended reach of the handles. Perhaps this visuomotor system participates in the process of depth perception, but only when one intends to touch a target that is within reach. If so, then one might see other shifts in visual information processing associated with an intention to reach.

The study reported here supports this perspective. Participants selected which of two disks seemed larger and indicated that choice with either a nonreaching verbal response or a reach to contact the target. We found that the judgments that preceded the reaching actions were nearly as resistant to the Ebbinghaus illusion as the grip scaling employed in the grasping action itself. Such a finding suggests (a) that perception changes as a function of action choice and (b) that these changes influence many (perhaps all) aspects of perception.

In previous studies of this topic, participants began by viewing two identical, three-dimensional disks placed in the context of the small- and large-circle arrays that produce the Ebbinghaus illusion (e.g., Aglioti et al., 1995). Participants made relative size judgments by adjusting the sizes of the two disks until they appeared equal. This step of the procedure produced a *perceptually same/physically different* stimulus, in which the disk surrounded by large circles was approximately 10% larger than the disk surrounded by small circles, in order to compensate for the effect of the illusion. The experimenters then used this stimulus, along with a *perceptually different/physically same* stimulus, in a series of reaching or further judgment trials. For reaching trials, participants were instructed to reach to one side if the disks appeared to be the same size or to the other side if the disks appeared to be different sizes (e.g., "If the disks appear equal, grasp the disk on the left; otherwise, grasp the disk on the right").

In this second phase of these experiments, the data of primary interest were typically the recordings of the distance between the thumb and index finger. Grip aperture is highly correlated with target size, and this is especially true for the maximum grip aperture (MGA), which occurs about 65% of the way through the reaching motion (Paulignan, MacKenzie, Marteniuk, & Jeannerod, 1997). Given this strong correlation between MGA and size, it was surprising to many researchers that the MGA was not strongly affected by the illusion. Rather than exerting the 10% effect observed for judgment, the illusion typically had a magnitude of around 6% (e.g., Aglioti et al., 1995). That is, the MGA exhibited when grasping the disk surrounded by the small circles was approximately 6% larger than the MGA produced when grasping an identical disk surrounded by the large circles, even though the two target disks were identical in actual size.

Additional data that most researchers have ignored are the left/right choices made by participants during the grasping phase of these studies. Aglioti et al. (1995) did not report these data, suggesting that their participants made choices that were always consistent with the judgments made in the initial phase of the experiment. In a replication of the study, however, Hanisch, Konczak, and Dohle (2001) found that participants often reached in the "wrong" direction. When the experimenter presented participants with the physically same target disks (initially judged as perceptually different), their reach direction indicated perception of different sizes only for 84% of trials. In the converse condition (perceptually same/physically different disks), reach choice indicated perception of the same size on only 75% of trials. Overall, participants' prereach choices were inconsistent with their initial nonreach judgments for approximately 21% of trials.

This high "error" rate suggested to us that the perceptual judgment process used to guide the reaching choices differed from that which mediated the verbal judgments. The three experiments presented here assessed this hypothesis, using a set of target disks with finer increments. In each block of trials in each experiment, a disk that was 28 mm in diameter was presented with comparison disks that were 27, 28, 29, 30, 31, and 33 mm in diameter. Participants were asked to indicate, on each trial, which of the two disks was larger. For half of the trials, the background was blank; for the other half, small circles surrounded the standard 28-mm disk, and large circles surrounded the comparison disk. The Ebbinghaus illusion resulted in an increased tendency to select the standard disk as larger. The extent of this effect provided an estimate of the magnitude of the illusion for tasks with verbal, grasp, and touch responses, under several different experimental conditions.

EXPERIMENT 1: EFFECT OF THE EBBINGHAUS ILLUSION ON GRASP CONTROL AND JUDGMENTS PRECEDING VERBAL AND GRASP RESPONSES

As in prior studies, participants began by making verbal judgments of the relative sizes of two disks. For each pair of disks, they stated which appeared larger. Participants then repeated the judgment process; half of the participants continued to respond verbally, and the others indicated their choice by grasping the disk that looked larger.

Method

Participants

Twenty-nine College of William & Mary students (16 female, 13 male) completed the experiment in return for course credit or as volunteers. One additional subject was excluded from the analyses because a position sensor malfunctioned.

Displays and Apparatus

Participants sat in a chair (45 cm tall) in front of a table surface (73 cm tall × 152 cm wide × 76 cm deep). In the plain-background condition, targets were presented on a rectangular piece of white paper (28 cm wide × 21.6 cm deep), which was secured to the table surface with clear tape. The paper was centered in front of the subject, with the closest edge of the paper placed 10.8 cm from the front edge of the table. Two locations were marked to ensure consistent placement of the target disks: 44 and 90 mm from the left and right edges of the paper, and 97 mm from the front edge. Target disks were placed on top of these markings. The illusion-background condition made use of a separate piece of paper, identical to the plain paper except that small- and large-circle arrays were printed around the disk-placement locations (see Fig. 1a). The small-disk array consisted of 11 black disks, 10 mm in diameter, with their closest edges located 19 mm from the target-placement mark. The large-disk array consisted of 5 black disks, 58 mm in diameter, with their closest edges located 25 mm from the target-placement mark. For half of the participants, the illusion background was placed with the small-disk array on the left; for the others, it was placed with this array on the right.

The target disks were cut from black plastic (4 mm thick). The standard disk was 28 mm in diameter; the comparison disks were cut with diameters of 27, 28, 29, 30, 31, and 33 mm. The standard disk was always presented in the marked location 44 mm from the edge of the paper; the comparison disk was always presented 90 mm from the other edge. Thus, in the illusion-background condition, the standard disk was always inside the small-circle array, and the comparison disk was always inside the large-circle array. Green and yellow cards were placed on the table in front of the left and right sides of the display, respectively. In the verbal trials, participants indicated their side choice by stating the color of the label on the selected side.[1]

Recordings of grip scaling were obtained using a two-sensor array of the miniBird 500 system (Ascension Technology, Burlington, VT). The system recorded three-dimensional positions of the sensors at approximately 100 Hz, with a position tolerance of approximately 0.5 mm. The experimenter secured the sensors to the thumb and index finger of each subject's preferred hand using latex finger protectors.

Design

We randomly assigned each subject, without replacement, to one of two side conditions (small-disk array on left vs. right). Each 12-trial block included six size comparisons (standard 28-mm disk vs. 27-, 28-, 29-, 30-, 31-, and 33-mm comparison disks) in one background condition (plain or illusion) and then the other. The order of the background conditions was counterbalanced across participants; within each of these conditions, the order of the six size comparisons was randomized. All participants began with a block of 12 verbal trials. For the second block of trials, half the participants completed the grasp task (*verbal-grasp* condition), and half completed an additional set of verbal trials (*verbal-verbal* condition).

[1]Color labels were used to make the procedure amenable for developmental work with child participants.

Procedure

After providing informed consent, participants were told that they would be making judgments about the relative sizes of two disks, and that they should indicate their response by stating whether the larger disk was on the left side (labeled "green") or the right side (labeled "yellow"). Next, the experimenter placed an occluding panel in position to hide the display while the target disks were placed on the background. The experimenter then moved the panel to the side, holding it there until the subject indicated a side choice, after which the process was repeated.

After 12 trials, participants assigned to the verbal-verbal condition were told that they had completed half of the experiment and should continue as before during the second half. For verbal-grasp participants, the experimenter attached the position sensors to the thumb and index finger. She then explained that they should continue selecting the larger of the three-dimensional disks, but that rather than stating its location, they should reach out, grasp the target with a pincer grip, and briefly lift it. Participants started each trial with the thumb and index finger together, at a standard position on the table surface. The experimenter then removed the occluding panel and gave a verbal start signal. The entire procedure lasted approximately 9 min (approximately 4.5 min spent on each trial block).

Data Analysis

Logistic regression functions were fit to the selection data for each subject in each of the four conditions: (a) Block 1 response task (always verbal), plain background; (b) Block 1 response task (always verbal), illusion-inducing background; (c) Block 2 response task (verbal or grasp), plain background; and (d) Block 2 response task (verbal or grasp), illusion-inducing background. For each condition, we determined the 50% criterion value, that is, the comparison size at which the subject was equally likely to select the 28-mm standard disk and the comparison disk. The difference between the criteria for the illusion background and the plain background was calculated for each subject in each task (verbal vs. grasp). A positive value for this difference indicates the magnitude of the illusion. All data are reported as a percentage of the standard target size (i.e., 28 mm). For instance, if the presence of the illusion background resulted in a 2.8-mm increase in the 50% criterion for a particular task, this would correspond to a 10% effect of the illusion. Repeated measures analysis of variance (ANOVA) was used to assess the influence of response measure on this percentage. All significant results are reported.

Grip aperture was calculated as the distance between the two position sensors; MGA was determined for each trial. For each subject, we identified trials in which the same-size target was grasped in the plain and small-disk background conditions and trials in which the same-size target was grasped in the plain and large-disk background conditions. The change in MGA, as a proportion of the target disk's size, was used to calculate the percentage effect of the illusion for each subject; this value was then divided by the linear regression slope relating MGA to target size in the plain-background condition (0.91) to account for task-specific response scaling (in accord with Franz, Fahle, Bülthoff, & Gegenfurtner, 2001).

We also assessed the correlations of the illusion magnitudes. For verbal-verbal participants, we calculated the correlation of the illusion magnitudes for the first and second blocks of trials. For verbal-grasp participants, we calculated correlations between first-block verbal choices, second-block grasp choices, and second-block MGA.

Results and Discussion

Participants' disk choice was a function of comparison size in all task and background conditions (Fig. 2). In the verbal-grasp condition, the two tasks exhibited significantly different illusion magnitudes. For the verbal and grasp choices, the mean effects of the illusion were 8.99% (SE = 1.04) and 5.58% (SE = 1.28). The mean effect of the illusion on MGA was 5.37% (SE = 1.98; Fig. 3). The effect of response measure was significant, $F(2, 28) = 3.41$, $p = .023$, $\eta_p^2 = .20$. Planned contrasts indicated significantly different illusion magnitudes for verbal and grasp choices, $F(1, 14) = 5.56$, $p_{rep} = .93$, $\eta_p^2 = .28$, and also for verbal choices and MGA, $F(1, 14) = 7.06$, $p_{rep} = .95$, $\eta_p^2 = .34$. There was no significant difference between the illusion magnitude for MGA and grasp choices ($p_{rep} < .54$).

The effect of the illusion on MGA in the grasp task was 40% smaller than the effect of the illusion in the verbal task. This

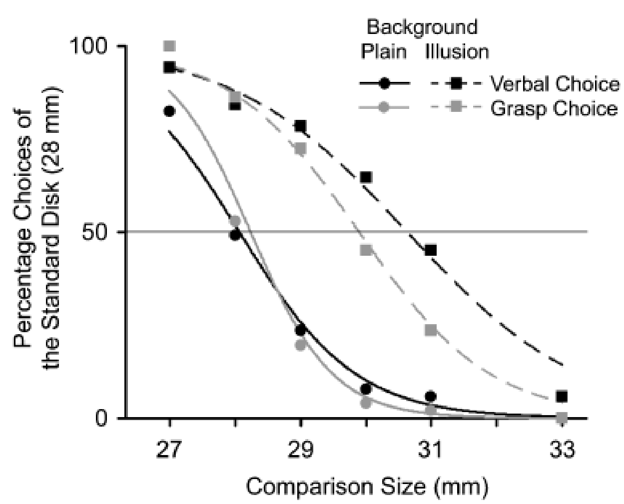

Fig. 2. Group means for the verbal-grasp condition of Experiment 1: percentage of trials on which participants chose the standard 28-mm disk as larger than the comparison disk as a function of the size of the comparison disk, for the verbal and grasp tasks and the plain and illusion backgrounds. Mean selection frequencies and group logistic regression functions are shown for each combination of background condition and task. The intersection of the horizontal line at 50% and each logistic function indicates the size (in millimeters) of the 50%-criterion stimulus for that condition. We infer that had we presented a comparison disk of this size, participants would have chosen it as larger than the 28-mm standard disk on approximately 50% of trials.

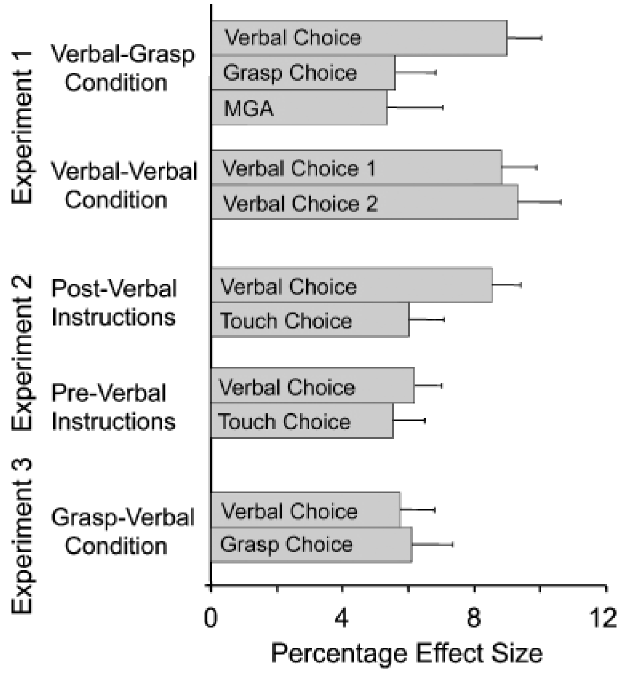

Fig. 3. Magnitude of the illusion (reported as a percentage of the 28-mm standard target disk) across the tasks in Experiments 1 through 3. In the verbal-verbal condition, Verbal Choice 1 refers to the first block of 12 verbal-response trials, and Verbal Choice 2 refers to the second block. Error bars represent 1 *SEM*. MGA = maximum grip aperture.

reduction in illusion magnitude for a visually controlled action is consistent with many previous findings. As we predicted, however, target choice in the grasp task was also less influenced by the illusion than was verbal choice; the magnitude of the illusion was reduced by 38%.

In the verbal-verbal condition, there was no apparent difference between the first and second blocks of trials ($p_{rep} < .64$); the mean illusion magnitudes were 8.81% ($SE = 1.08$) and 9.31% ($SE = 1.30$; Fig. 3). The interaction between block and task condition (verbal-grasp vs. verbal-verbal) was significant, $F(1, 27) = 4.86$, $p_{rep} = .93$, $\eta_p^2 = .15$. The illusion magnitude was significantly greater for second-block verbal choices than for second-block grasp choices, $F(1, 27) = 4.75$, $p_{rep} = .93$, $\eta_p^2 = .15$; this finding indicates that mere exposure does not explain the reduction in the illusion's magnitude in the grasp task.

The different measures of illusion magnitude exhibited consistent positive correlations. For the verbal-verbal participants, the illusion magnitudes in the two trial blocks were significantly correlated ($r = .55$, $p_{rep} = .92$); positive, nonsignificant correlations were also obtained for verbal-grasp participants ($r = .49$, $p_{rep} = .90$, for verbal choice and MGA; $r = .45$, $p_{rep} = .87$, for verbal choice and grasp choice; $r = .38$, $p_{rep} = .83$, for grasp choice and MGA). The consistently positive correlations support the claim that these three responses are not produced by fully independent subsystems.

At the onset of each verbal and grasp trial, the participants chose one of two disks as larger than the other. The only difference between the two tasks was the response behavior used to communicate this choice. If perceptual judgment truly precedes and operates independently of behavioral response, then the observed differences should not have emerged. The results demonstrate that the action for which the subject is preparing affects the subject's visual processing. The intention to reach for an object changes how the reacher perceives it.

EXPERIMENT 2: EFFECT OF THE EBBINGHAUS ILLUSION ON JUDGMENTS PRECEDING VERBAL AND TOUCH RESPONSES

Perhaps the reductions of the illusion's magnitude in Experiment 1 were produced by the haptic feedback received during the grasping task. According to this hypothesis, the illusion might strongly affect performance on the first trial, but as the hand provides additional information about size, the visual system compensates for the illusion. Several researchers have argued against this explanation for the reduction in illusion magnitude for visually guided action (Haffenden & Goodale, 1998; Vishton et al., 1999). We explored this issue by having participants indicate their choice of which disk was larger by touching it on the top rather than grasping it.

An extreme possibility is that reaching actions themselves are not necessary to effect the reduction in magnitude. Perhaps simply preparing to reach is sufficient. To assess this possibility, we provided some participants with instructions about both the verbal and touch tasks prior to beginning the verbal task. For other participants, as in Experiment 1, the action-response instructions were given only after the verbal task was completed.

Method

Forty-seven William & Mary students (27 female, 20 male) completed the experiment in return for course credit or as volunteers.

All methods were identical to those described for Experiment 1 except as noted here. The grasp task was replaced with a *touch* task. After completing a block of 12 verbal trials, participants continued selecting which of the two disks appeared larger, but indicated their answer by touching it with an index finger. Position sensors were not used. We used univariate ANOVAs to compare relevant conditions between experiments.

We instructed half of the participants about the touch task only after they completed the verbal task (*postverbal-instruction* condition); the others received instructions about both tasks prior to beginning the verbal task (*preverbal-instruction* condition).

Results and Discussion

For the postverbal-instruction participants, the results were similar to those observed in Experiment 1. For the verbal and touch tasks, the mean effects of the illusion were 8.52% ($SE = 0.89$) and 6.02% ($SE = 1.06$; Fig. 3). The effect of task was significant, $F(1, 20) = 7.88$, $p_{rep} = .96$, $\eta_p^2 = .28$. The illusion magnitudes produced by the verbal and touch tasks were significantly correlated (r = .45, p_{rep} = .92).

The touch choices were less influenced by the illusion than were the verbal choices, exhibiting a 29% reduction in the illusion's magnitude. There was no significant difference between the effect of the illusion on the touch choices and the effect of the illusion on either MGA or grasp choices in Experiment 1 (p_{rep} < .67). Thus, the reduction observed in Experiment 1 does not seem to require haptic feedback. It may be that any action directed into the target region changes how the actor perceives it. However, touch movement kinematics are influenced by target size (e.g., Fitts & Peterson, 1964), so perhaps only size-mediated actions will produce the observed effect.

Participants in the preverbal-instruction condition exhibited small illusion magnitudes for both tasks. For the verbal and touch tasks, the mean effects of the illusion were 6.18% (SE = 0.81) and 5.54% (SE = 0.97; Fig. 3). The effect of task was not significant (p_{rep} < .70). The magnitudes of the illusion in the verbal and touch tasks were significantly correlated (r = .51, p_{rep} = .97). The reduction in illusion magnitude for the verbal task in this condition, compared with the verbal task in the postverbal-instruction condition, approached significance, $F(1, 44) = 3.71$, p_{rep} = .91, $\eta_p^2 = .08$. The reduction in illusion magnitude for verbal responses in the preverbal-instruction condition, compared with verbal responses in the verbal-grasp condition of Experiment 1, was significant, $F(1, 38) = 4.39$, p_{rep} = .92, $\eta_p^2 = .10$.

Simply listening to a description of a reaching task seems to affect size perception. Again, this experiment demonstrates the strong interaction between response preparation and perception.

EXPERIMENT 3: EFFECT OF THE EBBINGHAUS ILLUSION ON JUDGMENTS PRECEDING REACHING AND ON SUBSEQUENT VERBAL JUDGMENTS

In Experiments 1 and 2, participants always began with a block of verbal trials; the task was varied only for the second block of trials. Experiment 3 explored how an initial block of grasp trials affects subsequent verbal judgments. If the effects of action planning last only a few seconds, then the verbal judgments should be similar to those observed in Experiments 1 and 2. If the effects last for several minutes, then the impact of the illusion should be reduced for the subsequent block of verbal responses.

Method

Fifteen William & Mary students (9 female, 6 male) completed the experiment in return for course credit or as volunteers.

All methods were identical to those described for Experiment 1 except that (a) all participants completed the grasp task first, followed by the verbal task, and (b) no position sensors were used.

Results and Discussion

We observed small illusion effects for both tasks. For the verbal and grasp tasks, the mean effects of the illusion were 5.74% (SE = 1.05) and 6.10% (SE = 1.25; Fig. 3). The illusion magnitudes exhibited a positive, nonsignificant correlation (r = .31, p_{rep} = .77). The effect of task was not significant (p_{rep} < .56). The effect on grasp choice was not significantly different from that observed in Experiment 1 (p_{rep} < .66); however, the effect of the illusion on verbal responses was significantly reduced, relative to the effect in Experiment 1, $F(1, 28) = 5.15$, p_{rep} = .94, $\eta_p^2 = .16$.

Thus, the experience of grasping the selected target for 12 trials seems to have had an impact on size perception that lasted for at least several minutes after the grasp task had ended. The results of this experiment further support the claim that intending to reach for a target changes how the reacher perceives it; they further suggest that this change lasts even after the intention to reach has passed.

GENERAL DISCUSSION

The experiments presented here provide evidence that action choice changes the nature of visual size perception. For every trial, the initial perceptual task of the participants was the same: choose the larger of two disks. When the participants indicated their choice with a verbal response, their perception was strongly influenced by the Ebbinghaus illusion. When their choice was indicated with a grasp or touch response, the magnitude of the illusion was significantly reduced. A similar reduction was obtained when an upcoming reaching task was described to participants. The reduction lasted for at least several minutes after participants performed a reaching task, affecting verbal responses made after a block of grasp trials.

The ability of the human visual system to mediate a wide range of behaviors is remarkable, both in its flexibility and in its precision. Differences in visual processing for perceptual judgment and visually guided action control have previously been interpreted as evidence for different visual subsystems within the human brain (e.g., Glover, 2004; Milner & Goodale, 1995). This interpretation may be correct, but it appears that the mapping of these different information-processing streams is not specific to particular actions. Instead, it seems that when a particular action is chosen, the operating characteristics of human vision change in a general fashion that affects a wide range of behaviors.

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