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RESEARCH NOTE

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Similar effects of a motion-in-depth illusion on manual tracking and perceptual judgements

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Abstract We previously demonstrated that changing the apparent extent of a target's apparent motion-in-depth, by manipulating pictorial depth cues in the surrounding, affected perceptual judgements and manual pursuit to the same extent. Here, we investigated whether a different manipulation of the extent of motion (expanding and contracting the object itself) also has the same effect on both tasks. Objects were presented that changed in size as they moved on an elliptical path. The size was related to the object's position in the sagittal plane, suggesting additional motion in depth; therefore the illusion was expected to affect sagittal measures for both perception and action. We measured manual tracking and perceptual judgements of the lateral and sagittal extents of the object's elliptical trajectories. A significant correlation was found across subjects between the effect of the illusion on the perceptual and the motor task. As expected, the illusion only had a significant influence on the sagittal dimension. The size of this illusory effect was equal for perception and action.

Keywords Perception · Action · Dissociations · Motion-in-depth · Manual pursuit

Introduction

One concern when studying the influence of visual illusions on action is whether the visual information that is influenced by the illusion is used to guide the action. The use of different, but related, sources of information (Smeets et al. 2002) might lead to apparent dissociations. Similarly, attending to different parts of the scene could lead to apparent dissociations (Franz et al. 2001). Pursuing a target is a task that minimizes these potential problems, since the subject is required to continuously focus on a specific property: the changing position. Some studies involving the pursuit of moving targets have compared perceptual judgements with ocular pursuit (Honda 1990; Stone et al. 2000). Very few studies compare perceptual judgements with manual tracking. Masson et al. (1995) showed that manual tracking was modified when the background moved in the opposite direction than the target. It did so in a way that is consistent with the perceptual consequences of having a moving background.

We have recently shown (López-Moliner et al. 2003) that using pictorial cues to make a target appear to move further than it really does has the same effect on the perceived extent of the target's changing position as on the amplitude of the trajectory of manual tracking. In that study, the target moved along an elliptical path that was superimposed on a background containing both perspective and compression gradients. Participants were told to judge the width and depth extent of the elliptical path (perceptual task) and to pursue the target with their nonvisible hand (motor task). By turning the background upside-down, we influenced the judged extent of the target's path. Perceptual judgements and hand displacements were equally affected. We concluded that perception and manual pursuit are affected in a similar way by contextual illusions.

In this paper, we explore whether changing the apparent extent of an object's motion by making the object itself expand and contract as it moves along an elliptical path also influences both tasks to the same extent. In our previous study the contextual information affected the perceived location, and thus the position of the hand, from the beginning. This could be interpreted in terms of a stable deformation of (perceived) space. As the size of the object does not provide direct information about its position, this is not the case in the present study. The illusion is only expected to emerge when the additional motion-in-depth interpretation is elicited by

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expanding and contracting the object. Thus, unlike in our previous study, we do not expect an effect on the starting position. However, we expect perceptual judgements and manual pursuit to use the same information, so we expect the effect of the illusion to be similar for judgements and manual tracking. The results reported below supported this view.

Methods

Subjects

Eight volunteers from the Department of Neuroscience of the Erasmus MC participated in the experiment. The participants were naive with respect to the purpose of the experiment. The research in this study is part of an ongoing research program that has been approved by the local ethics committee.

Apparatus and stimuli

Images were projected at a frame rate of 85 Hz on a back-projection screen. This screen was placed 40 cm above a graphic tablet (Wacom A2). Subjects looked at the image on the screen by way of a mirror so that the image appeared to be on the tablet in front of them, but was not occluded by their nonvisible hands as they moved over the image (open-loop manual tracking; see Fig. 1A). The image was 48×36 cm. The resolution of the display was 1,024×768 pixels (thus about 21.3 pixels/cm). Subjects sat comfortably in front of the tablet. The image was approximately 50 cm from their eyes.

The stimulus was a gray square with a white dot (diameter 0.2 cm) at its center. The dot was the pursuit target. The dot moved along an elliptical (or circular) path on a black background. The target appeared 6 cm further from the subject than the center of the tablet. It remained at that position for 0.8 s in order to give the subject enough time to fixate the target and to bring the pen to the starting point in the manual pursuit task. After that it moved through 2 cycles at 0.3 Hz or 3 cycles at 0.5 Hz (about 6 s). On each trial, the elliptical motion could be described by a sagittal cosine with an amplitude of either 6 or 12 cm and a lateral sine with one of the same two amplitudes.

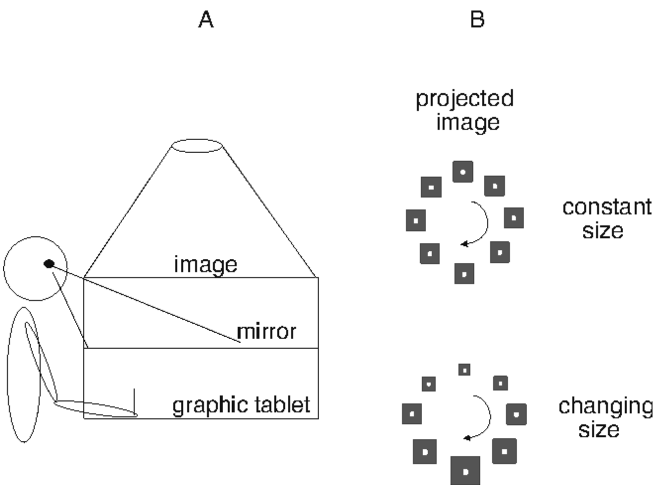

Fig. 1 **A** Schematic display of the experimental setup. The distance between the image and the mirror and between the mirror and the tablet was about 20 cm. **B** The object square with the target dot at eight moments during the presentation. The changing size condition (*bottom*) made the dot appear to move in depth with respect to the observer

The size of the square was either constant (no additional motion in depth suggested) or continuously expanding or contracting as if it were moving further in depth. When no additional motion-in-depth was simulated, the size of the square was either 1.78 or 3.56 cm (Fig. 1B, top). In order to generate the illusion of additional motion in depth, the square expanded and contracted (Fig. 1B, bottom). The range of sizes was larger for the longer sagittal extent (1.0–7.59 cm and 2.0–15.13 cm for the small and large square, respectively) than for the shorter one (1.28–2.88 and 2.58–5.77 cm for the small and large square, respectively). The increase in size was larger than the decrease and depended on the sagittal extent, because the angular size of an object increases hyperbolically when it approaches an observer. We expected the same sagittal extent to look larger when expansion or contraction was present than when it was absent. While both perceived and manual sagittal displacements were expected to be affected by the illusion, lateral measures were not.

Procedure

The combination of 2 lateral extents × 2 sagittal extents × 2 temporal frequencies × 2 square sizes × 2 conditions (with and without expansion or contraction) resulted in 32 different stimuli. The full set of stimuli was displayed twice, with a new random order each time, resulting in 64 trials for each task (perceptual judgement and manual pursuit). In the manual pursuit task, the subjects were instructed to move the tip of the pen to the position of the target, and then to keep the tip of the pen as close to the target as possible while it moved. In the perceptual task, subjects looked at the complete presentation. A white cursor then appeared. Subjects were asked to “stretch” the cursor to draw an ellipse by dragging the tablet’s pen from its initial position: the lateral and sagittal components of the movement of the pen defined the lateral and sagittal extents of this ellipse. The subject’s task was to adjust both the depth and width of this ellipse to match the sagittal and lateral extents of the dot’s motion. The cursor appeared at a random position to be sure that subjects matched the extent and not a position. Task order was counterbalanced. The two tasks were done in separate sessions.

Analysis

The lateral and sagittal extents of the adjusted ellipse served as perceptual dependent variables. For the manual pursuit task, we took the lateral and sagittal extent of the second cycle (0.3 Hz) or the average of the two last cycles (0.5 Hz). Since the amplitudes of the movements in the manual pursuit task differed considerably between subjects, we made sure that all subjects contributed equally to the average performance by normalizing the data (López-Moliner et al. 2003). To do so we determined the overall mean value for each of the physical extents and “stretched” or “compressed” (scaled) each subject’s data so that their individual average for each physical extent would be equal to the overall average. However, we performed all the analyses on both normalized and nonnormalized data to make sure that the normalization was not critical. To examine whether the illusion affected both dimensions of both tasks, we conducted a repeated-measures ANOVA for each task (perceptual judgement or manual tracking) and each physical dimension (sagittal or lateral). Each ANOVA was based on the individual subjects’ values for five within-subject factors: 2 sagittal extents, 2 lateral extents, 2 temporal frequencies, 2 square sizes, and 2 conditions (with and without expansion or contraction).

Since each task introduces its own errors and the degree of susceptibility to visual illusions is prone to large interindividual differences, we considered it inappropriate to conduct an overall analysis of variance. We therefore used two other approaches to evaluate the data. The first was to correlate the motor and perceptual effects across subjects (Franz et al. 2001; Bartelt and Darling 2002). If the same information is used, we expect a high correlation irrespective of the absolute values involved and irrespective of whether the illusion has a consistent effect across subjects. For a more quantitative evaluation, we applied a method that we have described in more detail elsewhere (López-Moliner et al. 2003). This second method is based on the assumption that there is a linear relationship between physical dimensions and our response to those dimensions, irrespective of the task. If so, then when the physical dimension is varied there will also be a linear relationship between our responses in the tracking task and our perceptual judgements. If an illusion has the same influence as varying the physical dimension, then the same relationship should also hold for the influence of the illusion. Thus, if we plot manual pursuit measurements as a function of perceptual judgements, all the data points should lie along the same straight line, regardless of the visual illusion condition. To test whether the points deviated significantly from a straight line, we used a chi-square merit function that compares the residual errors of the fit with the horizontal and vertical standard errors in the points themselves. Because subjects made systematic errors that are not related to the illusion, the raw data contain an additional source of between subject variability. By normalizing the data we get rid of such variability and make sure that all the subjects contributed equally to the mean, so that the chi-square test becomes more sensitive. Since both the measures contain errors, we used a function that considers both sources of error (equation 15.3.2 in Press et al. 1992). If the fit is good, (i.e., the chi-square value is below the critical value), then we cannot reject the hypothesis that all the points lie on a single line.

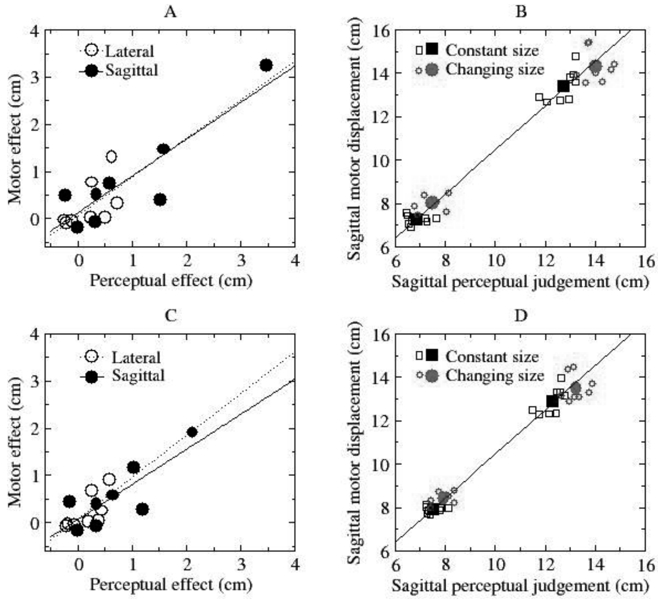

Fig. 2A–D The effects of the illusion on manual tracking and on perceptual judgements. **A** and **B** show raw data. **C** and **D** show normalized data. **A** and **C** show the correlation between the perceptual and motor influence of the illusion across subjects. Each symbol shows the average effects for one individual subject. **B** and **D** show the sagittal extent of the manual tracking movement and the corresponding perceptual judgement for each kind of stimulus. The *open symbols* show averages over all subjects for each condition (see text). The *solid symbols* show averages for each amplitude for targets that do or do not change size

Results

Effects of the illusion

Since ANOVAs conducted on normalized and raw data resulted in the same factors being significant, we only report the values obtained for the normalized data. As expected, the motion-in-depth illusion affected neither the perceived width nor the lateral manual displacement. Perceived and manual lateral extent were obviously affected by the actual lateral displacement ($F_{1,7}$=292.9, P<0.001, and $F_{1,7}$=410.1, P<0.001). Temporal frequency also affected manual lateral extent ($F_{1,7}$=47.7, P<0.001; movements were larger for the higher frequency) and the interaction between temporal frequency and lateral extent was significant ($F_{1,7}$=12.2, P=0.01; the difference between both frequencies was larger for the larger lateral extent).

The illusion had a clear effect on both perceptual and manual sagittal extents ($F_{1,7}$=6.8, P=0.035, and $F_{1,7}$= 5.73, P=0.048, respectively). The average effect of the illusion was 0.68 cm for the perceptual task and 0.57 cm for the motor task (an increase of 5–10%). Beside the expected effect of the actual sagittal extent on perceived and manual sagittal extents ($F_{1,7}$=353, P<0.001, and $F_{1,7}$=555.87, P<0.001, respectively), the interaction between temporal frequency and physical lateral extent was also significant for sagittal judgements ($F_{1,7}$=13.17, P=0.008; lateral physical extent affected perceived sagittal extent only in the low-frequency condition). None of the interactions involving the influence of the illusion were significant.

The pictorial depth illusion of our previous work (López-Moliner et al. 2003) influenced the initial position of manual tracking. As expected, we found no influence on the initial position of the manual tracking for the present illusion (paired t-test, $t(6)$=–0.92, P=0.8). Note that this is not completely trivial, because the initial size of the square was smaller for trials with than for those without additional motion-in-depth.

Comparing judgements and pursuit

Figure 2a (raw data) and c (normalized data) show the relationship between the influence of the illusion on manual pursuit and that on perceptual judgement. The points represent individual subjects. The influences on the sagittal dimension were highly correlated, both for the raw data (R=0.90, P=0.001) and normalized data (R=0.81, P=0.007). The slopes of linear fits to the data were also quite similar (0.82±0.39 and 0.74±0.17), with intercepts close to zero (0.06±0.58 and 0.06±0.15). Although there was no consistent effect of the illusion across subjects for the lateral dimension, there too we found a correlation between subjects' performance on the two tasks. For the raw data, the correlation was marginally significant (R=0.60, P=0.06), with slope 0.78±1.04 and intercept 0.12±0.44, and for the normalized data the correlation was significant (R=0.71, P=0.025), with slope 0.89±0.52

and intercept of 0.07±0.14. Since only sagittal measurements, as expected, were significantly affected by the illusion, we analyzed them further as described in the analysis section.

Figure 2b (raw data) and d (normalized data) show the sagittal extent of the manual tracking movement and the perceived sagittal extent of the ellipse for each kind of stimulus. Each symbol represents the average of all the subjects and the kind of symbol (square or circle) indicates the motion-in-depth condition. The open symbols give the values for each of the 32 conditions. The solid symbols give the averages for each sagittal extent and illusory condition (averaging across the two temporal frequencies, the two sizes, and the two amplitudes of the movement in the orthogonal physical dimension). The parameters of the line that were fit to the 32 points were virtually the same for the raw and the normalized data. The fit yielded an intercept of 0.26 cm (95% confidence interval ±0.75) and a slope of 1.02 (95% confidence interval ±0.07) indicating that the relationship between physical dimension and response is the same for perception and action. The $\chi^2(30)$ values were 10.8 (P=0.99) and 33.8 (P=0.29) for the raw and normalized data, respectively, indicating that the distribution of the points around the line did not differ from what could be expected on the basis of their standard errors. We therefore cannot reject the hypothesis that the illusion had the same effect on both tasks.

Discussion

The reported results clearly point to the same processing for manual pursuit as for perceptual judgements. The average effect of the illusion is considerably larger than most previously reported effects of illusions on grasping, which makes it unlikely that they are overshadowed by other effects (e.g., the obstacle explanation for the Ebbinghaus illusion; Haffenden and Goodale 2000; Smeets et al. 2003). Effects on perception and action were highly correlated across subjects. The linear relationship between the perceptual and motor measures, with a slope close to unity and intercept close to zero, indicates that both tasks are based on the same relationship between physical extent and perceived extent.

One might argue that performing the manual tracking task in open loop makes it similar to a perceptual judgement. It is not clear, however, how one can use a closed-loop task while preventing participants from using other sources of visual information than those under study; e.g., using the visual gap between the target and the tip of the pen to correct errors. The open-loop tracking task guarantees that the same information is relevant for the two tasks. This circumvents the problems that arise if subjects have several options for the use of visual information. For example, the lack of illusory effects of size illusions on grasping (Kwok and Braddick 2003) could be accounted for by the fact that grasping is not based on size estimates, but on position of final contact points (Smeets and Brenner 1999).

The present illusion affected the perceived depth in a different way than the illusion in the previous study. This is evident from the fact that the perspective illusion influenced the initial pointing position (López-Moliner et al. 2003), while the present, size-based illusion did not. We therefore extend previous arguments (Smeets and Brenner 1995; Smeets et al. 2002) to conclude that people use the same information for both perception and action, independent of the kind of visual illusion that is involved.

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