Research Article

COMPARING THE SENSITIVITY OF MANUAL PURSUIT AND PERCEPTUAL JUDGMENTS TO PICTORIAL DEPTH EFFECTS

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Abstract—*We examined whether a pictorial depth illusion influences the manual pursuit of a moving dot to the same extent that it influences the dot's apparent displacement. Fourteen subjects performed two tasks. In one case, they used their unseen hand to track a dot that moved on an elliptical path. In the other, they first watched the dot move on the same path, and then set an ellipse to match the shape of the dot's path. The illusion influenced the two tasks to the same extent, suggesting that the visual information processing is the same for the two tasks.*

Exploring whether a visual illusion has the same influence on a motor task as on its perceptual counterpart has become a standard way to test for common information processing for perception and action. Some studies have reported *dissociations*, with different patterns of results for perceptual-judgment and motor tasks. Such findings have been regarded as support for the separate processing of visual information for perception and action (e.g., Goodale & Milner, 1992; Loomis, Da Silva, Fujita, & Fukusima, 1992). However, visual illusions frequently involve incongruous effects on related visual attributes (Gillam, 1998). The reported dissociations can therefore also be interpreted as indicating that different visual attributes were used to perform the different tasks (Smeets & Brenner, 2001). In support of such an interpretation, it can be noted that similar dissociations are found even when both tasks involve perceptual judgments or both involve actions (Smeets & Brenner, 1995; Vishton, Rea, Cutting, & Nunez, 1999). Thus, whenever actions resist an illusion that distorts perception, it is necessary to check whether the motor response is being driven by the same visual attributes as the perceptual judgment. (See, e.g., Bruno, 2001; Carey, 2001; Goodale & Haffenden, 1998; and Smeets, Brenner, de Grave, & Cuijpers, 2002, for recent reviews on using illusions in perception-action dissociation experiments.)

In this article, we compare the effect of a pictorial illusion on the perceived trajectory and manual pursuit of a moving dot. The two tasks were devised to be as similar as possible while at the same time clearly representing perceptual judgment and action, respectively. Obviously, there are limitations in the extent to which both criteria can be met. We concentrated on trying to ensure that the same kind of information was used for the two tasks, although even this has proven to be difficult to guarantee (Franz, Fahle, Bülthoff, & Gegenfurtner, 2001; Vishton et al., 1999). We tried to meet this criterion by designing both tasks in a way that encouraged subjects to use changing position as the primary source of information. We reasoned that this would be the case if the tasks involved continuously tracking the position of a target. Thus, the manual-pursuit task was to constantly follow a dot with an (invisible) pen. For the perceptual-judgment task, subjects had to judge the shape and size of the dot's path. As the path was defined only by the dot's changing position, performance in this task also had to rely on tracking the target.

The most likely alternative source of information for performing these tasks is the perceived motion of the target. If, for instance, the perceptual judgment is based on the target's motion, whereas the pen's movement is based on the target's position, then an illusion that influences the two attributes to different extents will also influence the two tasks to different extents. Bridgeman, Kirch, and Sperling (1981) found that although moving the background could influence the extent to which a target was seen to move, it did not influence where subjects pointed when asked to point at it. This finding led them to conclude that perception and action use different visual information. However, it has subsequently been shown that changes in perceived motion that are induced by background motion can influence the speed of arm movements both in manual tracking (Masson, Proteau, & Mestre, 1995) and in hitting the moving target (Smeets & Brenner, 1995). In the study by Bridgeman et al., although the moving background influenced the target's perceived motion, it did not affect the perceived position. It may even have influenced perceived position in the opposite direction (Brenner & Smeets, 1997). We do not expect pictorial illusions of depth have such differential effects on these two attributes. Nevertheless, this possibility should be kept in mind.

We expected pictorial illusions of depth to lead to misjudgments of the extent of a target's path. Our main question was whether the path of the hand when manually tracking the dot would be influenced to the same extent. We examined this by asking subjects to both manually pursue the changing position of a moving dot and report the size and shape of the path it moved through. Separate presentations of identical stimuli were used for the two tasks, in order to ensure that subjects did not judge the movement of the hand during pursuit, rather than that of the target, when making the perceptual judgments. Two different backgrounds were used. We predicted that the extent of the hand's movement during manual pursuit would be larger when the background made the target appear to be further away. We show that the effect of the illusion was equivalent in the two tasks.

METHOD

Subjects

Fourteen volunteers participated in the experiment. They were naive with respect to the purpose of the experiment.

Apparatus and Stimuli

Computer-generated images were projected on a back-projection screen at a frame rate of 60 Hz. The screen was placed 44 cm above a graphic tablet. Subjects looked at the images on the screen by way of a

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mirror, so that each image appeared to be on the tablet in front of them but was not occluded by their (invisible) hands as they moved over it (see Fig. 1a). Each image was 50 × 37 cm. The resolution of the display was 1,024 × 768 pixels, thus about 20.5 pixels/cm. Subjects sat comfortably in front of the tablet so that the images were approximately 50 cm from their eyes. Each image contained a green dot that moved along an elliptical path. The dot appeared 14 cm below the center of the display and remained at that position for 0.8 s in order to give the subject enough time to bring the pen to the starting point in the manual-pursuit task. The dot then moved for 3 s. On each trial, the dot's elliptical motion was described by a sagittal cosine (in depth) with an amplitude of either 1.72 or 3.44 cm and a lateral sine (width) with an amplitude of 2.58 or 4.30 cm. For each combination of amplitudes, the dot moved at one of two temporal frequencies: 0.5 or 1 cycle/s.

The dot was superimposed on a background that looked like a tiled floor or ceiling (see Fig. 1b). Because the elliptical path was closer than the center of the image, the target appeared to be nearer when presented on the "floor" than when presented on the "ceiling." The green dot's path on the screen (or tablet) was identical for the two backgrounds, so we could be sure that any differences in responses were due to the background. We expected the backgrounds to have very similar illusory effects on the sagittal and lateral extents of the dot's displacement, but nevertheless analyzed the results for sagittal and lateral extents separately.

Procedure

There were 16 different stimuli resulting from the combination of two depths, two widths, two temporal frequencies, and two backgrounds. Stimuli were displayed in random order until all 16 stimuli had been presented. This procedure was repeated three times (with a new random order each time), resulting in 48 trials for each task (perceptual judgment and manual pursuit).

In the manual-pursuit task, the subjects were instructed to move the tip of a pen to the position of the target, and then to keep the tip of the pen as close to the dot as possible while it moved. In the perceptual task, subjects first looked at the complete 3-s presentation. A black background then appeared, with a cursor 2 cm above the center of the previous image. Subjects could "stretch" the cursor to draw an ellipse

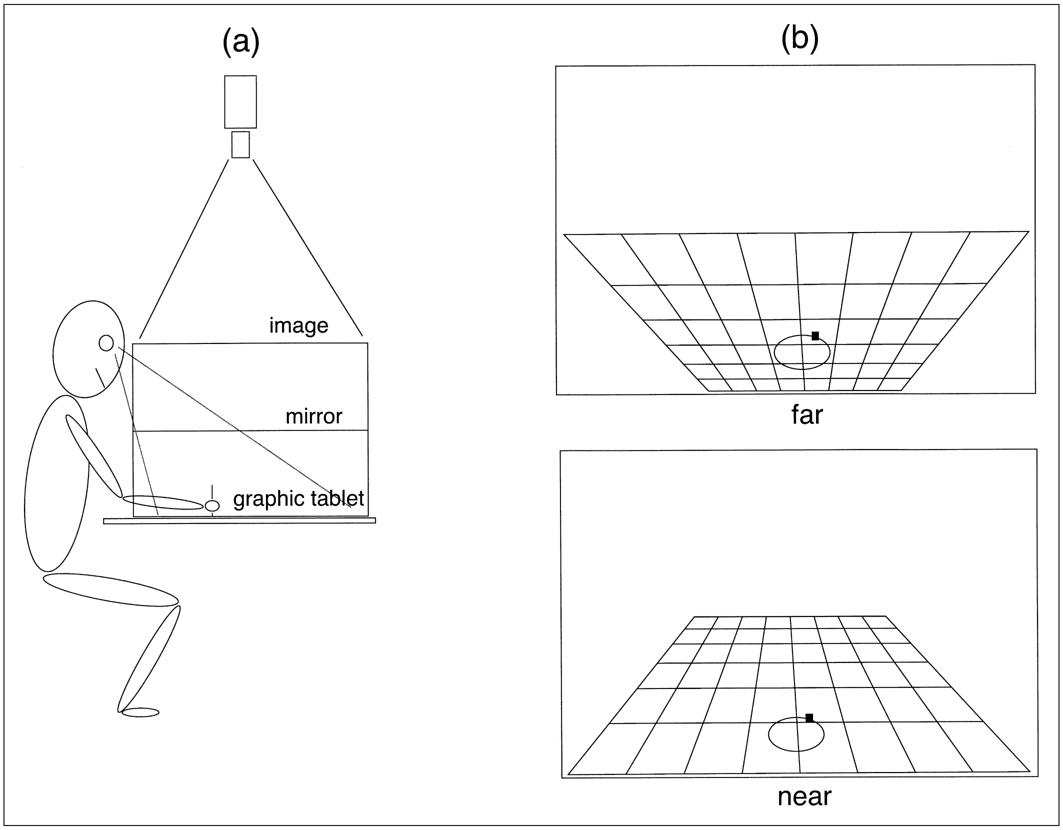

Fig. 1. Illustration of the experimental setup (a) and of the background in the display (b). Subjects saw an image that coincided with the surface of a tablet on which they moved a pen, but the image was seen via a mirror so that the subjects could not see their hands. The distance between the image and the mirror and between the mirror and the tablet was about 20 cm. On each trial, a dot moved on an elliptical path, as shown in (b). The dot appeared to be further away when the background looked like a ceiling (far) than when it looked like a floor (near).

by dragging the tablet's pen from its initial position: The lateral and sagittal extents of the ellipse were defined by the horizontal lateral and sagittal components of the movement of the pen. The task was to adjust both the depth and the width of the ellipse to match the sagittal and lateral extents of the dot's motion. Half of the subjects performed the motor task first, and the other half performed the perceptual-judgment task first. Each subject performed both tasks during a single session.

Analysis

For the perceptual-judgment task, we used the set width and depth of the ellipse as an indicator of the perceived extent of the dot's path. For the manual-pursuit task, we measured the lateral and sagittal extent of each cycle (i.e., complete elliptical path of the dot), after eliminating the first cycle (for stimuli presented at 1 Hz) or the first half cycle (for stimuli presented at 0.5 Hz). Because 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. To do so, we determined the overall mean value for each of the physical extents, and shifted and "stretched" or "compressed" (scaled) each subject's data so that each subject's average for each physical extent was equal to the overall average.

We assumed that the backgrounds we used would induce differences in the performance of the two tasks. To make sure that this was the case, we conducted a separate repeated measures analysis of variance (ANOVA) for each task (perceptual judgment or manual tracking) and each physical dimension (sagittal or lateral extent). Each ANOVA was based on the individual subjects' values for four within-subjects factors: two sagittal extents, two lateral extents, two backgrounds, and two temporal frequencies. There was also one between-subjects factor: task order.

Although we assumed, as argued in the introduction, that subjects would track the target's position in our manual task, they could also have performed the task by copying the target's motion. In order to check that the judged position was really influenced by the illusion, we performed an additional ANOVA on the initial position of the pen in the manual task. We expected to find that the background's effect on the pen's initial position would be similar to its effect on the extent of the motor response.

Hypothesis Testing

Our test was based on the assumption that there is a linear relationship between physical dimensions and judgments of those dimensions. We assumed that this holds both for the judgments reported in perceptual tasks and for the judgments that are used to guide actions. If these linear relations exist, one can use them to determine whether these two kinds of judgments are influenced differently by a visual illusion (see Franz et al., 2001).

Let us suppose that both perceptual judgments (P) and manual pursuit (M) depend linearly on the physical dimension D:

$$P = b_p * D + a_p \tag{1}$$

and

$$M = b_m * D + a_m \tag{2}$$

We can now express M as a function of P:

$$M = (b_m / b_p) * P + a_m - a_p * b_m / b_p \tag{3}$$

Thus, M and P are related linearly, with a slope of b_m/b_p. Note that this relationship is independent of D. Our hypothesis was that the backgrounds would influence b_p and a_p to the same extent as they influenced b_m and a_m, so that the slope and offset of the relationship between M and P would be the same for the two backgrounds. The alternative is that the background influences b_p or a_p to a different extent than b_m or a_m, in which case the relationship between M and P will have different slopes, offsets, or both for the two backgrounds. In other words, our hypothesis was that if we plotted manual-pursuit measurements, M, as a function of perceptual judgments, P, all the data points would lie along the same straight line, regardless of the background. In contrast, if the background influenced the perceptual judgments and actions differently, then the points for the two backgrounds would lie on two different lines.

In our experiment, we had 16 measurements for each dimension (lateral or sagittal), resulting from the 16 distinct stimuli (2 widths × 2 depths × 2 temporal frequencies × 2 backgrounds). We averaged the values for each of these measurements across subjects for each task (perceptual and motor). We then fit a line to a plot of the amplitude of lateral hand movements as a function of the perceived width using these 16 points. We did the same for the amplitude of the sagittal hand movement as a function of the perceived depth.

Finally, we determined the extent to which these best-fitting lines really fit the data. To do so, we used a chi-square merit function that compares the residual errors of the fit with the horizontal and vertical standard deviations in the points themselves. In our case, both the coordinates contained measurement errors, so we used a function that is defined in a manner that considers both sources of error (Equation 15.3.2 in Press, Teukolsky, Vetterling, & Flannery, 1992). If the fit was bad (i.e., if the chi-square value was above the critical value), we would reject the hypothesis that the background has a similar influence on the two tasks.

RESULTS

Figure 2a shows the sagittal extent of the manual tracking movement as a function of the perceived depth of the ellipse in the perceptual task. Similarly, Figure 2b shows the lateral extent of the manual tracking movement as a function of the perceived width of the ellipse. Because task order did not yield significant differences, each symbol represents the average of all the subjects.

Lateral Effects of the Illusion

Neither task order nor any interaction involving task order yielded a significant difference for either perceptual judgments or hand displacements. We found a significant effect of the background on both perceptual judgments (0.21 cm) and hand displacements (0.15 cm), indicating that the pictorial depth influenced both perception and action, $F(1, 12) = 15.02$, $p = .002$, and $F(1, 12) = 15.25$, $p = .002$, respectively. As expected, we also found an effect of the lateral physical displacement (2.58 and 4.30 cm) on both perceptual judgments, $F(1, 12) = 353.08$, $p < .001$, and hand movements, $F(1, 12) = 139.11$, $p < .001$. The interaction between sagittal and lateral physical amplitudes also had a significant effect on lateral judgments, $F(1, 12) = 13.73$, $p = .003$. No other comparisons were significant.

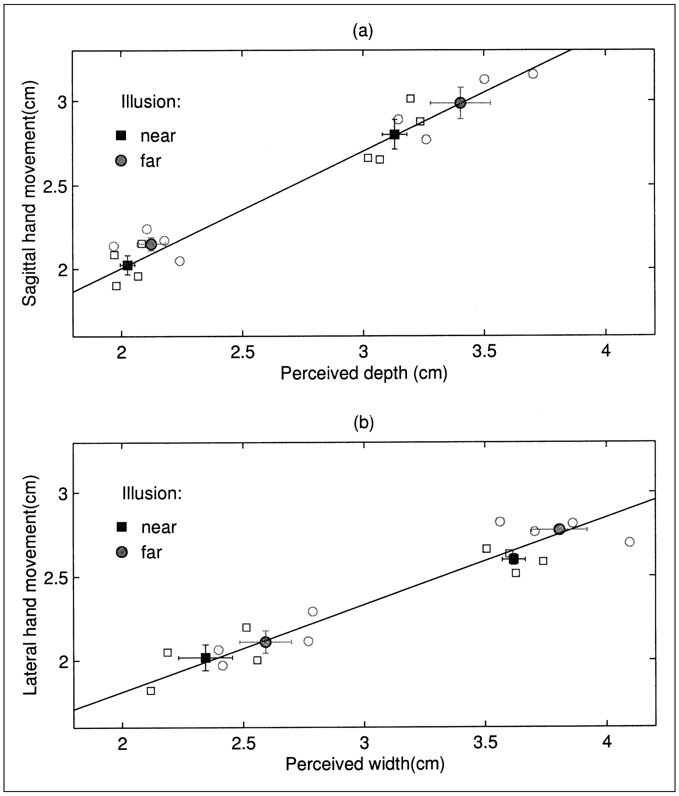

Fig. 2. Sagittal (a) and lateral (b) extents of the manual tracking movements as a function of the corresponding perceptual judgments (depth, width). The kind of symbol (square or circle) indicates the background condition (near or far). The open symbols show averages over all subjects for each of the 16 conditions. The solid symbols show averages across factors that were not included in the simple model (Equation 3): temporal frequencies and amplitudes in the orthogonal direction. The error bars indicate the standard error in the averages across subjects.

Sagittal Effects of the Illusion

Again, neither task order nor any interaction involving task order yielded a significant difference for either perceptual judgments or hand displacements. The background had a significant effect on both perceptual judgments (0.18 cm), $F(1, 12) = 46.59$, $p < .001$, and hand movements (0.125 cm), $F(1, 12) = 18.1$, $p = .006$. There was a significant effect of lateral physical displacement on the perceptual judgments, $F(1, 12) = 27.43$, $p < .001$: The same sagittal extent was perceived to be smaller when combined with the larger rather than smaller lateral displacement, as previously reported by Armstrong and Marks (1997). This effect was also evident for the hand movements, $F(1, 12) = 20.98$, $p < .001$. The sagittal physical extent also influenced both the perceptual judgments, $F(1, 12) = 538$, $p < .001$, and manual pursuit, $F(1, 12) = 520.8$, $p < .001$. The interaction between sagittal and lateral physical displacement had a significant effect on both perceptual judgments, $F(1, 12) = 15.1$, $p = .002$, and hand movements, $F(1, 12) = 11.9$, $p = .005$. Finally, the interaction between lateral physical displacement and background had a significant effect on perceptual judgments, $F(1, 12) = 6.3$, $p < .02$. No other comparisons were significant.

Effects on the Initial Pointing Position

The influence of the background not only was visible in the extent of the manual pursuit, but also could already be observed when the subjects moved the pen to the initial position of the dot on the screen. A repeated measures ANOVA on the initial position revealed a significant effect of the background for this measure, $F(1, 12) = 6.02$, $p = .03$. The magnitude of this effect ($M = 0.12$ cm) was not significantly different from the magnitude of the effect of the background on manual pursuit ($M = 0.1375$ cm), $t(7) = -1.19$, $p = .135$.

Testing for the Use of Common Information

The points in each panel of Figure 2 appear to cluster along a single line. The intercept and slope of the fitted lines (using the 16 values indicated by the open symbols) were 0.488 cm and 0.706 (sagittal) and 0.77 cm and 0.52 (lateral). The chi-square values of these fits were, respectively, $\chi^2(14) = 12.43$ ($p = .57$) and $\chi^2(14) = 21.25$ ($p = .09$). These values are below the critical value of $\chi^2(14, 0.05) = 23.685$, indicating that the lines are good descriptions of the pattern in the data (considering how certain one can be of the positions of the data points). We thus cannot reject the hypothesis that the illusion had the same effect on perception as on action.

DISCUSSION

Figure 2a shows that the influence of the background on sagittal manual pursuit (the positions of the circles and squares within each cluster of points) was quite close to what one would predict on the basis of a linear relationship between motor responses and perceptual judgments (the positions of the two clusters). Thus, the pictorial illusion of depth influenced the two tasks to the same extent. The pattern in Figure 2b is less perfect, with a tendency for a larger slope and smaller intercept for the far condition than for the near condition. This would correspond to larger values for b_m/b_p and smaller values for $a_\text{m} - a_\text{p} * b_\text{m}/b_\text{p}$ in Equation 3. Such a pattern could be caused by a difference between perception and action in their sensitivity to the illusion, but we conclude that this was not the case because the chi-square test indicated that the line is a good fit.

An alternative explanation is that the relationship between the physical width and the judgment of that extent is not completely linear (in contrast to the assumption of Equations 1 and 2). This not only could explain the possible deviation from a straight line in Figure 2b, but also could explain why such a deviation is not apparent in Figure 2a. If the relationship between the physical extent and the judgment of that extent is exactly the same for the two tasks, then the values for the two tasks will not only be related linearly, but will be identical, resulting in a slope close to unity and almost no intercept. This is almost the case in Figure 2a. If the relationship is not exactly the same for the two tasks, then the values will differ and the relationship between them may become nonlinear. This may be the case in Figure 2b, in which all points appear to lie on a parabolic curve.

Irrespective of how the deviation from a perfect fit in Figure 2b is interpreted, it is clear that the illusion of pictorial depth influenced the perceptual and motor tasks to a very similar extent. That perceptual illusions can influence limb motor control has been reported before. Abrams and Landgraf (1990) reported that the hand's movement when reproducing a perceived distance was more strongly affected by motion of the background than the hand's movement when pointing to a target's perceived final position. As mentioned in the introduction, a moving background affects perceived motion and perceived position differently (Smeets & Brenner, 1995); this makes it difficult to speak about the magnitude of the illusion. We tried to circumvent this problem by using pictorial depth rather than a moving background. Our illusion influenced the judged amplitude similarly in the two tasks, and influenced the amplitude of the manual pursuit in much the same way as it influenced the initial position of the hand. Thus, we were able to avoid the kind of dissociation between position and extent that was observed with a moving background. We conclude that pictorial depth influences actions in the same way that it influences perceptual judgments.

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