Position uncertainty and the perception of apparent movement

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Two experiments compared the perception of apparent movement when the second of two successive stimuli always appeared in the same position and when it varied randomly between two spatial positions. The results of both experiments showed that foreknowledge of the position of the second stimulus does not facilitate the perception of apparent movement. Experiment 2 also clearly showed that the space-time relationships of Korte's third law of apparent movement does not depend on foreknowledge of the position of the second stimulus. These findings imply that apparent movement in real time occurs after the second stimulus has been registered by the visual system. It suggests that apparent movement involves a delayed decision mechanism that stores the first stimulus, the interstimulus temporal interval, and the second stimulus, and then impletes a motion compatible with the stimulus information.

A subject's expectation can affect the perception of apparent movement. The more nearly two stimuli presented in sequence connote a familiar moving object, the greater will be the range of other stimulus variables (such as exposure duration, the interstimulus spatial separation, and the interstimulus temporal separation) giving rise to the perception of good apparent movement (Neff, 1936). The present experiments further investigate the role of expectation by examining how position uncertainty affects the perception of apparent movement. Knowledge of the spatial position of the second of two stimuli allows an expectation to be established concerning the direction of apparent movement. An expectation concerning the direction of apparent movement may not only facilitate the perception of apparent movement, but may also cause the perception of apparent movement to begin in real time before the presentation of the second stimulus. In contrast, when the position of the second of the two stimuli varies randomly between two spatial positions, no expectation concerning the direction of apparent movement can be established. Under these conditions, the perception of apparent movement in real time must occur after the second stimulus has been presented. Phenomenally, of course, the light is seen to move from the initial position to the second position.

Two experiments investigated how knowledge of the spatial position of the second of two stimuli affects (a) the perception of simple apparent movement produced by two successive light flashes, and (b) Korte's third law, which asserts that for optimum apparent movement an increase in spatial separation

must be accompanied by an increase in temporal separation.

EXPERIMENT 1

Method

Apparatus and stimuli. Figure 1 shows the experimental arrangement. The stimuli were light flashes that were presented on the circumference of an imaginary circle with a radius of 10.2 cm. A fixation stimulus was placed in the center of the imaginary circle. The first light flash was always in the same position and was presented in the 6 o'clock circle position. The second light flash was at one of four loci on the circle. Lights were placed at positions determined by rotating the circle radius 17 and 90 deg counterclockwise (Positions 1 and 3) and clockwise (Positions 2 and 4) from the 6 o'clock position.

The stimulus lights were CM 49 bulbs and were placed behind paper to diffuse the light. Circular masks, .64 cm in diameter (.23 deg), were placed in front of the lights. The steady-state luminances of the lights were approximately 10 fL (34.3 cd/m²). The stimuli were viewed in a dimly lit room in which the fixation target, a .64-cm-in-diameter white circle, was continuously visible. The illumination in the region of the stimulus display was approximately .1 fc (1.1 lx). The duration of the lights and the interstimulus temporal separation were controlled by brushes which made contact with a metal plate on a turntable run by a constant-speed motor. The exposure durations of the lights were 50 msec.

The stimulus display was 160 cm from a subject and painted black. There were eight alternative stimuli consisting of two experimental conditions (constant vs random direction of motion), two spatial separations 2.9 cm (1.0 deg) and 14.4 cm (5.1 deg) from center to center, and two temporal intervals which will be described in terms of the stimulus onset asynchronies (SOAs) (55 and 250 msec). A trial consisted of five successive presentations of two lights separated by a constant SOA and spatial separation. In the constant-motion condition, a second stimulus always was presented in the same position. In the random-motion condition, the second stimulus was presented either in Positions 1 and 2 for the 2.9-cm spatial separation or in Positions 3 and 4 for the 14.4-cm spatial separation. The direction of apparent movement in the random experimental condition changed randomly between left and right. The randomization was constrained so that no more than three presentations were in the same direction.

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Figure 1. The stimulus arrangement in Experiment 1. F is the fixation stimulus. L₁ is the position of the first stimulus light. P₁ and P₂ are the two alternative positions of the second stimulus light with a 2.9-cm spatial separation. P₃ and P₄ are the two alternative positions of the second stimulus light with a 14.4-cm spatial separation.

The time interval between the onset of successive presentations was 1,800 msec. Thus, the interpresentation time interval in a trial with a 55-msec SOA was 1,695 msec, and with a 250-msec SOA, 1,500 msec.

Procedure. A chinrest was used to place the fixation stimulus at eye level. Each subject was adapted to the room illumination for 5 min. The experiment began with a practice session in which a subject was shown one of each of the eight alternative stimuli. An experimental session consisted of 64 trials divided into eight blocks of the eight alternative stimuli. The eight trial types within the block were presented in a different irregular order to each subject. Of the four constant direction trials in a block of eight, two were presented to the right and two were presented to the left. A subject was told at the beginning of a trial whether the stimulus would appear to move in the same direction or would change direction randomly. A subject was instructed to rate the goodness of the movement of the last presentation of the five presentations in a trial on a 1-to-5 scale. A rating of 1 indicated the perception of no movement, a rating of 3 the perception of partial movement, and a rating of 5 the perception of smooth continuous movement.

Subjects. Sixteen University of Oregon undergraduates served in the experiment. They were paid to participate in a 1-h session. All were naive as to the purpose of the experiment and had normal or corrected-to-normal vision.

Results

The mean of a subject's eight ratings was taken as representative of his judgment. Table 1 presents the means and standard deviations of subjects' ratings. A three-way analysis of variance (random over subjects) examined the effects of expectation (constant vs random direction), spatial separation (2.9 vs 14.4 cm), and SOA (55 vs 250 msec). As may be seen from the similarity of the mean ratings in Table 1, there was no significant difference in mean ratings as a function of whether the direction of apparent motion was constant or random. Only the spatial separation, $F(1,15) = 28.5$, $p < .01$, the SOA, $F(1,15) = 39.9$, $p < .01$, and the Spatial Separation by SOA interaction, $F(1,15) = 28.8$, $p < .01$, were significant. The interaction between the variable of spatial separation and the SOA reflects the fact that increasing the spatial separation with an SOA of 55 msec caused subjects' ratings

to become significantly worse than increasing the spatial separation with an SOA of 250 msec.

Korte's law states that the interstimulus spatial separation is proportional to the SOA for optimum apparent movement. In the present study, Korte's law can be tested in two ways. First, for an SOA of 55 msec, subjects' ratings of movement should be better when the interstimulus spatial separation was 2.9 cm than when it was 14.4 cm; in contrast, for an SOA of 250 msec, subjects' ratings should be better when the interstimulus spatial separation was 14.4 cm than when it was 2.9 cm. All 16 subjects' mean ratings with a 55-msec SOA were higher with a 2.9-cm spatial separation than with a 14.4-cm spatial separation for both the constant and random motion conditions. Seven subjects followed Korte's law, and their mean ratings with a 14.4-cm spatial separation were higher with a 250-msec SOA than with a 55-msec SOA for both the constant and random motion conditions. One subject's mean ratings followed Korte's law for the constant motion condition but not for the random motion condition, and eight subjects failed to follow Korte's law, and their mean ratings with a 14.4-cm spatial separation were higher with a 55-msec SOA than with a 250-msec SOA for both the constant and random motion condition.

A second test of Korte's law is that with a 2.9-cm spatial separation subjects' ratings of movement should be better for a 55-msec SOA than for a 250-msec SOA; in contrast, at the 14.4 spatial separation, subjects' ratings should be better for the 250-msec SOA than for the 55-msec SOA. All 16 subjects' mean ratings with a 2.9-cm separation were higher with a 55-msec SOA than with a 250-msec SOA for both the constant and random motion conditions. Three subjects followed Korte's law, and their mean ratings with a 250-msec SOA were higher with a spatial separation of 14.4 cm than with a spatial separation of 2.9 cm for both the constant and random motion conditions. Three subjects'

Table 1
Means and Standard Deviations of Ratings of Apparent Movement as a Function of Direction of Motion, SOA, and Spatial Separation

Experimental Conditions	Stimulus Onset Asynchrony (Milliseconds)			
	55		250	
	Spatial Separation (Centimeters)			
	2.9	14.4	2.9	14.4
Constant Direction				
Mean	4.5	2.8	2.7	2.4
SD	.44	.91	.67	.72
Random Direction				
Mean	4.4	3.0	2.7	2.5
SD	.55	.81	.72	.84
Overall Mean	4.5	2.9	2.7	2.5

mean ratings followed Korte's law for the constant motion condition but not for the random motion condition, and 10 subjects failed to follow Korte's law, and their mean ratings with a 250-msec SOA were higher with a spatial separation of 2.9 cm than with a spatial separation of 14.4 cm for both the constant and random motion conditions. One subject's mean ratings followed Korte's law by the first test, but not by the second, and one subject's mean ratings followed Korte's law by the second test, but not by the first.

Table 2 presents the means and standard deviations for five subjects whose mean ratings were in substantial agreement with Korte's law by both Test 1 and Test 2.¹ It may be seen from Table 2 that Korte's law does not depend on an expectation concerning the direction of apparent movement. There were no significant differences in mean ratings as a function of whether the direction of apparent motion was constant or random. A three-way analysis of variance (random over subjects) showed that only the spatial separation, $F(1,4) = 28.2$, $p < .01$, and the Spatial Separation by SOA interaction, $F(1,4) = 48.2$, $p < .01$, were significant.

EXPERIMENT 2

Experiment 2 was designed to further test whether Korte's law relationship depends on whether a subject can anticipate the direction of apparent motion. In this experiment, the effect of position uncertainty on the perception of apparent movement was investigated using the method of adjustment. According to Korte's law, an increase in the spatial separation between two successive stimuli must be accompanied by an increase in their temporal separation for apparent motion to be seen. Subjects were instructed to adjust a time interval between the two light flashes to produce the perception of apparent motion. This is a weaker test of Korte's law than that undertaken in Experiment 1. A longer temporal separation may be required to produce the perception of apparent motion at a larger spatial separation, but the rated quality of motion may still be worse than that produced by the same temporal separation with a smaller spatial separation. The purpose of the experiment was to discover whether knowledge of the spatial position of the second of two stimuli affects the temporal interval thresholds to see apparent motion.

Method

Apparatus and Procedure. The apparatus was the same as in Experiment 1. The stimuli were light flashes that were presented on the circumference of an imaginary circle with a radius of 10.2 cm. The first light flash was always in the same position and was presented in the 6 o'clock circle position. The second light flash was at one of four loci on the circle. Lights were placed at positions determined by rotating the circle radius 17 and 135 deg

Table 2
Means and Standard Deviations of Ratings of Apparent Movement as a Function of Direction of Motion, SOA, and Spatial Separation for Five Subjects Meeting Korte's Third Law

Experimental Conditions	Stimulus Onset Asynchrony (Milliseconds)			
	55		250	
	Spatial Separation (Centimeters)			
	2.9	14.4	2.9	14.4
Constant Direction				
Mean	4.6	2.1	2.6	3.0
SD	.36	.67	.81	.54
Random Direction				
Mean	4.2	2.6	2.6	3.1
SD	.56	1.0	.88	.98
Overall Mean	4.4	2.4	2.6	3.1

counterclockwise and clockwise from the 6 o'clock position. The exposure durations of the lights were 50 msec. The stimuli were viewed in a dimly lit room in which a fixation stimulus, in the center of the imaginary circle, was continuously visible. The illumination in the region of the stimulus display was approximately .06 fc (.65 lx). The steady-state luminance of the lights was approximately 25 fL (85.7 cd/m²). The stimulus display was 119 cm from a subject. There were four alternative stimuli consisting of two experimental conditions (constant vs random direction of motion) and two spatial separations, 2.9 cm (1.4 deg) and 18.9 cm (9.0 deg) from center to center. In the constant-motion condition, the second stimulus was presented always either counterclockwise or clockwise. In the random motion condition, the second stimulus was presented randomly counterclockwise and clockwise. The time interval between the onset of successive presentation was 1,800 msec.

Each subject was seated with his chin in a rest, and adapted to the room illumination for 5 min. The temporal separation between stimuli was varied by having subjects adjust a movable rod. The rod and his hand were hidden from the subject's view by a screen. At the beginning of each trial, the rod was set so that the two light flashes were simultaneous. The subjects were shown examples of apparent movement and instructed to increase the temporal separation between the light flashes until he saw "good" apparent movement. The subjects were encouraged to take as much time as they needed to make a judgment and were allowed to freely move the rod back and forth. Each subject made a total of 44 threshold judgments. The 44 trials were divided into 11 blocks of four trials each. The four trials in a block were presented in a random order. In each block, there were two trials in which the light flashes were presented in a constant direction and two trials in which the light flashes were presented in a random direction. Of the two constant- and random-direction trials in a block, one was presented with a 2.9-cm separation and one with an 18.9-cm separation. Of the two constant-direction trials in a block, one was with a second light flash to the left and one with the second light flash to the right. The first block of four trials was a practice set in which a subject was encouraged to refine his adjustment in making a threshold judgment. Subjects' means are based on the remaining 10 settings.

Each subject was instructed, after making his threshold setting, to observe three additional stimulus flashes to make sure his adjustment was satisfactory. A subject was required to observe the stimuli for a minimum of seven presentations on each trial. After adjusting the temporal interval to produce apparent movement, a subject was asked to make two ratings of the goodness of the apparent movement. First, five presentations of the two light flashes were presented at the spatial separation for which he made his setting judgment and asked to rate the goodness of

the movement. Second, five presentations were presented of the two light flashes at the second spatial separation and a subject was asked to rate the goodness of the movement. For example, if a subject adjusted the temporal separation between the stimuli with a 2.9-cm spatial separation to produce apparent movement, the subject was asked to rate the goodness of movement, first with the 2.9-cm spatial separation and, second, with an 18.9-cm spatial separation. The temporal separation was the setting the subject had adjusted for the 2.9-cm separation.

Subjects were given the following instructions for making their ratings: "I shall be showing you two lights on the screen, first one and then the other one. Perfect apparent movement will be the case when you have the impression of a single light that moves smoothly from one position to another, without disappearing or changing in brightness along the way. Partial motion is the case when the two lights are seen as separate but there is a feeling of motion between them. Your task is to rate each display as to how well what you see corresponds to this description of apparent motion. Use numbers for your ratings as follows: number 5 indicates that you saw a single light moving from one position to the other. The number 3 indicates that there is a feeling of motion but that you do not see a light move in the intervening space. The number 1 indicates that you saw no motion. That is, the two lights are almost simultaneous or overlap and there is no sense of motion. Use intermediate numbers to indicate various degrees of correspondence between the description and what you see."

Subjects. Five new subjects were paid for their participation. Two University of Oregon graduate students in education, one female and one male, and three female undergraduates served in the experiment. Each subject was tested in a session lasting approximately 1½ h. All subjects had normal or corrected-to-normal vision, and were naive as to the purpose of the experiment.

Results

Table 3 presents the mean SOAs of individual subjects. For all subjects, increasing the spatial separation between the light flashes caused an increase in the temporal thresholds for apparent motion. On the average, the SOAs increased by 32.7 msec when the spatial separation was increased from 2.9 to 18.9 cm. A two-way analysis of variance (random over subjects) confirmed the fact that spatial separation was significant, $F(1,4) = 49.5$, $p < .01$. However, there was no significant difference in the mean SOAs as a function of whether the direction of apparent motion was constant or random, $F(1,4) = .00$, n.s. The conclusion is clear

Table 3
Mean Stimulus Onset Asynchronies in Milliseconds
at Threshold for Apparent Movement

Subjects	Experimental Conditions			
	Constant Direction		Random Direction	
	Spatial Separations (Centimeters)			
	2.9	18.9	2.9	18.9
1	69.0	98.5	63.0	92.0
2	39.1	82.7	36.3	87.0
3	68.3	105.0	67.0	108.3
4	92.0	110.5	96.0	119.5
5	42.0	70.9	42.2	67.1
Overall Mean	62.1	93.5	60.9	94.8
SD	21.9	16.4	23.6	20.2

Table 4
Means and Standard Deviations of Ratings of Apparent
Movement as a Function of Direction of Motion,
SOA, and Spatial Separation

Experimental Conditions	Separation for SOA Settings (2.9 cm)*		Separation for SOA Settings (18.9 cm)**	
	Spatial Separations (Centimeters)			
	2.9	18.9	2.9	18.9
Constant Direction				
Mean	4.6	1.8	4.2	3.6
SD	.50	.43	.92	.80
Random Direction				
Mean	4.3	1.8	4.2	3.4
SD	.52	.56	.70	.91
Overall Mean	4.5	1.8	4.2	3.5

*A subject adjusted the SOA to produce apparent movement with a 2.9-cm spatial separation. Keeping this SOA setting, the subject then rated the goodness of apparent movement when the light flashes were separated, first, by 2.9 cm and, second, by 18.9 cm.

**A subject adjusted the SOA to produce apparent movement with an 18.9-cm spatial separation. Keeping this SOA setting, the subject then rated the goodness of apparent movement when the light flashes were separated, first, by 18.9 cm and, second, by 2.9 cm.

that the SOA threshold for apparent movement increases with spatial separation, but that it does not depend on whether a subject can anticipate the direction of apparent movement.

Table 4 presents the means and standard deviations of subjects' ratings. A three-way analysis of variance (random over subjects) examined the effects of expectation, spatial separation, and SOA. The similarity of the mean ratings in Table 4 show that there were no significant differences in mean ratings as a function of whether the direction of apparent motion was constant or random. Only the spatial separation, $F(1,4) = 16.9$, $p < .02$, the SOA, $F(1,4) = 22.4$, $p < .01$, and the Spatial Separation by SOA interaction, $F(1,4) = 11.2$, $p < .05$, were significant. The interaction between the variable of spatial separation and the SOA reflects the fact that decreasing the spatial separation from 18.9 to 2.9 cm (for subjects' settings with an 18.9-cm separation) did not much affect a subject's rating, but increasing the spatial separation from 2.9 to 18.9 cm (for subjects' SOA settings with a 2.9-cm separation) caused a subject's rating to clearly become worse. The latter is to be expected since the subject's SOA threshold for the perception of movement with a 2.9-cm separation was well below his SOA threshold for the perception of movement with an 18.9-cm separation.

Table 4 shows that, as in Experiment 1, the ratings did not fully conform to Korte's law. For subjects' SOA settings with a 2.9-cm separation, the ratings should be better at the 2.9-cm separation than at the 18.9-cm separation. This occurred for all five

subjects in both the constant and random experimental conditions. For subjects' SOA settings with an 18.9-cm separation, the ratings should be better at the 18.9-cm separation than for the 2.9-cm distance. This occurred for only two of the subjects in both the random and constant experimental conditions. Statistical tests confirm that the differences between the mean ratings with a 2.9- and 18.9-cm separation for both the constant, $t(4) = 11.3$, $p < .01$, and random, $t(4) = 8.6$, $p < .01$, experimental conditions for subjects' SOA settings with a 2.9-cm separation were significant; the differences between the mean ratings with a 2.9- and 18.9-cm separation for both the constant, $t(4) = .90$, and random experimental conditions, $t(4) = 1.3$, for subjects' SOA settings with an 18.9-cm separation were not significant.

DISCUSSION

These experiments unequivocally indicate that the perception of motion from two asynchronous stimuli is as good when the position of the second stimulus is varied randomly as when it is constant. Since an expectation concerning the direction of apparent motion does not facilitate its perception, this would indicate that the perception of apparent motion in real time occurs after the second stimulus is presented and not during the interstimulus interval. This conclusion is consistent with physiological research showing that there are cells which are stimulated by the successive stimulation of neighboring retinal regions at appropriate temporal and spatial separations (Barlow & Levick, 1965). It is reasonable to suppose that the stimulation of such cells is involved in the perception of apparent movement (Beck & Stevens, 1972). Apparent movement, however, cannot be identified with the excitation of a succession or movement detector. To perceive apparent movement, the firing of a succession detector needs to be consistent with contextual stimulus information which indicates that motion is a plausible explanation of the alternating appearance and disappearance of the stimuli (Sigman & Rock, 1974). Otherwise, the signal from a succession detector appears to be inhibited and apparent movement is not seen.

An important question is the origin of Korte's third law. The results of experiments show that the threshold SOA and the spatial separations between stimuli need to be varied directly for the perception of apparent motion. If apparent motion occurs during the interstimulus interval, one may suppose that the basis for Korte's law is that the longer SOA with the larger spatial separation provides the time necessary for the traversal of the larger path. If apparent motion, however, occurs after the registration of the second stimulus by a subject, it is unclear

why it is necessary to increase the pause between the first and the second stimulus for apparent motion to occur when the spatial separation is increased. One possibility is that the threshold SOA for discriminating two stimuli as successive and nonsimultaneous increases with spatial separation. Because of greater neural interaction, small spatial separations may allow the discrimination of nonsimultaneity with smaller interstimulus intervals than larger spatial separations. A serious difficulty with this interpretation is that experiments show that the SOA threshold for apparent movement varies with the phenomenal separation between stimuli rather than with their retinal separation (Attneave & Block, 1973). One interpretation consistent with Korte's third law and with the present results is that the visual system introduces an illusory object between an original stimulus and a second stimulus after the presentation of the second stimulus, but in a way that is compatible with the time interval between the stimuli. This implies that apparent motion involves a storage mechanism that stores the first stimulus, the interstimulus interval, and the second stimulus, and then impletes a motion compatible with the stimulus information.

More generally, the temporal interval between stimuli has been found to be an important variable in determining the kind of apparent motion. For example, Kolers and Pomerantz (1971) investigated a situation in which there were two possible interpretations: either a rigid motion in depth or a motion in the plane accompanied by a plastic deformation of one shape into another. They found that the rigid motion in depth was more probable with the longer interstimulus intervals. In the Kolers and Pomerantz experiment, repeated presentations allowed an expectation concerning the direction of motion to be established. It is important to investigate whether when a subject is unable to anticipate the direction of apparent motion the interstimulus time interval will affect whether a rigid motion in depth is seen or a plastic deforming motion in the plane is seen. According to the hypothesis that apparent motion involves a delayed decision until enough information has accumulated to warrant an interpretation, the results should be the same whether a subject is able to anticipate the direction of motion or not.

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was 2.9 and 14.4 cm. Test 2 was met by all five subjects in the constant-motion condition, and by two subjects in the random-motion condition. Two subjects in the random motion condition gave the same mean ratings with a spatial separation of 14.4 cm when the SOA was 55 and 250 msec, and one subject's mean rating was higher with an SOA of 55 msec than with an SOA of 250 msec.

NOTE

1. Test 1 was met by all five subjects in the random-motion condition and by four subjects in the constant-motion condition. One subject gave the same mean ratings in the constant-motion condition with an SOA of 250 msec when the spatial separation

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