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The influence of visual illusions on grasp position

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Abstract Visual size illusions have been shown to affect perceived object size but not the aperture of the hand when reaching to those same objects. Thus, vision for perception is said to be dissociated from vision for action. The present study examines the effect of visual-position and visual-shape illusions on both the visually perceived center of an object and the position of a grasp on that object when a balanced lift is required. The results for both experiments show that although the illusions influence both the perceived and the grasped estimates of the center position, the grasp position is more veridical. This partial dissociation is discussed in terms of its implications for streams of visual processing.

Key words Motor control · Visual pathways · Illusions · Prehension · Human

Introduction

There is a growing body of evidence suggesting that the aspects of visual information frequently used for visually guided action are distinctly different from those used for visual perception. For instance, Bridgeman et al. (1981) demonstrated that observers accurately point to a static target, even though the target is visually perceived to be moving. Further, when a static target is moved to a new location during a saccade, observers accurately guide their hand to that new location although they do not perceive the target's movement (Bridgeman et al. 1979; Goodale et al. 1986).

Similarly, in spite of their inability to appropriately orientate their hand or to scale their grasp when reaching to objects, patients with optic ataxia can accurately perceive object orientation and size (Jakobson et al. 1991; Perenin and Vighetto 1988). In addition, Milner et al. (1991) have shown the opposite dissociation in a patient with visual form agnosia. Despite being grossly impaired in the perception of an object's orientation, she is quite unimpaired in appropriately orientating her hand when reaching toward that object. Goodale et al. (1991) extended this finding by demonstrating that this same patient, when reaching to rectangular blocks of varying shape but equivalent surface areas, quite accurately scales her grasp aperture to an appropriate size.

Several recent studies have shown that when reaching to grasp an object, the maximum aperture of one's grip is dissociated from the object's apparent size. Instead, it is scaled during the trajectory to the actual size of the object. In 1995, Aglioti et al. used Titchener circles to demonstrate this dissociation both when the objects were perceptually the same size but actually different and when the objects were perceptually a different size but actually the same.

These and other dissociations are extensively reviewed by Milner and Goodale (1995) and subsequently used to suggest that the two major visual pathways traditionally thought of as mediating "what" and "where" may be better conceptualized as mediating "what" (the ventral stream) and "how to" (the dorsal stream).

Brenner and Smeets (1996b) confirmed that the Ponzo illusion has little influence on the aperture size of the hand in flight to the object, notwithstanding the fact that it does influence the speed at which that object is unloaded subsequent to contact. They contend that the more veridical performance of the grip aperture is based not on visual size information (an intrinsic object property), which influences the lifting force, but rather on positional information (the object's relationship to the observer) and that object properties are more susceptible to illusions than is positional information. A problematic aspect of this explanation is that, in order to accurately guide the hand to a position on the object where a stable, balanced grasp can be achieved (particularly with a two-digit, precision grip), the object's size and shape must be considered. To the extent that this is true, the boundary Brenner and Smeets (1996b) delineate between the "in-

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formation about positions rather than about size" appears somewhat uncertain. Be that as it may, they point out that a dissociation between visual perception and visually guided movement seems contingent on the aspect of the stimulus that is driving the action. In support of this hypothesis (and somewhat in contrast to the static target studies referred to earlier), Brenner and Smeets (1996a) have shown that, when hitting a moving target, illusory changes in target velocity do influence the velocity of the hitter's hand.

This paper presents two experiments which examine the effect of visual positional illusions on both the visually perceived location of an object's center and the grasp location chosen when the participants are instructed to grasp and lift that same object such that it is balanced in the grip. Based on the findings of both Aglioti et al. (1995) and Brenner and Smeets (1996b), we anticipated a dissociation between these two locations: the visually perceived estimates should be affected by the illusory background while the grasp location should be veridical.

Experiment 1

The present experiment examines the relative effect of a position illusion on both the visual perception of an object's center and the grasp position chosen to lift that same object. The background illusion chosen was the Judd illusion (Judd, 1899), a variation of the Müller-Lyer illusion in which the arrowheads both point in the same direction. In this illusion, observers inaccurately bisect the shaft away from the direction in which the arrowheads point (Coren 1986; Judd, 1899).

Materials and methods

Participants

Sixteen (13 women, 3 men) right-handed university students, ranging in age from 18 to 25 years, with normal or optically corrected-to-normal vision participated in this study.

Stimuli

A steel bar (shown in Fig. 1A), 7×25×203 mm, weighing 209 g was used in this experiment. Two arrowheads, both pointing in the same horizontal direction, were centered and printed in landscape orientation on a white piece of 216×279 mm paper. Each arrowhead consisted of two 70-mm lines (7 mm in thickness). One end of each line met and overlapped such that they were aligned at 90° to each other. The tips of the arrowheads were 217 mm apart. Figure 1B depicts the Müller-Lyer illusion variation background with the steel bar in place.

Procedure

This experiment consisted of two parts. All participants performed both parts and no feedback was provided at any time during the experiment. To ensure that haptic feedback regarding the bar's true center location did not influence the participant's perceptual judgment, part 1 always preceded part 2 (see Appendix).

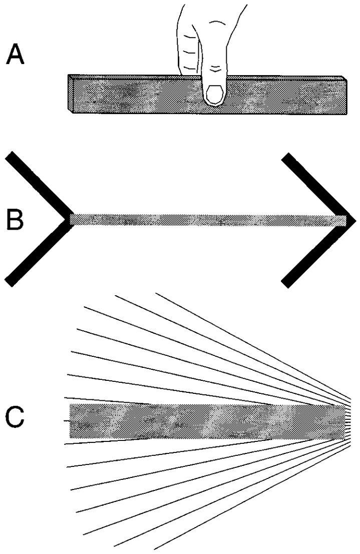

Fig. 1A–C Schematic depictions (scale approximate) of **A** the steel bar, **B** the variant of the Müller-Lyer illusory background used in experiment 1, with the steel bar in place, and **C** the Ponzo illusion background used in experiment 2, with the steel bar in place

Part 1 – perceptual task. The paper with the printed arrowheads was placed on the table (10 mm from the edge) with the arrowheads pointing either to the right or to the left (counterbalanced across subjects but otherwise randomly determined). The steel bar was centered on the arrowheads such that its length (203 mm) ran left to right and its leading edge was 9 mm back from the leading arrow's point. The bar stood on its 7-mm edge. In this way, the bar and arrowhead background together formed a variant of a Müller-Lyer illusion in which both arrows point in the same direction.

The participants stood in front of the table at a spot that would allow them to easily lift the bar with their right hand. They remained in this position for the balance of the experiment. The data were collected using a method of adjustment in which the experimenter did the adjusting. A thin piece of tape was attached to a thin Plexiglas rod such that the tape extended past the end of the rod. The experimenter then moved the rod down the length of the bar with the tape just above the top edge of the bar. The participant was asked to say when the tape's position was in the center of the bar. They were encouraged to have the experimenter adjust the position of the tape by instructing him to move it left or right. At no time were the participants allowed to reach towards or to point at the bar. When the participants were satisfied with the tape's position, the experimenter lowered the rod so that the tape stuck to the bar at that location. The bar was then removed and the location of the tape recorded. This procedure was repeated with the arrows pointing in the other direction.

Part 2 – motor task. A thin mark was inscribed on the center of the pad of the participant's index finger. A small piece of double-sided tape was scuffed on one side and this side was stuck on the inscribed mark. The paper was then randomly orientated (counterbalanced across the order imposed in part 1) so that the arrows pointed either to the left or to the right and the participant was asked to "lift the bar using only the thumb and index finger of your right hand so that it comes up off the table level or, in other words, so that it is balanced in your grip." After lifting, the bar was handed to the experimenter and the position of the tape that had now transferred to the bar was recorded. This procedure was then repeated, using the same finger mark, for the other arrow direction.

Results

Part 1 – perceptual task

The participants visually judged the center of the bar to be a mean of 97.59 mm and 104.75 mm from the left edge of the bar when the arrows of the background pointed to the right and to the left, respectively. As revealed by *t*-tests, both of these distances are significantly different from the true center of the bar (101.5 mm) ($t(15)=-5.032$, $P<0.001$; $t(15)=6.221$, $P<0.001$, respectively). The magnitude of the distance of the perceptual centers from the true center point is not significantly different for the two arrowhead orientations.

Part 2 – motor task

The participants grasped the bar an average of 99.25 mm and 103.88 mm from the left edge of the bar when the arrowheads were pointing to the right and to the left, respectively. *t*-Tests revealed that both of these distances are significantly different from the true center of the bar (101.5 mm) ($t(15)=-3.169$, $P=0.006$; $t(15)=2.357$, $P=0.032$, respectively). The absolute magnitude of the grasp centers from the true center point is not significantly different for the two arrowhead orientations.

Part 3 – comparison of perceptual and motor results

Figure 2A portrays the mean difference in center positioning between the arrowheads pointing to the left and pointing to the right for both the perceptual system and the action system. Note that positive values indicate that the judged center position is offset from the true center in the opposite direction in which the arrows of the background pointed. Both offsets are positive and *t*-tests indicated that each was significantly different from zero ($t(15)=6.238$, $P<0.001$; $t(15)=3.958$, $P=0.001$; from one another, $t(15)=2.775$, $P=0.014$).

The best-fit linear equation of grasp position (y) as a function of the visually perceived center position (x) across arrowhead orientations was $y=0.619x+0.265$.

The relationship between these variables was significant ($F_{1,30}=23.820$, $P<0.001$). The coefficient of determination was 0.443.

Discussion

The results of the *t*-test show that a reliable illusion occurred both in the participants' visual estimates of the bar's center and in the grasp position the participants chose when instructed to lift the bar in a level manner. The direction of the positional shift in both conditions was the same as that reported by Coren (1986) and Judd (1899), specifically, away from the direction that the arrows pointed. No left or right bias was recorded in either measure. A simple linear regression revealed that 44% of the variance in the grasp position can be predicted by the visual estimate of the bar's center. However, a *t*-test further revealed that the grasp position is more veridical to the actual center of the bar than is the visual estimate of the bar's center. The offset of the grasp position was, on average, 65% of the perceived offset. The implications of these findings are considered in the general discussion.

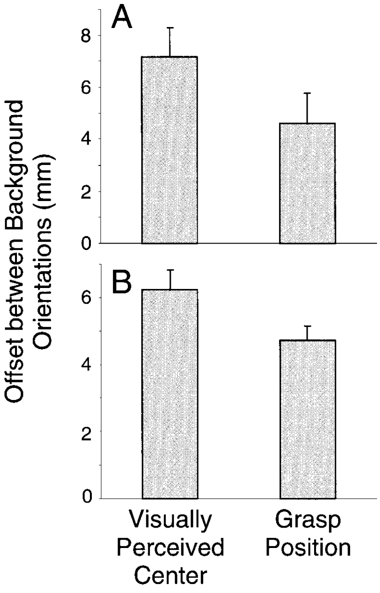

Fig. 2 A The mean difference (millimeters) in center positioning (arrowheads pointing left minus arrowheads pointing right) for both the perceptual system (Visually Perceived Center) and the action system (Grasp Position). Positive values indicate that the recorded shifts in position from true center were opposite to the direction in which the arrowheads pointed. **B** The mean difference in center positioning (background lines radiating to the left minus background lines radiating to the right) for both the perceptual system (Visually Perceived Center) and the action system (Grasp Position). Positive values indicate that the recorded shifts in position from true center were toward the direction of the background's convergence

Experiment 2

Experiment 2 is designed to replicate and extend the general findings of experiment 1 with a variation of the Ponzo illusion similar to the one employed by Brenner and Smeets (1996b). It is hypothesized that by centering the bar used in experiment 1 on the Ponzo background it will appear to an observer to be wedge-shaped (i.e., wide at the converging end and narrow at the diverging end). The results of experiment 1 indicate that this background illusion should influence a participant's visual estimate of the bar's center of mass and, to a lesser degree, the location of their grasp upon lifting that same bar. In both cases, the offset from the true center of the bar should be toward the converging (apparently wider) side of the background display.

Materials and methods

Participants

Sixteen (12 women, 4 men) right-handed university students, aged 18–29 years, with normal or optically corrected-to-normal vision participated in this experiment. None reported any muscular or cutaneous problems and none had served as a participant in experiment 1.

Stimuli

The background display consisted of 15 diverging lines centered both horizontally and vertically on a piece of 216×279 mm white paper in landscape orientation. The angle of divergence between adjacent lines was 4° and it was orientated such that the middle line was parallel to the horizontal edges of the paper. The first 32 mm of the diverging display (as measured along the middle line) were not utilized. This resulted in a vertical offset at the converging end of the display of 2.5 mm per adjacent line. The uppermost and lowermost lines were 163 mm, their immediate neighbors were 208 mm, and the other 11 lines were all 213 mm long.

The bar was the same as that used in experiment 1, but here it was placed on its broad edge (25×203 mm) in such a way that these dimensions were centered vertically and horizontally, respectively on the middle line of the background display. This is depicted in Fig. 1C.

Procedure

The methodology of this experiment was very similar to that of experiment 1. All participants performed in both parts and part 1 always preceded part 2. No feedback was provided at any time.

*Part 1 – perception task.*Here, the participants were required to provide two visual estimates of where on the bar a vertical cut would have to be made so that the resulting two pieces would each have the same weight or mass. One of these estimates was with the background display diverging to the right and the other was with it diverging to the left (the order was counterbalanced but random within that constraint). The method of determining the participants' visual estimates of these locations was the same as that outlined in part 1 of experiment 1. We emphasize that, as in experiment 1, the participant was not allowed to reach toward or point at either the bar or the display during this part of the experiment.

Part 2 – action task. Here, the participants were required to use a precision grip to lift the bar so that it was balanced in their grip. The methodology was the same as that utilized in experiment 1 except that the two background displays consisted of one in which it diverged to the right and one in which it diverged to the left (the order was counterbalanced about the order imposed in part 1 but random within that constraint).

Results

Part 1 – perceptual task

The participants visually judged the center of the bar to be a mean of 97.875 mm and 104.125 mm from the left edge of the bar when the lines of the background radiated out to the right and left, respectively. As shown by *t*-tests, both of these judged distances are significantly different from the true center of the bar (101.5 mm) ($t(15)=-7.590$, $P<0.001$ and $t(15)=-7.106$, $P<0.001$, respectively). The absolute magnitudes of these two visual perceptual centers from the true center of the bar are not significantly different from each other ($t(15)=1.620$, $P=0.126$).

Part 2 – motor task

On average, the participants grasped the bar 98.656 mm and 103.375 mm from the left edge of the bar when the lines of the background radiated to the right and to the left respectively. As revealed by *t*-tests, both of these distances are significantly different from the true center of the bar (101.5 mm) ($t(15)=-9.115$, $P<0.001$ and $t(15)=7.097$, $P<0.001$). The absolute distances of the two grasp locations from the true center point of the bar are significantly different from each other ($t(15)=2.664$, $P=0.018$), with the larger offset occurring when the radiations were to the right.

Part 3 – comparison of perceptual and motor results

Figure 2B depicts the mean difference in position between the background radiating to the left and to the right. Note that positive values indicate that the judged center position was shifted from the true center position toward the converging side of the background. As shown by *t*-tests, both are significantly different from zero ($t(15)=10.596$, $P<0.001$, $t(15)=10.499$, $P<0.001$; and, from each other, $t(15)=3.381$, $P=0.004$).

The best-fit linear equation of grasp position (y) as a function of the visually perceived center position (x) across both background displays is: $y=0.646x-0.162$.

The visually judged center is a significant predictor of the grasp location ($F_{1,30}=97.108$, $P=0.001$) and the coefficient of determination is 0.764.

Discussion

The results reported above are highly consistent with those found in experiment 1. Reliable illusions were generated both in the participants' visual estimate of the bars center and in their grasp position. The positional shift in all cases was in the expected direction (toward the converging side of the background display) and, as in experiment 1, the grasp location was more veridical to the true bar center than was the visual estimate (the grasp offset was 75.5% of the visual estimate offset). The simple regression indicated that 76% of the variance in grasp position can be predicted by the visual estimate of the bar's center.

One difference between the results of the two experiments is that, while experiment 1 found no left-right bias in either the perception or the action data, a weak bias does appear in the action data of experiment 2. A possible explanation for this effect is occlusion. Since all subjects used their right hand, some occlusion of the right side of the background display would occur when reaching and grasping the bar. In experiment 1, the Müller-Lyer background display is relatively symmetrical and partial occlusion of either the leading or the trailing arrow is unlikely to have a differential effect on the illusion. In experiment 2, however, the circumstances are rather different. The Ponzo illusion is quite asymmetrical about its centered, vertical axis. The lines comprising the converging side of the illusion are much more densely packed than those on the diverging side. Hence, it seems reasonable to speculate that partial occlusion of the converging side of the illusion would have more of a detrimental effect on the illusion than would an occlusion of equal area (but less information) on the diverging side. The results do show that the grip position offset is somewhat less when the converging, as opposed to the diverging, side of the display is partially occluded by the participants' hand.

General discussion

The above findings provide mixed support for a dissociation between the visual perception of an object's center and the position the hand was directed to when the participants were instructed to lift that same object by its center of mass. Clearly, the illusory backgrounds did affect both the visually perceived estimate of center and the grasp position. Further, the significant positive correlations (r=0.67 and 0.87) between visual perception and visually guided action obtained in both experiments 1 and 2, respectively, reveal that these effects are related. Participants who reported the strongest visual illusions tended to show the largest offsets in their grasp positions.

However, it is equally clear that these grasp centers were not as skewed from true center as were the visual percepts of center. This occurred despite the fact that each participant provided only one grasp of the object on each background. Thus, partial rather than absolute dissociation was documented. Evidence of partial dissociation suggests that, for this task at least, the motor system has access to both the illusory perceptual information (presumably obtained from the ventral stream) and the veridical information (presumably obtained from the dorsal stream). The motor system may integrate these two streams of information and direct an initial compromise solution to its output program. Presumably, this output could be modified with experience and, over repeated lifts of the bar, the grasp position could become more and more veridical.

It may be, as Brenner and Smeets (1996b) suggest, that the veridical and illusory information is processed in distinctly different ways. The veridical position of the center of mass of the bar may be coded in terms of its relationship to the observer (presumably in the dorsal stream) or observer coordinates whereas the illusory shape information and the center of this shape may be stored in object coordinates (presumably in the ventral stream) as an intrinsic object property. These different coordinate systems may in fact provide some "insulation" between, and hence facilitate the independence of, the two processing streams. However, while differing coordinate systems seem quite plausible for experiment 2's results, where there is a distinct shape illusion (the bar appears wedge-shaped), this explanation becomes somewhat more problematic for the results of experiment 1. Here, there is no obvious illusion other than an apparent shift in position of the entire object. Given that a perceptual illusion of position occurs, the perceptual stream must have position information and, given the relativity of the concept of position, it is difficult to conceptualize position as an object property.

The preceding statements aside, the partial dissociation reported here may seem discordant with the results reported by Aglioti et al. (1995) and Brenner and Smeets (1996b) in respect to apparent size and grip aperture. But is it? Inspection of Fig. 5 on page 683 of Aglioti et al. (1995) indicates that the effect of the Titchener illusion on grip aperture is in the same direction as, and is approximately 60% the magnitude of, the effect on the percept of object size. In addition, the error bars seem to indicate that the grip aperture was significantly larger when the disk appeared to be larger than it was when the same-sized disk appeared to be smaller. Unfortunately, the results of a statistical test of this comparison were not reported. Brenner and Smeets (1996b) report that illusory size does affect the size of the maximum grip aperture (in the expected direction) but that the effect was not significant (P=0.18). However, with only eight participants in their experiment, low power may help to explain the lack of significance.

Furthermore, both Aglioti et al. (1995) and Brenner and Smeets (1996b) used a design in which the same participant performed multiple reaches and grasps to the same object on the same background, 18 and 10 times, respectively. This creates a problem for the interpretation of this data because, on each grasp of the object, the observer would presumably acquire the veridical size of the object through haptic information from the hand. It may be the case that, in the initial reach toward the objects, the maximum grip aperture was substantially influenced by the illusory background, but, as more reaches were made to that same object on the same background, the aperture size may have been calibrated toward the veridical size information provided by the hand on previous grasps. When the data were collapsed across trials, as both studies did, an initial measurable effect of illusory background on grip aperture may have been diluted by subsequent trials in which the aperture was more veridical due to haptic feedback. In other words, the difference in the visual perceptual stream and the visual action stream may not be simply the way in which exclusively visual information is processed. It may be that the action stream can more easily process, integrate, and utilize sensory information acquired by other modalities such as touch. It seems reasonable to suppose that, in a reaching and grasping task, visual and haptic information would need to be integrated for efficient object manipulation, but this integration and upgrading need not affect the recognition system of either modality. In fact, such intersensory information would be undesirable, since it would probably interfere with constancy mechanisms inherent in object recognition systems. Thus, while either a visual or haptic perceptual illusion would tend to be preserved across repeated presentations of the same stimulus, an inappropriate action would not.

In summary, the current paper presents two experiments in which illusory backgrounds were used to obtain a shift in an object's perceived center. In both experiments, when participants were asked to grasp the object about its center of mass, the grasp position was more veridical than the visually perceived center position. As such, they provide support for a partial dissociation between visual perception and visually guided action. The experimental paradigms used are straightforward, and the results sufficiently robust that they may be used as a classroom demonstration of this partial dissociation.

Appendix

The magnitude of visual illusions tends to decrease only when patterns are repeatedly presented in the same positions. Right and left reversals return the illusions to full strength (Hochberg 1971). In experiments 1 and 2 all transitions from presentations 1 to 2 and presentations 3 to 4 were direction reversals and therefore no decrement in illusion strength would be expected. However, the transition from presentation 2 to 3 was counterbalanced for the same and/or reversed directions. Eight subjects received the same direction pattern and eight received a reversed direction pattern. The results of between *t*-tests for these two groups of subjects in each experiment reveal no significant difference in their first grasp positions (third judgment overall) on the bar ($t(14)=0.424$, $P=0.678$; $t(14)=0.177$, $P=0.862$, respectively).

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