The influence of depth-cues on paths of apparent motion

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In the present study, we examined how the disparities in length, size or luminance between stimuli would affect the choice of apparent motion path when a stationary stimulus was spatially interposed between two apparent motion stimuli. The results were as follows; (1) the perceived motion path in depth differed in quality as to whether or not there was a depth impression based on the disparity; (2) with depth cue, say, when apparent motion stimuli were larger (or smaller) in length, size or luminance than the stationary stimulus, subjects often saw a single object translating in the frontal plane, in front of (or behind) the stationary stimulus; (3) on the other hand, with no depth cue, they saw indiscriminated motion in depth or curving motions, especially back-curving motion, at the stationary stimulus. It was suggested that in apparent motion the visual system avoids a collision between a moving object and interposed stimulus, by choosing a path of translating motion in depth, but it occasionally shows a tendency to choose a path of motion, curving behind the interposed stimulus.

Key words: apparent motion, depth cue, path of apparent motion.

When two spatially separated stimuli are alternated at an appropriate rate, a single object is seen to move between them. If all attributes of two stimuli are identical, the path of apparent motion is usually seen in the frontal plane. When another stimulus, however, is interposed between two stimuli, the path of motion is not always seen in the frontal plane.

Kolers (1963, 1964) and Goldstein and Weiner (1963, 1969) have found that “interposing lines or rectangles into the visible field during the interstimulus interval induces a perception of depth in the alternated stimuli”, without crossing or colliding with an object in apparent motion. Kolers (1972) presented two circles a and b in the first frame, which were arranged in a horizontal row, in alternation with two other circles b’ and c in the second frame, which were shifted horizontally to the right so that the position of b’ overlapped that of b. As a results, motion from a to c was seen in depth while the central stimuli b and b’ remained stationary. In this case, the path of motion did not curve above or below the central stimulus, but in front of or behind it.

Anstis and Ramachandran (1985) have found that apparent motion could cause the perception of occlusion under appropriate conditions. In their experiment, a small square and a large triangle below it were presented simultaneously in the first frame, and were replaced by a large triangle alone in the second frame, which was shifted upwards and to the right from the position of the triangle in the first frame. As was expected, most of the observers perceived the triangle only moving obliquely between two locations in both frames, but the square was perceived to move horizontally and hide behind the triangle in the second frame without fusing with it—Anstis and Ramachandran referred to this perception as ‘apparent kinetic occlusion’. They have explained ‘apparent kinetic occlusion’ as follows: When there is no object in the second frame corresponding to the object in the first frame, the visual system invokes the occlusion ‘hypothesis’ that physical objects are normally opaque, in order to explain the sudden disappearance of the object, and solves intelligently its disappearance as kinetic occlusion.

Recently, Saigo and Ohmura (1990) have re-examined ‘apparent kinetic occlusion’ studied by Anstis and Ramachandran (1985) in terms of the effect of depth cue between stimuli. They presented successively two
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Kolers (1972) reported that kinetic occlusion was not observed when the disparity between the stimuli was exactly the same as the disparity of the occluder and the occluded object. They concluded that kinetic occlusion is fundamentally based on 'the depth impression between two objects' rather than on 'the opacity of objects' as proposed by Anstis and Ramachandran (1985): The visual system chooses the way of the intelligent processing (depth processing) that closer objects occlude distant objects, by resolving disparity of size or luminance as differences in depth.

We supposed that the phenomenon reported above by Kolers (1972) might be involved in the underlying mechanism similar to that in the visual system which invoked the phenomenon of 'apparent kinetic occlusion', for both phenomena could generate not only the perception of motion but the perception of depth at the same time. Both phenomena, however, were obtained in different stimulus situations: In Kolers' experiment, there was no depth cue between the stimuli, that is to say, all the stimuli were identical in dimensions. On the other hand, in Saigo and Ohmura's experiment, there was a depth cue between them. The present study, therefore, was designed to examine how the existence of the disparities (depth cues) of the stimuli would affect the choice of apparent motion path, when a stationary stimulus was spatially interposed between two apparent motion stimuli, as in Kolers' experiment.

Experiment

Method

Apparatus. The stimuli were generated by a micro computer (NEC 9801-vx) and displayed on an Analog Color Display (NEC PC-KD861) with a refresh rate of 56.4 Hz. Subjects observed the screen (24\,\times\,15 cm in size, visual angle of 13.7°\,\times\,8.6°) binocularly from a distance of 1 m in a dark room. The two stimuli separated horizontally by1.8°, the first stimulus (left) and the second (right), were presented successively. At the midpoint of these stimuli, a stationary stimulus was located and presented during the trial in experiment. A fixation point, consisting of a cross (0.09° in length, 60 cd/m²), was set at 1.0° below the stationary stimulus.

Stimulus conditions. As shown in Figure 1, we used the three kinds of stimulus conditions (A), (B) and (C), which contained different disparities of stimulus in length, size or luminance, respectively. Moreover, each condition consisted of the five subconditions (a1)-(a5), (b1)-(b5) or (c1)-(c5). In each subcondition, the central stimulus in the stimulus arrangement was a stationary stimulus and the two stimuli of both sides of it were apparent motion stimuli.

In each condition (A), (B) or (C), the stationary stimuli were kept constant in length (0.47° of visual angle), size (contour circle with 0.47° in diameter) or luminance (solid circle with 2.79 cd/m²), respectively, but the motion-inducing stimuli were different in length a1:0.21°, a2:0.30°, a3:0.47°, a4:0.64°, a5:0.94°, size (in diameter, b1:0.21°, b2:0.30°, b3:0.47°, b4:0.64°, b5:0.94°) or luminance (c1:0.11 cd/m², c2:0.49 cd/m², c3:2.79 cd/m², c4:13.61 cd/m², c5:118.64 cd/m²), respectively. In conditions (A) and
the luminance of all the stimuli was fixed to 60 cd/m², and in condition (C), their size was 0.47° in diameter.

Temporal conditions. The duration of the apparent motion stimuli was 89 ms. SOAs (stimulus onset asynchronies: the time intervals between the onsets of the first stimulus and the second) were 89, 159, 248, 336, 425, 549 and 640 ms. ICI (the intercycle interval between the offset of the second stimulus and the onset of the first) was 900 ms. Hence the perceived direction of apparent motion was always seen from left to right.

Subjects. The subjects were eight undergraduates, who had normal or corrected-to-normal vision. They were acquainted with experiments of apparent motion, but were all naive as to the purpose of the experiment.

Procedure. The experimental trials consisted of three blocks, divided by the three stimulus conditions. Within each block, there were four trials for each combination of seven SOAs and five subconditions in random order, making 140 trials overall. The order of three blocks was counterbalanced among the subjects. Preceding the experiment, each subject was dark-adapted for 10 min, during which instructions were read to him and apparent motion was demonstrated. The subjects binocularly saw a fixation point. Each subject was required to report whether motion was seen or not, and if seen, what kind of phenomenon it was. The stimuli were repeatedly given until the subjects were able to report. The numbers of each type of perceived motion which all the subjects reported were pooled for each stimulus and temporal condition, and the probability of these numbers to the total trials (32 trials; 8 subjects × 4 repeats) of each condition was obtained.

Results and Consideration

In Figure 1, the probabilities for each type of perceived motion paths were plotted as a function of SOAs, for each of condition (A), (B) and (C).

In conditions (a1, a2), (b1, b2) and (c1, c2), in which the apparent motion stimuli were smaller in length, size or luminance than the stationary stimulus, back motion was perceived exclusively: A single object was seen to translate in the frontal plane behind the stationary stimulus.

In conditions (a4, a5), (b4, b5) and (c4, c5), in which the apparent motion stimuli were larger inversely, two types of motion were reported; one was front motion and the other was back-curving motion, in which a single object was seen to curve behind the stationary stimulus. As compared to the probabilities of these motions, front motion was perceived much more frequently than back-curving motion (p < .01 for all the conditions).

In conditions (a3), (b3) and (c3) without any disparities between the stimuli, indiscriminate motion in depth was reported besides back-curving motion and front-curving motion. Back-curving motion was perceived more frequently as compared with front-curving motion (p < .05 for all the conditions). Among three types of motions, the frequencies of front-curving motion were remarkably few. In the probabilities of indiscriminate motion in depth, there were differences according to the stimulus conditions; the probabilities tended to be higher in conditions (b3) and (c3) with the extent of area, than in condition (a3) with the extent of line.

From the above results, it was found that the types of path of apparent motion could be distinguished by whether or not there was a depth cue based on disparities between apparent motion stimuli and stationary stimulus. When there was a depth cue, subjects saw a single object translating in the frontal plane, in front of or behind the stationary stimulus. On the other hand, with no depth cue, they saw front- or back-curving motion at the stationary stimulus, or indiscriminate motion in depth.

The type of motion path translating in depth uniquely corresponded to the disparity between the stimuli used: Front motion (or
Figure 1. The probabilities for each type of perceived motion were plotted as a function of SOAs, for each of the stimulus conditions (A), (B) and (C).

- - - - - - - : front motion, back motion,  - - - : front-curving motion,  - - - - - - - : back-curving motion,  - - - - - - - : indiscriminate motion in depth.
back motion) was predominantly perceived when the apparent motion stimuli were larger (or smaller) in length, size or luminance: namely, when the apparent motion stimuli might be seen to be closer (or further) in depth, by the perception of linear perspective between the stimuli. These findings show that ‘depth impression dependent on disparities between objects’, as suggested by Saigo and Ohmura (1990), contributes also to the choice of the motion path. It should be noted, however, that in conditions (a1, a2), (b1, b2) and (c1, c2) back motion was reported exclusively, while in conditions (a4, a5), (b4, b5) and (c4, c5) back curving motion was reported unexpectedly. This motion was in opposite direction to the motion path (front motion) expected from disparities between the stimuli. This seems to suggest that the choice of motion path is not perfectly determined by the given depth only, but it is, in some cases, strongly biased toward the choice of back-curving motion, against the expected motion path from depth cue.

The fact that back-curving or front-curving motion was perceived in the condition without the stimulus disparity is in agreement with Kolers’ (1972) findings. The probabilities of seeing back-curving motion, however, were not equal to those of front-curving motion; the former was significantly higher than the latter. It is interesting, moreover, that indiscriminate motion in depth was reported only in the condition without the stimulus disparity. This result was consistent with the subjects’ verbal reports that they found much difficulty in deciding the type of motion path because of the lack of depth cues. For the decision of motion in depth, inconsistent with those expected from depth cues (i.e. back or front-curving motion), or without the stimulus disparity, it seems to be reasonable that we regard these motion paths as the results of irregular solutions in the visual system: the visual system may avoid collision of a moving illusory object with the central stimulus, in order to maintain the continuity of motion in spite of longer motion path (the unparsimonious way of processing).

To summarize, when a stationary stimulus was spatially interposed between two apparent motion stimuli, the perceived path of motion in depth differed in quality as to whether or not there was a depth impression based on the stimulus disparity. The results suggest that in apparent motion the visual system ordinarily avoids a collision between a moving illusory object and the interposed stimulus, by choosing a path of translating motion in depth. However it occasionally shows a tendency to choose a path of motion, curving behind the interposed stimulus.

References

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