Notes and Comment

Extraretinal signals combine with induced motion: A note

K. PRAZDNY and MIKE BRADY

*Computer Vision Laboratory, Computer Science Center
University of Maryland, College Park, Maryland 20742
and*

*The Artificial Intelligence Laboratory
Massachusetts Institute of Technology*

345 Technology Square, Cambridge, Massachusetts 02139

If the eye engages in smooth pursuit movement, the observer's perception of the path of the tracked object is often far from veridical (Festinger & Easton, 1974; Fujii, 1943; Mack, Fendrick, & Sirigatti, 1973). For example, Mack et al. (1973) reported that when a horizontally moving dot is tracked by the eyes and stops suddenly, it is seen to rebound sharply backwards. Fujii (1943) reported a surprising difference between the actual and the perceived path of movement of a luminous dot moving on a square or triangular path: at the corners of the figure, where the dot changed its physical motion suddenly, the phenomenal path was a curved trajectory. Here, we report another interesting example of a discrepancy between the actual and perceived motion of a tracked object involving a target in induced motion.

Refer to Figure 1. When the rectangle, R, moves vertically upward and the dot, D, moves obliquely upward, the dot is perceived to move horizontally to the left, sliding along the upper edge of the rectangle. This is a typical induced-motion situation encountered in the laboratory (Duncker, 1929; Wallach, 1959). If, at a randomly determined point during this sliding motion, the dot is suddenly stopped and kept stationary while the rectangle maintains its upward motion, the dot is seen to move along a curved trajectory. The phenomenal motion of the dot is illustrated in Figure 1b. This illusory motion of the dot was seen by every observer when the dot was tracked by the eyes. The illusion is crucially dependent upon pursuit eye movement. If the dot is not fixated, subjects report the dot as moving along the path illustrated in Figure 1c. This is a percept due to the induced motion (Duncker, 1929; Wallach, 1959). It is the form and extent of the curved part of the phenomenal trajectory which is interesting as an indication of the way in which extraretinal signals combine with other information to determine phenomenal motions. Note that in Figure 1b, the phenomenally

We would like to thank Professor Jacob Beck for advice and encouragement.

Figure 1. (a) The dot, D, moves obliquely upward with velocity v_D . When the enclosing framework (R) moves vertically upward with velocity v_v , the dot is seen as moving along the upper horizontal boundary of the rectangle. (b) When the dot stops while the rectangle continues to move upward, the phenomenal path curves and finally merges into a vertically downward motion along a straight line. The speed of the dot's motion is perceived to decrease as it moves along the curved portion of the path. (c) When the dot is not fixated, the phenomenal path described by the dot does not curve.

vertically downward motion of the dot (which is often described as along a straight line asymptotic to the curved part of the trajectory) is horizontally displaced with respect to the point (e) where the dot became physically stationary. Preliminary observations indicated that the major determinant of the extent of the curved path was the angle θ (see Figure 1a). The following two experiments were designed to evaluate this observation.

Method

All experiments reported here were carried out using a DEC GT44 graphic display terminal controlled by a PDP-11/10 single-user minicomputer. The stimuli were sequences of discrete "snapshots," but, due to the phi-motion, all phenomenal motions were continuous and smooth. The observers were located approximately 1.7 m in front of the display, which subtended a visual angle of about 12 deg of arc. The observer was seated with head fixed by a restraining apparatus and a bite board. The experimental room was dimly lit, and the display was viewed binocularly (monocular viewing was found to yield nonsignificant differences). Two target dot speeds were used: 1 and 2 deg of arc/sec. To measure the curved part of the phenomenal trajectory, we measured its width (w) and height (h).¹ The position of the point, e, where the dot objectively ceased to move and the experimental condition (one of the three angles θ) were chosen at random under the control of the program. Each experiment consisted of two sessions determined by the speed of the dot (1 or 2 deg of arc/sec). The order of presentation of these sessions was counterbalanced. Each session consisted of 60 measurements (20 pairs of values of h and w for the three values of the angle θ). Before the measurements were taken, the subjects were made familiar with the display and

Figure 2. Results for Experiment 1. (a) The speed of the dot was 2 deg of arc/sec. Each data point is the mean of 20 observations. (b) The speed of the dot was 1 deg of arc/sec. Each data point is the mean of 20 observations.

Figure 3. (a) When the dot, D , moves obliquely upwards with velocity v_D while the wedge moves vertically upward with velocity v_v , the dot is seen to move along the upper sloping boundary of the wedge. This is the percept consistent with the results of past induced motion studies. (b) When, at the moment the dot, D , stops physically moving, the wedge begins to move horizontally to the left instead of continuing to move upward, the observers see the dot move along the curved path, as indicated.

the manner in which responses were to be recorded; they had approximately 10 practice presentations, 5 at each dot speed. Four subjects, all with normal vision, participated in the experiments.

Results

In the first experiment, we measured the values of w and h in the situation in Figure 1. The values of θ were 120, 140, and 160 deg of arc. The results are summarized in Figure 2. As can be seen, the effect of the slope of the oblique (physical) motion of the dot completely overshadowed any effect of the speed of motion of the dot. Furthermore, as can be seen in Figure 2, as h decreased with θ , w also increased. These tendencies were found in all subjects.

In the second experiment, we changed the shape of the enclosing framework of the dot to produce a different phenomenal part. Refer to Figure 3. As can be predicted from our knowledge of induced motion (Duncker, 1929), when the wedge moves vertically upward and the dot moves obliquely upward, observers see the dot traveling along the upper sloping edge. When the wedge changes its motion so that, at the moment the dot stops, it begins to move horizontally to the left with the same speed, the dot is seen to move along the path sketched in Figure 3b. Again, as in the first experiment, the curving of the path after the abrupt change of the dot's physical motion is a function of the angle θ , and attributable to the pursuit eye movements. No curving is perceived when, for example, a corner of the enclosing framework is tracked. As in the first experiment, the width, w , and the height, h , were measured as functions of the angle θ (110, 130, and 150 deg of arc/sec). The results of these measurements are summarized in Figure 4. As can be seen, w decreases monotonically while h is an "inverted U-shape" function of the angle θ .

Discussion and Conclusion

The phenomenal path of the dot in the situations

Figure 4. Results from Experiment 2. (a) The speed of the dot was 2 deg of arc/sec. Each data point is the mean of 20 observations. (b) The speed of the dot was 1 deg of arc/sec. Each data point is the mean of 20 observations.

used in our experiments can easily be explained in terms of the combined effect of two variables: the consequence of the unmonitored overshoot of the target by the eyes (Mack et al., 1973) and the motion induced in the dot by the moving enclosing framework (Duncker, 1929; Wallach, 1959) (it remains to be determined, however, exactly why this induced motion effect occurs).

Mack et al. (1973) suggested that when the tracked target stops suddenly, there is a time lag between the command to stop the pursuit eye movements and the actual effect of this command (as is the case in any real physical dynamic system). Assume that the visual system monitors the efferent commands for use in the retinal-motions/eye-movement comparator (see, e.g., Festinger & Easton, 1974). After the command "eye stationary" is issued (and monitored), the eye still moves for a time period (e.g., due to delays in the transmission lines), during which the retinal motion of the dot is unaccounted for in the retinal-motions/eye-movement comparator. The net result is phenomenal motion of the dot in the direction exactly opposite to the residual eye movements remaining after the command "eye stationary" is issued. Instantaneously, both the effects (the induced motion and the effect of the unmonitored overshoot of the target by the eyes) can be described by two velocity vectors. Assuming that the component velocity vectors are added vectorially and that the effect of the unmonitored overshoot decays over time [the exact form and origin of this decay function is not crucial (for our purposes here) as long as it is monotonic], the integration of the instantaneous velocity vector over time does, indeed, yield paths closely matching the observations. This simple additive model also produces the monotonic decrease of $w(\theta)$ and the "inverted U-shaped" function $h(\theta)$ in Figure 4.

To summarize, the kinetic illusion described here can be regarded as yet another interesting example of the way in which efferent signals are used by the visual system to codetermine perceptions of moving objects. Our explanation is based on combining hypotheses offered for the two component phenomena in separation. The illusion may prove useful in further research into the way in which various sources of information combine to produce phenomenal motions.

REFERENCES

- DUNCKER, K. Über induzierte Bewegung. *Psychologische Forschung*, 1929, 12, 180-259.
- FESTINGER, L., & EASTON, M. Inferences about the efferent system based on perceptual illusions produced by eye movements. *Psychological Review*, 1974, 8, 44-56.
- FUJII, E. Forming a figure by movement of a luminous point. *Japanese Journal of Psychology*, 1943, 18, 196-232.
- MACK, A., FENDRICK, R., & SIRIGATTI, S. A rebound illusion in visual tracking. *American Journal of Psychology*, 1973, 86, 425-433.

WALLACH, H. The perception of motion. *Scientific American*, 1959, **201** (June), 56-60.

NOTES

1. To measure the position of the point where the phenomenal path stops curving and starts to resemble a straight line, the observers manipulated a vertical movable line (which could change position as well as length) so as to bring its upper endpoint into coincidence with the required asymptotic point. This was established by using the light pen facilities of the display processor. To maintain the fixed position of the subject's head, the exper-

imenter manipulated the light pen under verbal instructions from the subject. The display was programmed so that the pen movements were performed outside the enclosing boundary (to assure the uninterrupted visibility of the whole region). While performing this localization of the asymptotic point, a horizontal (in Experiment 1) or oblique (in Experiment 2) line was displayed (representing the first segment of the phenomenal path due to induced motion only), with its left endpoint coinciding with the point e, where the dot physically ceased to move. All measurements of w and h were thus relative to this point e.

(Received for publication March 10, 1981;
accepted March 26, 1981.)