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Perceived Velocity of Apparent Movement: Evidence for a Distance/Time Rule

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PERCEIVED VELOCITY OF APPARENT MOVEMENT:
EVIDENCE FOR A DISTANCE/TIME RULE

by

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LIFE

Kathleen Ann Carlson was born on June 28, 1948, in Chicago, Illinois. She is the only daughter and youngest child of Earl and Margaret Carlson's three children. She graduated from Alvernia High School, a parochial school for women run by the School Sisters of St. Francis, in 1966. She then attended Loyola University of Chicago, where she received a Bachelor of Science degree in Psychology (magna cum laude) in June, 1970.

After graduating from college, Kathleen served on a vice-presidential staff of Illinois Bell Telephone Company as an assistant staff supervisor. In that position, she was responsible for collecting and analyzing accident data for more than 10,000 Chicago area employees. Her research experience with Illinois Bell motivated Kathleen to pursue a doctor's degree in Experimental Psychology.

In September, 1972, Kathleen entered the graduate program at Loyola, where she has concentrated her interests in human learning and memory, and visual information processing. Upon completion of her graduate work, Kathleen will seek an academic position in which it will be possible to teach and conduct research.

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INTRODUCTION

Apparent Motion: An Overview

In 1912, Max Wertheimer published his classic studies about the phenomenon of apparent motion. The paradigm that he first utilized entailed the stroboscopic presentation of two parallel lines separated spatially by about 5 cm. The durations of each of the stimuli were approximately 20 msec., and the major independent variable was the amount of time between the offset of the first line and the onset of the second one. This latter variable will hereafter be referred to as the "interstimulus interval", or ISI.

Wertheimer found that variations of the ISI values produced some markedly different visual experiences. At relatively brief ISIs (30 msec. or less), the two lines appeared to be simultaneous in time. None of his observers could accurately distinguish the temporal order of the stimuli under those conditions. When the ISIs were relatively long (130 msec. or longer), the two lines were perceived as two distinct, successive events in time. In this case, observers clearly detected that a temporal interval separated the offset of the first line and the onset of the second one. Finally, when the ISIs were within a medium range of values (approximately 60 msec.), observers reported seeing a <u>single</u> line that moved from the spatial location of the first stimulus to that of the second. This latter visual experience was termed "apparent motion". According to Wertheimer, it was so subjectively compelling that even the most sophisticated of observers could not distinguish it from "real movement", in which one of the lines was actually made to traverse the space between them.

According to Neff (1963), Wertheimer was not the first scientist to investigate apparent motion phenomena. The physiologist, Sigmund Exner, had reported a similar phenomenon 35 years before Wertheimer's publication. However, Wertheimer's major contribution was his particular theoretical treatment of the data. Contrary to the Zeitgeist of his day, Wertheimer proposed that apparent motion is a dynamic perceptual experience that cannot be analyzed into elements or stages. He postulated a general "cortical" theory for motion perception, which was to become the cornerstone of the Gestalt School of psychology.

Immediately after Wertheimer's publication, early adherents of the Gestalt school set out to ascertain the major parameters of apparent motion. Notable among them was Korte, who in 1915 concluded that this phenomenon was contingent upon 3 principal variables: (a) the spatial distance separating stimuli; (b) the ISIs separating them; and (c) the intensity of stimuli. Korte defined this latter variable as "...anything that contributed to a figure's salience or impressiveness, such as its luminous energy, size, or figural detail." (cited in Kolers, 1972; p 21).

Korte also specified the manner in which these three variables interacted with one another in the production of motion. He determined their interrelationships by first arranging conditions so that an observer reported seeing good motion. He then changed the value of one of the three variables, and measured the value of another that was required for the restoration of the original percept. His findings have been summarized in Bartley (1941) as follows:

(1) When ISI is held constant, the variables of distance and intensity are directly related to one another. An increase in distance must be accompanied by an increase in intensity in order for the motion percept to be preserved.

(2) When distance is held constant, the factors of intensity and ISI are inversely related. An increase in intensity must be accompanied by a decrease in ISI to maintain movement.

(3) When intensity is held constant, the variables of ISI and distance are directly related to one another. A change in ISI must be compensated by a corresponding change in distance for the preservation of the percept.

The above formulations have frequently been referred to as "Korte's Laws" of apparent movement (e.g., in Boring, 1942; Graham, 1965). Since their original publication in 1915, literally hundreds of investigations have utilized them to produce apparent motion in the laboratory (see Squires, 1928; Hovland, 1935; Aarons, 1964; & Levy, 1972, for reviews). However, the term "laws" is somewhat misleading in that some of their basic premises and implications have since been challenged and/or disputed. For example, Kolers (1972) pointed out that Korte's "laws" were formulated much like Ohm's laws of electrical circuits. They therefore implied that apparent motion is perceived at very specific intersections of distance, ISI, and intensity. That is, a change in any one of the variables must be accompanied by alterations in at least one of the others in order to preserve the motion percept. This particular assertion was clearly disputed by Neuhaus (1930), who found that with distance and intensity held constant, "good" motion could be perceived over a fairly wide range of ISIs. In fact, under some conditions, motion was found with ISIs ranging between 60 and 375 msec., <u>without</u> any alterations of distance or intensity.

According to Kolers (1972), Neuhaus' findings also challenge a specific implication of Korte's third "law". This "law", it should be recalled, asserted that an increase in ISI must be compensated by an increase in distance, in order to maintain the motion. Since the velocity of a moving stimulus is usually defined by the distance traversed, divided by the time it takes to traverse it, Korte's third "law" implied that an apparently moving stimulus is always perceived at some constant velocity. This particular implication follows from the assumption that, under conditions of apparent motion, the ISI values correspond with the "time variable" in the velocity formula. However, Neuhaus' data suggest that apparent movement can be perceived over a range of velocities. Specifically, Neuhaus' data suggest that, with distance and intensity held constant, the velocity of apparent motion will decrease when ISIs are increased, and vice versa.

Preliminary support for this idea can be found in some early research published by DeSilva in 1928. Like Wertheimer before him, DeSilva manipulated the ISIs between parallel line stimuli that were presented tachistoscopically. Among other things, he recorded the perceived velocity of the movement. However, this was done in a completely qualitative fashion. On any given trial, his observers reported whether the motion appeared "faster" or "slower" than the movement observed on the immediately preceding trial. He found that when the ISI on any given trial was <u>greater</u> than that of the preceding one, the velocity of motion was reported as being "slower". When the ISI was reduced, he found that the motion appeared "faster". DeSilva also manipulated the distance between stimuli while holding ISI values constant. Under these conditions, the perceived velocity of motion increased as the spatial distance between stimuli increased.

In the discussion of the above findings, DeSilva proposed that apparent motion behaves like real movement becasue the velocities of both phenomena appear to conform to the same distance/time rule. He further proposed that the attribute of velocity is the single most important determinant of apparent motion perception. He wrote:

> ...the time element is the most fundamental determinant of movement, and that in this connection the angular velocity of the movement as measured from O's eyes...is especially significant. In order that either apparent movement <u>or</u> real movement may be perceived without inference, it seems obvious that the optimal angular velocity of this movement must lie within certain limit. (p. 574)

In effect, DeSilva proposed that apparent motion be theoretically understood as a phenomenon of velocity. Presumably, as long as the variables of distance and time interact to yield a velocity value within an optimum range, apparent motion will be perceived by an observer. If the velocity is either above or below this optimum range (i.e., either too fast or too slow), motion will not be detected.

There is a particularly noteworthy aspect to the theoretical perspective outlined above. Notice that DeSilva did not separate "real" motion and "apparent " motion into two distinct theoretical categories. Instead, he treated them both within the single underlying concept of motion <u>per se</u>, and it is assumed that the human perception of motion is primarily dependent upon the factor of angular velocity. Thus, according to DeSilva, "real" motion and "apparent" motion are arbitrary distinctions, because both phenomena are thought to be governed by the same underlying parameters of distance and time (i.e., velocity). In addition, DeSilva did not treat apparent motion as an aberration or illusion of something real. In this respect, he was in agreement with the basic theoretical underpinnings of Wertheimer, who wrote in 1912:

> As to the question of whether we are dealing with illusions of judgement, the following essential points should be made. Here it cannot be a question of illusions over something physically real, but rather an illusion of something given psychically. It is not a matter of: 'I am deceived over something physically present' but, 'I am deceived in the judgement of something seen.' (p. 1077.)

Kolers (1972) has since labeled the above viewpoint as "equivalence theory" of apparent motion, because both real and apparent movement are treated as "equivalent" phenomena. In a fairly lengthy discussion of this topic (Kolers, 1972; pp.174-180), Kolers disputed the claim of equivalence by citing several examples in which "real" motion and "apparent" motion are perceptually distinguishable from one another. For example, if an object were placed in the path of a luminous stimulus in apparent motion, its detectability would not be affected. In view of these examples, Kolers argued that "real" motion and "apparent" motion represent distinct perceptual phenomena, subsumed by different mechanisms, and governed by different parameters. In Kolers view, equivalence theory would, at its very best, only apply to a limited set of situations in which real motion and apparent are perceptually indistinguishable. In other words, Kolers argues that real motion and apparent motion can only be treated as equivalent phenomena when they are perceptually equivalent, i.e., indistinguishable.

In response to Kolers' arguments, the present author would like to raise two very important points. First, there is no a priori reason to assume that perceptual differences between two visual phenomena imply that they are, theoretically, dichotomous. Consider, for example, a hypothetical situation in which there are two luminous stimuli in real motion, but the luminous energies of each are considerably different from one another. Now suppose that a third stimulus was placed within the path of motion of each. An observer would probably report two different perceptual experiences. Specifically, the detectability of the third stimulus would probably be impaired to a greater extent when it was in the path of higher luminous energy. In this case, however, one would not necessarily conclude that the two paths of motion represent fundamentally distinct phenomena. Or, for that matter, that one of the movements was real, and that the other one was illusory. Rather, in this hypothetical situation, one could only conclude that the detectability of a third stimulus is affected differentially in the two movement situations.

Secondly, Kolers overlooked the fact that "equivalence" between two phenomena can be established on objective, as well as on subjective levels. For example, in De-Silva's (1928) original work, an objective equivalence between real and apparent motion was argued for, in the form of a distance/time rule of velocity. "Velocity" is an objective, mathematically derived construct that can be systematically related to a subjective level of experience. That is, "faster" or "slower" motion on a subjective level, is associated with various objectively derived values of velocity. DeSilva's original findings suggest that the subjective experience of apparent motion velocity conforms to a general distance/time rule, also known to characterize the subjective experience of velocity of real motion. In short, DeSilva was attempting to relate the experience of real and apparent movement to a common, objective rule. The conformity of each to the same rule was the basis of DeSilva's "equivalence" between real and apparent motion. Kolers, on the other hand, was defining "equivalence" on a purely subjective level, i.e., perceptual identity.

It is interesting to note that, despite his arguments against equivalence theory, Kolers recommended that the research initiated by DeSilva in 1928 be continued. According to Kolers, it would be very worthwhile to ascertain the extent to which the perceived velocity of apparent motion will conform to a general distance/time formula. However, after a careful review of the literature since the publication of DeSilva's work, the present author could not find a single published study devoted to the perceived velocity of apparent motion. Given this state of affairs, the present paper will attempt to extend the work first begun by DeSilva in 1928. At this point, it should be recalled that in the preliminary investigation of perceived velocity, no numerical measures were taken. Observers merely reported if the motion was "faster" or "slower" than what was perceived on the immediately preceding trial. Clearly, numerical measures of perceived velocity are needed to see how it will vary along a continuum of values for objective velocity (i.e., distance/time ratios).

In the present paper, several experiments will be reported in which numerical measures of perceived velocity are compared with objectively defined values for velocity. However, the research paradigm employed in these experiments is somewhat different than the one traditionally used to investigate apparent motion in the laboratory. This new paradigm will first be described in considerable detail.

Paradigm of the Present Research

In order that the reader may fully understand the nature of the present paradigm, the "standard" paradigm for apparent motion should first be described. The standard paradigm was the one first introduced by Wertheimer in 1912. It entailed the presentation of two, spatially non-overlapping stimuli that were flashed in sequence. The luminance and durations of each stimulus were usually kept equal to one another. Also, when motion is produced under the foregoing conditions, it is perceived to go in a direction that corresponds with the temporal order of the stimuli. Motion appears to go from the location of the first stimulus to be flashed, towards the location of the second stimulus.

Exceptions to the above rule for direction of movement have been reported when the second stimulus has a much greater luminance and/or duration than the first one (Graaham, 1965). In this latter situation, the perceived direction of motion is exactly the reverse of that which is typically reported for apparent motion: that is, movement proceeds from the location of the second stimulus towards the location of the first one. Graham (1965) refers to this latter case of reversed movement as "delta" motion; and the standard type of movement as "beta" motion. Apparently, the essential requirement for the production of delta movement is that the second stimulus be much brighter than the first one. This particular aspect of delta movement is pertinent to some research which will be discussed later in this section.

Over the past 65 years of investigation of apparent motion, various modifications of the standard, beta paradigm have been developed. A particularly relevant one was described in Bartley (1941). This paradigm differs from the standard one in that the two stimuli flashed in sequence overlap each other spatially. Further more, the second stimulus subtends a greater visual angle than the first one. A description of the motion produced with this paradigm was also provided by Bartley:

> A second special case is that in which an object is presented, and following its emergence, another object is added...The first object may subjectively remain fixed and the second one disengage from it and move to its final position. At other times, the first object may appear to divide, one part moving alongside, both comprising members of a final figure. It is to be noted that the first member (stimulus) does not move from its position, only the second carries the movement. (p. 166).

Bartley referred to the above type of motion as a "special case" of beta movement produced with spatially overlapping stimuli. Unfortunately, he was very sketchy with respect to the details of size, shape, duration, and ISI values needed to produce this type of motion. Nor did he provide any published references dealing with this type of movement. This ommission of details by Bartley reflects the fact that this "special" case of apparent movement has received very little empirical investigation. In fact, until quite recently, there have only been two other published accounts of this type of movement.

The first known description of apparent motion with spatially overlapping stimuli can be found in Ternus (1926). Ternus flashed two separate arrays of dots, in sequence, on a tachistoscope. The first array was either completely overlapped, or almost entirely overlapped by the points of the second array. Furthermore, the second array usually consisted of a greater number of points than the first one, arranged so that it would subtend a larger visual angle than the first array. Ternus reported that under these conditions, motion was perceived among the points of the second array which _did not overlap with_ any of the points of the first array. Specifically, motion proceeded _from_ the locations of the overlapping points, _towards_ the perimeter of the second array. Ternus' description of the movement agrees fairly well with the one by Bartley (1941), in that the second stimulus to be flashed was the only one to "carry" the percept of motion.

The other published account of movement with spatially-overlapping stimuli can be found in Kolers (1972; pp. 61-68). Like Ternus before him, Kolers used arrays of dots flashed in sequence on a tachistoscope. In one particular case, a single dot was the first stimulus, and a horizontal array of dots (with the middle dot overlapping the first stimulus) comprised the second stimulus. It should be noted that the durations of the first and second stimulus were always equal to one another. Kolers reported that under these conditions, movement was perceived among the dots of the second array which did not overlap with those of the first. The middle, overlapping point of the second array appeared stationary, while the two non-overlapping points seemed to move centrifugally towards the perimeter of the second array. These findings, coupled with those of Ternus, suggest that movement with overlapping stimuli only occurs among the <u>non</u>-overlapping points of the second stimulus. Furthermore, the perceived direction of motion in this paradigm seems to conform to the general rule for the standard type of beta motion. That is, motion proceeds <u>from</u> the overlapped points of the <u>first</u> stimulus <u>towards</u> the non-overlapping points of the <u>second</u> stimulus.

Quite recently, the present author has conducted some research with a paradigm quite similar to the ones described by Ternus (1926) and Kolers (1972). As was the case with the previously described research, the stimuli consisted of arrays of light-points flashed in sequence. However, a computer-based cathode ray tube (i.e., CRT), instead of a tachistoscope, was used to display the stimuli. The first array, which will hereafter be referred to as the "test signal", was either a (a) single vertical line of dots; (b) a single horizontal line of dots; (c) two parallel vertical lines; or, (d) two parallel horizontal lines. Each line of a test signal consisted of 5, equally-spaced points of light (see Carlson & Mayzner, 1977, for more details). The second stimulus to be flashed was always a 5 x 5 square matrix of points. This latter stimulus, which will hereafter be referred to as the "grid", was comprised of 5 rows and columns of points, that completely overlapped the points of a test signal. The duration of each test signal was only 350 microseconds, while that of the grid was 500 milliseconds. The ISI between the test signal and grid was kept at a constant value of 40 msec.

Ten different observers reported their perceptions on 20 trials in each of the four test-signal conditions. On the average, motion was perceived on 92% of the trials. Phenomenally, this motion appeared among the points of the grid which did not overlap the test signal, and it proceeded from the spatial location of the overlapping points, towards the perimeter of the grid. Furthermore, the direction of motion was always perpendicular to the spatial orientation of the test signal. Thus, with vertical test signals, motion was towards the left & right sides of the grid (Left-Right motion). With horizontal signals, motion was towards the upper and lower edges of the grid (Up-Down movement). Of particular interest, the observers were completely unaware that two separate stimuli were flashed in sequence. Their subjective visual experience was always that of a single grid with moving points.

The above research was identical to the investigations reported by Ternus and Kolers, except for the vastly different durations of the stimuli. Specifically, the duration of the grid was approximately 1000 longer than that of the test signal. Moreover, the luminance of these stimuli were not equated. Hence, the grid stimulus was always considerably brighter than the test signal. In paradigms with non-overlapping stimuli, delta movement (i.e. reversed motion) is generally produced under those conditions. With overlapping stimuli, however, the perceived direction of motion still corresponded to the temporal order in which the test signal and grid were presented. That is, motion was perceived to go from the overlapped locations of the first stimulus toward the perimeter of the second stimulus. At the present time, there is no explanation for this discrepancy between the two paradigms.

As mentioned earlier, there have been very few investigations of apparent motion produced with overlapping stimuli. Quite possibly, this might be due to the fact that this particular paradigm bears little physical resemblance to the typical conditions for real motion. (Motion among overlapping objects is usually not perceived in the world outside of the laboratory.) Indeed, Ternus (1926) himself commented in his own preliminary investigations with this paradigm that: "It is apparent from this experiment that the kind of approach represented by the foregoing...is essentially unnatural and foreign to actual experience." (p.150) In most published investigations of apparent motion, every attempt is usually made to relate this phenomenon to "real" movement situations (see Kolers, 1972, pp.172-181; Levy, 1972, for extensive reviews). As a result of this endeavor, paradigms appearing "remote" from real movement conditions probably have not been developed to their fullest extent.

It seems that a paradigm with overlapping stimuli is a particularly useful one for the investigation of perceived velocity of motion. This particular paradigm might be especially amenable for the continuation of the work begun by DeSilva in 1928. DeSilva, it should be recalled, hypothesized that the perceived velocity of apparent motion would vary consistently and predictably with a distance/time formula of objective velocity. He made no distinctions between "real" movement and "apparent" movement with respect to the above formula. Theoretically, the degree to which laboratory conditions resemble real motion is of little consequence in his view. According to DeSilva, as long as a factor of distance and a factor of time yield a velocity value within the range of human sensitivity, motion will be perceived by an observer. In short, a paradigm with overlapping stimuli (i.e., one that seems remote from real motion) could provide us with the opportunity to put some of DeSilva's ideas to a rigorous test.

For all of the above reasons, the present paper employed a paradigm with overlapping stimuli to investigate the velocity of apparent motion. The research to be reported was quite similar to the previously described investigations by the present author. That is, motion was produced by flashing a test signal, of minimum duration, prior to a grid of points having a much longer duration. The major dependent variable of this research was perceived velocity, which was measured by a 5-point scale, corresponding to relative degrees of "swiftness" on a subjective level. Measures of <u>perceived</u> velocity were analyzed to see how well they conformed to an <u>objective</u>, distance/time rule of velocity. Values from this latter formula were derived by dividing the distance traversed by the moving points (in degrees of visual angle), by the ISI value separating the test signal and grid. Thus, the ISI was used to define "time" in that formula.

It should be mentioned that there has been some debate as to whether the ISI value is an appropriate definition of "time" in that formula. Kolers (1972) pointed out that the ISI will sometimes produce mathematically absured values of objective velocity. For example, there have been cases where apparent motion is produced with ISIs of zero msec.. If applied to the objective formula, this ISI would yield an uninterpretable value of velocity. Kolers therefore suggested that the onset-onset interval (i.e., SOA) be used for these purposes. However, it must be stressed that in the present research, the test signal's duration was a very small value (i.e., msec.). Under these conditions, there is virtually no difference between the ISI and SOA values between the test signal and grid. Moreover, in the experiments to be described shortly, the ISI value proved to be a more convenient measure for "time" in the velocity formula.

Four different experiments were conducted utilizing the measure described above. In the first experiment, a single test signal was flashed prior to the grid on any given trial. It should be noted that the spatial distance separating the stimuli was held constant in all conditions.

The major purpose of the first study was to see if DeSilva's basic assertions regarding a distance/time conformity are correct. Experiments II, III, and IV were similar to the first one, except for the fact that two test signals were flashed in sequence prior to the grid. These latter experiments were conducted to see how well perceived velocity would conform to a distance/time rule under the more complex situation of intermittent stimulation prior to the grid. Each experiment will now be described in detail.

EXPERIMENT I

There were two independent variables in this experiment: the geometric orientation of the test signal, and the ISI separating the test signal and the grid. On any single trial, one of three different test signals was flashed before the grid. Either a vertical array of points, a horizontal array, or a "cross" signal, composed of the first two types, was presented for 1 msec. prior to the grid. In some earlier research conducted by the present author (cf. Carlson & Mayzner, 1977), the perceived direction of motion in this paradigm was always found to be perpendicular to the spatial orientation of the test signal. However, this earlier research had employed test signals having a single orientation only (i.e., either a horizontal <u>or</u> vertical array of points). The "cross" test signal was included in the present study to see if the motion percept would incorporate <u>both</u> of the directions already observed for each of the single test signals, when they were each presented alone.

The ISIs between a test signal and grid ranged from zero to 120 msec., in 20 msec. increments. Four observers were given 20 trials in each of the test signal/ISI conditions. On each trial, an observer reported three things: (a) whether or not they perceived movement in the grid; (b) the perceived direction of any movement they perceived; and, (c) their assessment of the apparent velocity of motion. The order in which the various experimental conditions was presented was completely random.

Forty catch trials, in which the grid was flashed without the preceding test signal, were also interspersed among the above experimental conditions. In some of our previous research (cf. Carlson & Mayzner, 1977), "No Movement" was usually reported when the grid was flashed without a test signal. In the present study, this particular condition was included as a control for spurious "movement" responses in the other experimental conditions. That is, a high percentage of movement responses in the control condition would make the other reports of motion (in the remaining conditions) highly suspect.

As was mentioned in the previous section, the major purpose of this experiment was to see if DeSilva's original assertions regarding a distance/time rule for apparent motion would obtain here. It should be noted that in the present experiment, the spatial distance between each test signal and the grid was held constant. Thus, if DeSilva was correct, the perceived velocity of motion should decline as the ISI between the test signal and grid becomes larger. Moreover, the perceived velocities of motion at each ISI condition, should bear a consistent and predictable relationship with the equivalent velocity (i.e., distance.time) inherent in each ISI condition.

Method

Subjects

Two male and two female volunteers, ranging in age from 24 to 29 years, participated in this experiment. All of them had either normal or corrected vision, and all but one of them was a graduate student in psychology.

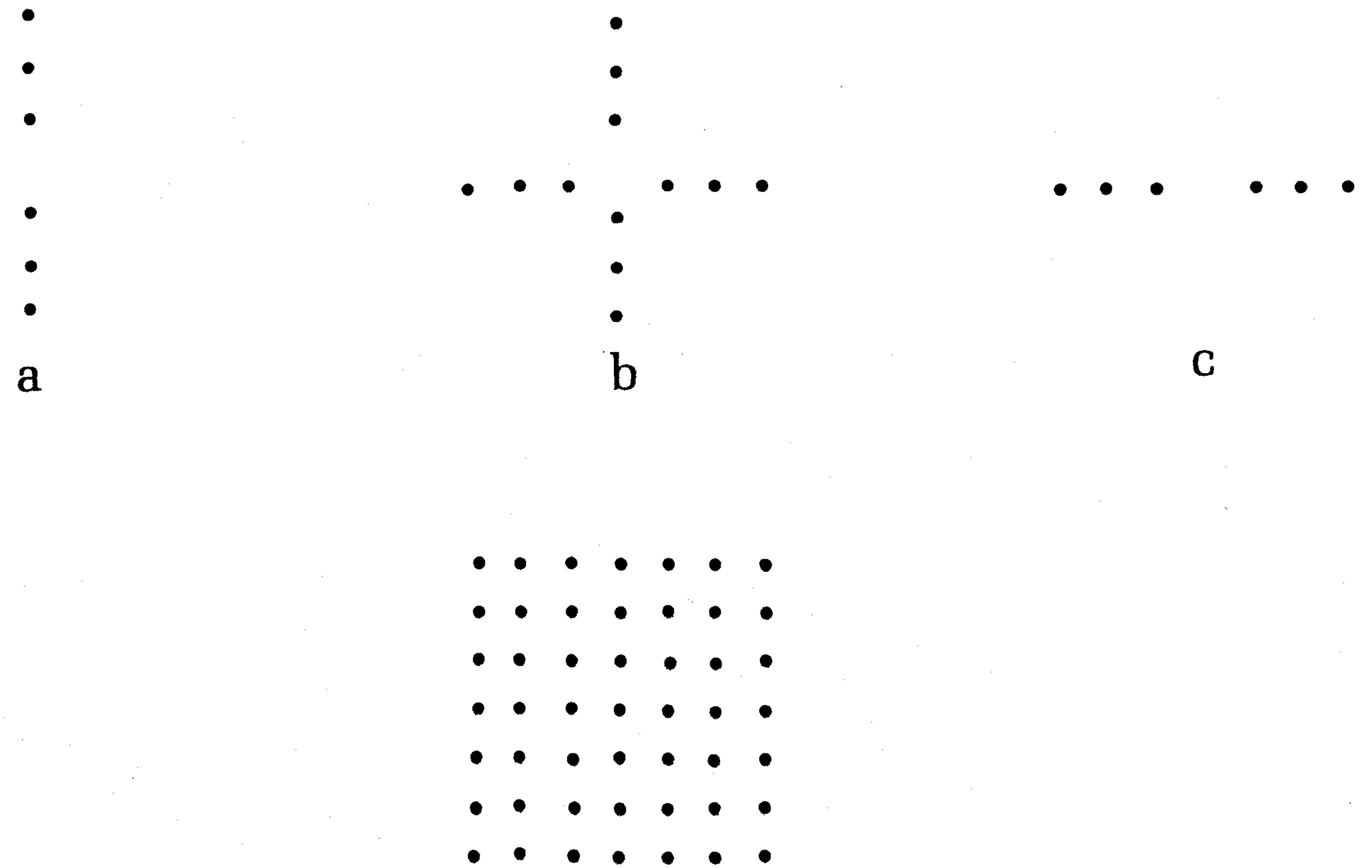
Apparati

All stimuli were constructed and displayed by a VR-14 CRT driven by a PDP-8/E computer. A more detailed description of this hardware can be found elsewhere (Mayzner, 1968; 1975). The CRT was located in a viewing room adjacent to the one containing the computer hardware. A constant, low level of illumination was maintained in the viewing room by means of a small reading lamp positioned in one corner of the room. Observers viewed the CRT with the aid of a chin rest (binocular viewing) placed approximately 70 cm. from the center of the CRT screen. A frame, made from black construction paper taped to the CRT screen, outlined a small central portion of the screen (5 cm. x 5 cm.), that served as a general fixation area for the stimuli.

Stimuli

Figure 1 depicts the test signals and grid used in this study. Each point of light comprising an array was

Figure 1



.025 cm. in diameter, with a display luminance of approximately 1 millilambert. Each of the three test signals had a display duration of 1 msec. It should be noted that the single vector signals were constructed with a complement of 6 "dummy" or null points. This was done to equate the refresh rate (by the electron gun) for each stimulus point, thereby equating the subjective level of brightness for the single-array and double-array test signals.

The 7 x 7 grid of points, also shown in Figure 1, had a display duration of 500 msec. Thus, the grid was a much brighter stimulus than any of the test signals. The grid was positioned on the CRT so that its middle column and middle row spatially overlapped the vertical and horizontal array of each test signal respectively. Notice, also, that each column and row of the grid contains 7, equally-spaced points of light; whereas, there were only 6 such points in each vector of a test signal. The middle dot of light in each of the test signal vectors was deleted because of some limitations in our computer software. Specifically, with our current software program (needed to display the points of light on the CRT), the middle point in the cross signal would have been refreshed (by the gun) twice as frequently as the other points in that signal. Thus, to ensure an equal amount of brightness in all of the points, this middle dot of light was deleted altogether.

Procedure

Each observer was tested within a single experimental session lasting approximately 1 hour and 15 minutes, including a 10 minute rest period. The following instructions were given to each observer:

> Please focus your attention on the matrix of points which will appear within the area outlined by the black frame on the screen. On each trial, please report whether or not you perceived motion among the points in the grid. If your answer is "yes", I would like you to report two other things. First, the direction in which this motion appeared to be going. Was it: "Left-Right", "Up-Down", or "Both" of those directions. Second, please rate the relative speed with which the motion appeared to be going. (A 5-point scale was shown to them.) The number "1" means that is was very slow (relatively speaking), and the number "5" means that is was very fast. The intervening numbers represent intervening degrees of velocity.

Forty practice trials were then given to familiarize each observer with the experimental task. Once the testing session began, an observer would initiate each trial by saying, "Go" through a walkie-talkie. Their responses were verbally communicated to, and recorded by, the experimenter who was situated in an adjacent room housing the computer hardware.

Results and Discussion

Incidence and Perceived Direction of Motion

In the first step of the data analysis, the percent number of trials in which movement was detected, and the perceived direction of movement, was determined. The raw percentages of movement detection were corrected according to a formula prescribed by Engen (1971, p. 34): raw % - % False alarms/1 - % False alarms. The "false alarm" rate was defined as the percent number of movement responses (of a given direction) on the catch trials. It should be noted that "movement responses" on catch trials were acceptably low, occurring less than 9% of the trials overall.

The corrected data are shown in Table 1. There are two basic points to be drawn from them. First, the overall incidence of motion detection increased monotonically with ISIs between zero and 60 msec., after which, it asymptoted. This was true in each of the test signal conditions. Second, the perceived direction of motion was different among the three test signal conditions. "Left-Right" motion occurred almost exclusively in the vertical signal condition; "Up-Down" with the horizontal signal; and, "Both" of those directions was reported on a majority of trials with the cross test signal. Notice, also, that each directional response (in every test signal condition) predominated among all the ISI values. This suggests that the perceived direction of movement was independent of ISI. Specifically, perceived direction of movement was primarily determined by the spatial orientation of the test signal: motion was usually perpendicular to the spatial orientation of the test signal.

Table 1

Incidence* and Perceived Direction of Movement

In Experiment 1

Test Signal	ISI						
	0	20	40	60	80	100	120
Vertical							
L-R**	.00	.47	.80	.95	.94	.92	.94
U-D	.00	.01	.00	.00	.00	.00	.00
Both	.00	.00	.06	.02	.03	.04	.02
Total	.00	.48	.86	.97	.97	.96	.96
Horizontal							
L-R	.00	.00	.00	.00	.00	.00	.00
U-D	.00	.40	.74	.95	.98	.95	.95
Both	.00	.05	.03	.01	.00	.03	.03
Total	.00	.45	.77	.96	.98	.98	.98
Cross							
L-R	.00	.09	.13	.05	.00	.03	.05
U-D	.00	.12	.20	.03	.05	.03	.03
Both	.01	.10	.40	.83	.86	.84	.84
Total	.01	.31	.73	.91	.91	.90	.92
$\overline{X}$	.00	.41	.77	.95	.95	.95	.95

* = corrected % # of trials

**L-R = Left-Right; U-D = Up-Down

Overall, the data in Table 1 indicate that when spatially-overlapping stimuli are flashed in sequence, motion can be observed over a fairly wide range of ISIs. In the present study, an optimum range (for motion) appears to be between 40 and 120 msec.. The data further imply that the ISI threshold value for motion (i.e., ISI at which motion is perceived on 50% of the trials) is slightly larger than 20 msec. under the present circumstances. At ISIs greater than 20 msec., motion can be observed on a clear majority of the trials. Thus, the perceived velocity ratings, to be discussed below, were based on a fairly large sample of movement responses among most of the ISIs manipulated in this study.

Perceived Velocity

The mean velocity ratings of movement responses in each of the experimental conditions was computed. These values, along with their standard deviations, are given in Table 2. It should be explained that the zero ISI condition was deleted in this table because virtually no movement was reported there. Overall, the data in Table 2 reveal that velocity appeared to become slower as the ISI values increased. This trend was practically identical among all three perceived directions of motion, indicating that the perceived direction of motion had little influence upon the perceived velocities.

The means and standard deviations of the ratings for each of the 4 observers were also examined, and these data

Table 2

Mean and Standard Deviation of

Perceived Velocity Judgements

Motion		ISI 20	40	60	80	100	120
L-R	$\overline{X}$	4.57	3.62	3.12	2.58	2.63	2.39
	SD	.61	1.04	1.01	1.03	1.14	1.16
U-D	$\overline{X}$	4.41	3.57	3.14	2.87	2.52	2.65
	SD	.69	.85	.97	.87	1.21	1.22
Both	$\overline{X}$	4.45	3.79	3.24	2.64	2.61	2.52
	SD	.91	.90	1.02	1.01	.99	1.09
Mean		4.50	3.68	3.18	2.70	2.59	2.54

can be found in Table 3. This table shows that the responses of three of the observers (S_1, S_2, & S_4) were quite similar. Each of these individuals rated velocity "slower" as the ISI values increased. However, one observer (S_3) deviated from the others in that his ratings tended to increase (i.e., movement appeared faster) after the 80 msec. ISI. This particular person, it should be noted, reported afterwords that he frequently saw both the test signal and the grid, as two distinct temporal events, under those latter ISIs. He also reported being distracted from the motion *per se* under such circumstances. In the present study, the motion observed on any given trial was quite transient. Under these viewing conditions, even a momentary "distraction" could alter the apparent velocity of movement. Thus, the performance of observer number 3, at the largest ISIs, could feasibly be explained by his being distracted from motion because of his detection of the test signal.

There is another noteworthy aspect of the data in Table 3. Notice that the standard deviations of judgements were usually rather small, and quite similar among all four observers. This implies that the mean ratings of velocity at each ISI reflect a fairly cohesive sampling of judgements. That is, perceived velocity consistently decreased with ISIs, both within and between the observers.

Table 3

Mean and Standard Deviation of Perceived Velocity

Among Observers in Experiment I

Subject		ISI 20	40	60	80	100	120
1	$\overline{X}$	4.49	3.74	3.18	2.75	2.29	2.36
	SD	.62	.95	.99	1.08	.96	1.03
2	$\overline{X}$	4.57	3.69	3.00	2.50	2.43	2.40
	SD	.69	.91	.96	.93	.96	.99
3	$\overline{X}$	4.36	3.77	3.39	3.12	3.25	3.60
	SD	.82	.97	1.10	1.11	1.08	.63
4	$\overline{X}$	4.61	3.47	3.14	2.42	2.08	1.72
	SD	.52	.76	.94	.87	.83	.88

In order to see how well perceived velocity conformed to an objective distance/time rule, perceived velocity ratings were compared with the calculated values of objective velocity at each ISI. These latter measures, which were expressed as degrees of visual angle per second, were found by dividing the spatial distance traversed by the motion (i.e., 27' of visual angle), by each of the 6 ISIs manipulated. Objective velocities ranged from 3.75 degrees/sec. (at 120 msec. ISI0, to 22.5 degrees/sec. (at 20 msec. ISI). Measures of perceived velocity and objective velocity were plotted against the 6 ISIs, and the resulting functions are displayed in Figure 2. Notice that, in both functions, the greatest decline in velocity occurred between 20 and 80 msec.. Between 80 and 120 msec., this gradual decline began to level off somewhat. However, this "leveling off" was more pronounced in the function for perceived velocity.

Overall, Figure 2 indicates that the function for perceived velocity was quite similar to the one for objective velocity. This obviously implies that perceived velocity, like objective velocity, conformed to a distance/time rule. To better assess the accuracy of this idea, perceived velocity was also re-plotted _against_ values of equivalent velocity. A perfect correspondence between perceived and objective velocity would result in a perfect linear function. Figure 3 shows that a linear function would describe the perceived velocity data rather well. The most

FIGURE 2

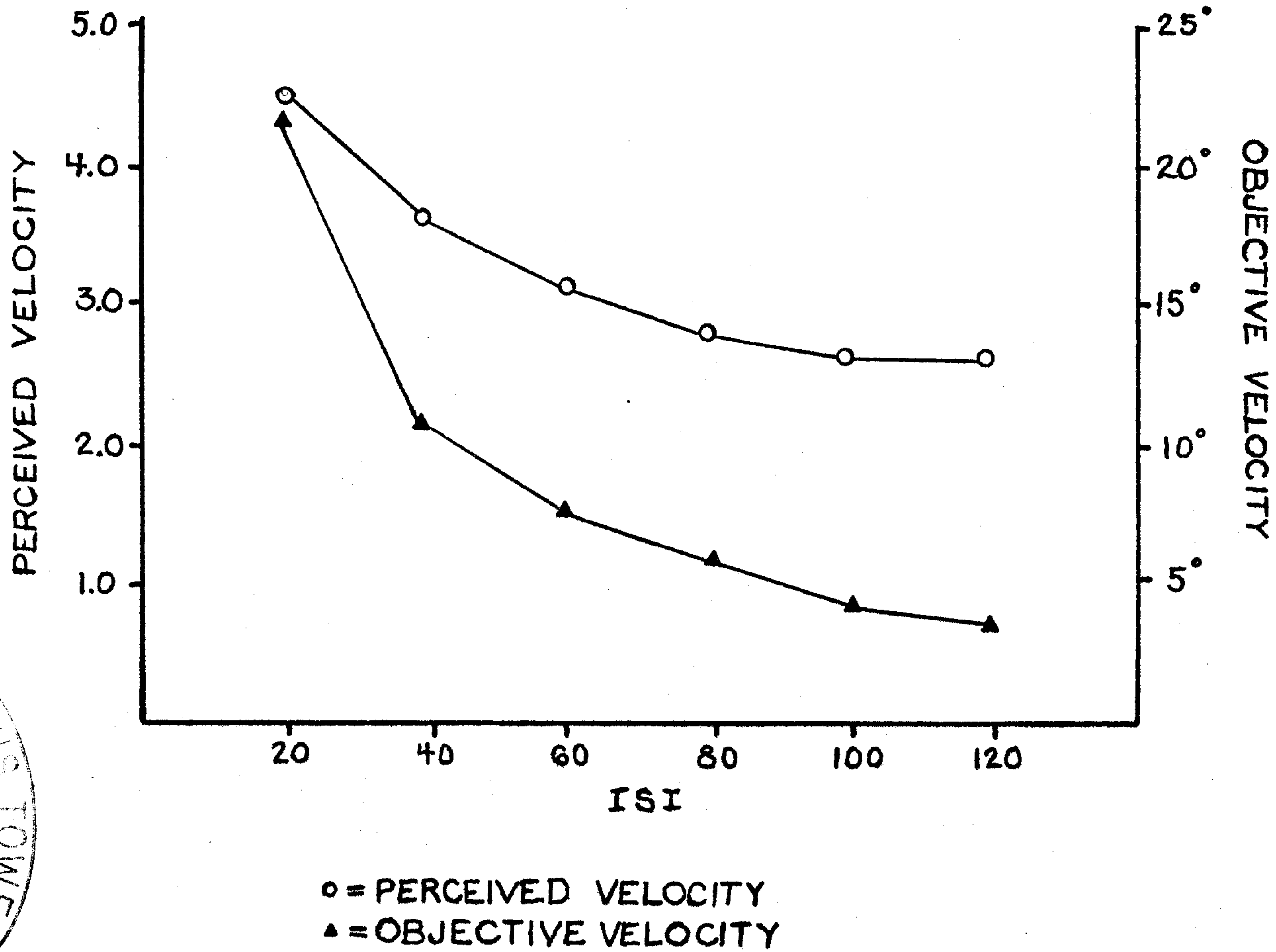
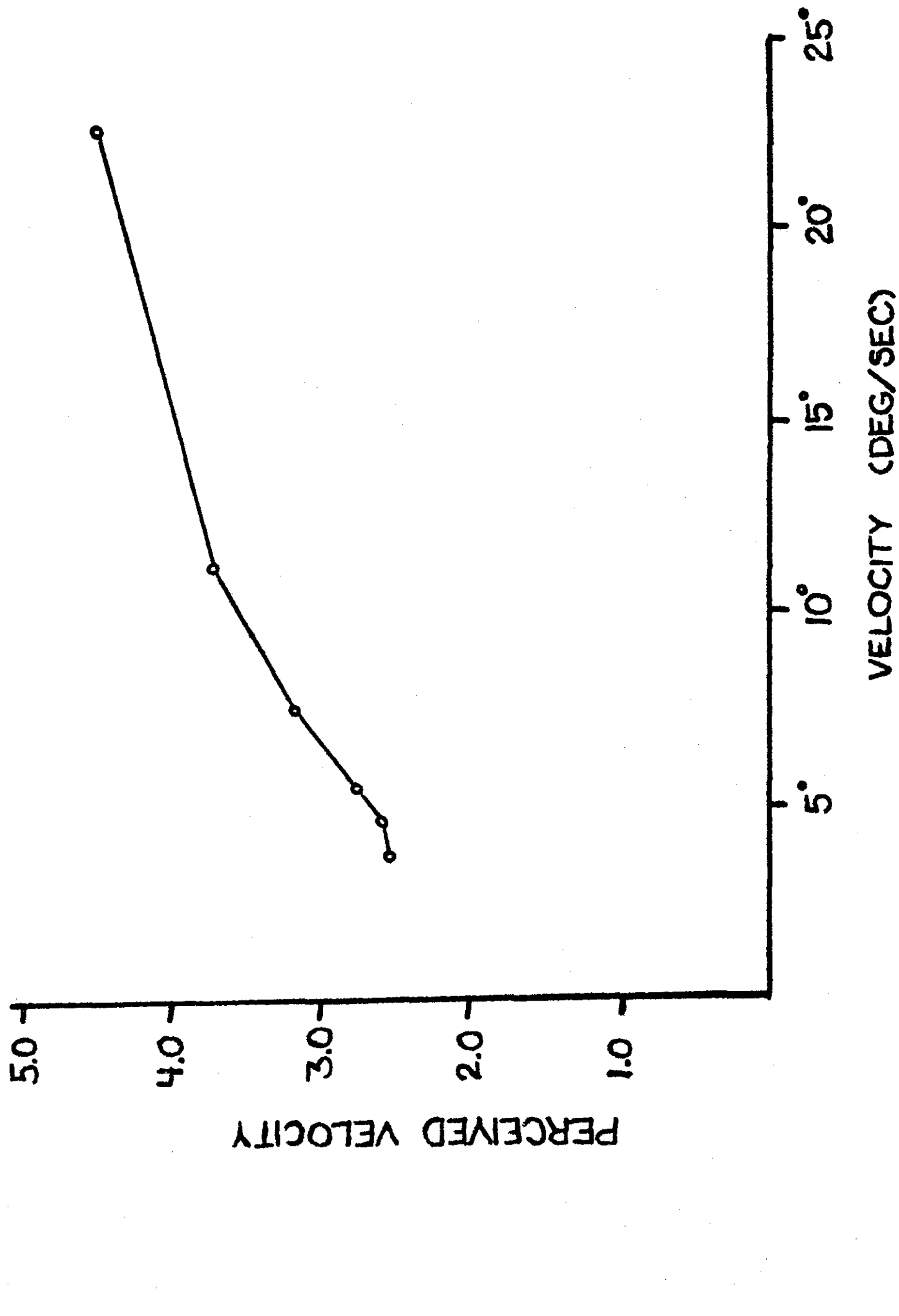

5.0
4.0
3.0
2.0
1.0
PERCEIVED VELOCITY
25°
20°
15°
10°
5°
OBJECTIVE VELOCITY
20
40
60
80
100
120
ISI
o = PERCEIVED VELOCITY
▲ = OBJECTIVE VELOCITY

FIGURE 3



PERCEIVED VELOCITY
5.0
4.0
3.0
2.0
1.0
5°
10°
15°
20°
25°
VELOCITY (DEG/SEC)

pronounced departures from linearity occurred at two points along the abcissa. The first one was at the fastest objective velocity of 22.5 degrees/sec. (corresponding to the 20 msec. ISI condition). A higher mean rating at this value would have produced a much bettwe fit to linearity. However, it should be pointed out that the incidence of motion detection was only 41% in that condition, indicating that it was slightly below the threshold of motion detection. Furthermore, most of the observers had reported that, on many occasions, motion appeared to be going "so fast", it was very difficult to tell that there was motion at all. In which case, they often reported seeing no movement. Quite possibly, the prevalence of "No Movement" responses at the 20 msec. ISI (i.e., 22.5 degrees/sec.) condition tended to lower the overall mean rating of velocity there.

The most pronounced departure from linearity in Figure 3 was at the largest ISI msec. (i.e., 3.75 degrees/sec.). This particular departure can be attributed to at least two factors. First, it must be remembered that one of the observers ratings increased in this condition, thereby raising the overall mean rating there. Reasons for this particular subject's performance were already given. Secondly, the difference between the objective velocities in this condition and the immediately preceding ISI condition (i.e., 100 msec., or 4.5 degrees per second) were minimal, probably making it very difficult to detect a <u>noticeable</u>

difference in their velocities. Furthermore, the difficulty in detecting a noticeable difference in velocities was probably accentuated by the inherent lack of sensitivity in the simple, 5-point ordinal scale used to measure perceived velocity in this study. Specifically, one should consider the fact that the objective velocities ranged from 3.75 degrees per se. to 22.5 degrees per sec., while the perceived ratings could only vary among 5 integer values. Perhaps, if a more sophisticated rating scale had been employed in this study, the function for perceived velocity would have fit a linear one in a more precise manner.

Summary And Additional Comments

In 1928, DeSilva asserted that the velocity of apparent motion conformed to a distance/time rule. DeSilva had reached such conclusions on the basis of some qualitative observations by his observers. As mentioned earlier, no numerical measurements of perceived velocity were taken at that time. Overall, the data from this experiment support DeSilva's early speculations. With the exception of two minor departures, the perceived velocity of motion in this study corresponded with an objective, distance/time rule very closely. In otherwords, when the factor of distance is held constant in a paradigm with overlapping stimuli, perceived velocity was found to be a very stable, and predictable percept along a continuum of time (i.e., ISIs). This is a very interesting finding, especially when one remembers that the present paradigm seems rather remote from the typical conditions of "real" motion outside of the laboratory. Despite this apparent remoteness from real movement arrangements, a gen-conformity with a distance/time rule was observed here.

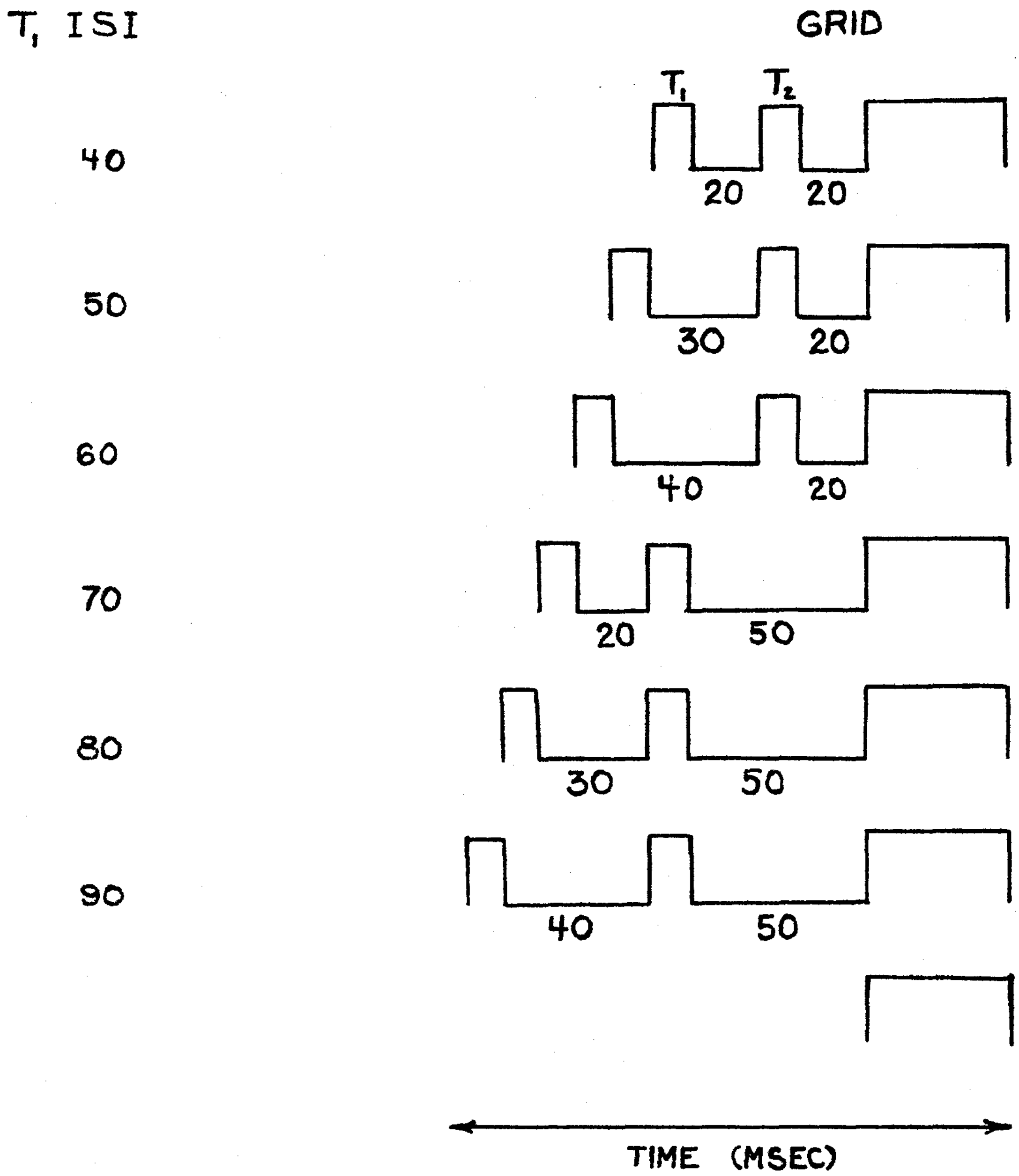
Earlier in this paper, it was explained that Kolers (1972) argued against the notion of "equivalence" between "real" and "apparent" motion because the two are perceptually distinguishable in several types of laboratory arrangements. Kolers was defining "equivalence" on a strictly subjective level of perceptual identity between the two phenomena. The present study demonstrated another type of equivalence between real and apparent movement. Specifically, it showed that an objective velocity rule operates within the realm of apparent motion, just as it does, theoretically, for real movement. The following experiment was conducted to see if this present finding would also generalize to another viewing situation for apparent motion. In this next experiment, two test signals (instead of one) were flashed, in sequence, prior to the grid. Measurements of perceived velocity were taken to see how well velocity of motion induced by the first test signal would conform to a distance/time rule under these more complex conditions.

EXPERIMENT II

Figure 4 graphically depicts the basic design of this experiment. The term "T_1" refers to the first test signal flashed prior to the grid; and, "T_2", to the second one. The test signals were the vertical and horizontal vectors described in the previous experiment (See Figure 1). Furthermore, the spatial locations of each stimulus on the CRT were identical to those of the previous study. On half of the trials, T_1 was a vertical array flashed for 1 msec.; and, T_2, a horizontal array, also flashed for 1 msec.. On the other half of the trials, the converse was true. As was the case in the first experiment, 7 x 7 grid of points had a duration of 500 msec..

Because there were two different test signals flashed prior to the grid, the paradigm of this experiment resembled the "cross test signal" condition of the previous one. Hence, observers were expected to frequently detect both Left-Right and Up-Down movements in the grid simultaneously. However, the primary purpose of this experiment was to examine the perceived velocity of motion induced by the first test signal only. This would obviously require <u>a velocity discrimination</u> (between Left-Right & Up-Down motion) on the part of our observers. In the present study, velocity discriminations were measured by asking observers to report whether one of the directions of motion (i.e.,

FIGURE 4


T_1 ISI
GRID
T_1
T_2
40
20 20
50
30 20
60
40 20
70
20 50
80
30 50
90
40 50
TIME (MSEC)

either Left-Right or Up-Down) appeared discernibly slower than the other. Theoretically, the slower of the two movements would pertain to motion induced by the first test signal (i.e., because its ISI was always larger than that of the second test signal). The frequency with which observers could make such velocity discriminations, as well as the velocity ratings of the slower-appearing motion, were the major dependent variables in this experiment.

The perceived velocity of motion induced by the first test signal was analyzed to see if it would still conform to a distance/time rule under the present viewing conditions. Figure 4 shows that in this present study, 6 different ISIs separated the presentation of the first test signal and the grid. Specifically, ISIs ranging between 40 and 90 msec. were observed here. The findings of Experiment I had indicated that, within this particular range of ISIs, perceived velocity showed the closest adherence to an objective, distance/time rule. However, in the present study, a second test signal was flashed either 20, 30, or 40 msec. after the first one. Under these latter conditions, a conformity to the distance/time rule could occur <u>as long as</u> the second test signal did not interact, on any temporal dimension, with the first one. That is, the ISIs between T_1 and the grid could not be altered, in any way, by the presentation of T_2, in order for a distance/time conformity to result. In one sense, the visual system would have to treat the first test signal, as if the second one were not presented at all. In short, an adherence to a distance/time rule in the present study would indicate that the velocity of motion induced by one test signal (i.e., T_1) is a very stable, and predictable percept, even in the midst of movements induced by another test signal.

However, given the very short intervals separating the first and second test signals in the present study, the hypothetical occurrence described above is rather doubtful. An extensive body of research has shown that two visual stimuli separated by about 20 or 30 msec. are usually perceived to be simultaneous in time (e.g., Hirsch & Sherrick, 1961; Boynton, 1962; Allport, 1968). Some sort of temporal integration is assumed to occur within the visual system at ISIs (between two stimuli) that are below the threshold of perceived simultaneity. According to this view, "temporal integration" entails the combination of two or more stimuli in time, thereby effectively reducing any objective temporal differences between them. Applied to the conditions of the present experiment, the concept of "temporal integration" would imply that, at T_1-T_2 intervals below the threshold of perceived simultaneity, the ISIs separating test signals and grid would deviate from their objectively defined values. Should this occur, a conformity to a distance/time rule for velocity would be highly improbable.

The concept of temporal integration also implies that velocity discriminations (between T_1 & T_2) would be very infrequent when the T_1-T_2 intervals were below the threshold of simultaneity. This is because the objective temporal differences between T_1 and T_2 are assumed to be minimized below threshold; thereby minimizing the differences between their objectively defined velocities. For this reason, the threshold of perceived simultaneity for T_1 and T_2 was determined to see if it influenced the frequency with which velocity discriminations could be made. In the present paper, this threshold was defined as the T_1-T_2 interval at which the first and second signals would appear simultaneous (in the absence of the grid) on 50% of the trials. Moreover, this threshold value was also assumed to reflect a theoretical "integration period" for the test signals, when presented without the grid. It was of great interest to see the extent to which this concept of temporal integration was related to the perceived velocities of apparent movements investigated here.

Method

Subjects

The same four observers from the first experiment also participated in this study.

Procedure

As in the previous experiment, observers were instructed to report the perceived direction and apparent velocity of motion among the grid of points. Perceived velocity was measured with the same 5-point ordinal scale used in the first experiment. In cases where they detected motion in both directions, they were told to report the one that appeared to be discernibly slower, and to base their velocity rating on this movement alone. If they couldn't make a velocity discrimination between the two types of movement (i.e., Left-Right & Up-Down), they were to report that "Both" movements appeared to go at equivalent velocities.

Each observer was given 60 trials at each of the 6 ISIs between T_1 and the grid (see Figure 4). In addition, 40 "catch" trials were interspersed among the above experimental conditions. As was the case in the first experiment, the experimental conditions were presented in a completely randomized order. Each observer was tested within a single experimental session lasing approximately 1 hour and 30 minutes.

To find the threshold of perceived simultaneity, two of the observers (S_1 & S_2) attended an extra session in which the two test signals were viewed on the CRT without the grid following them. The T_1-T_2 intervals were varied, ranging from zero to 70 msec., in 10 msec. increments. On half of the trials, the horizontal array was flashed for 1 msec. before the vertical array (which also had a duration of 1 msec). On the other half of the trials, the converse was true. Each observer was given 20 trials at each of the T_1-T_2 intervals. On each trial, the observer reported whether or not the two test signals appeared "simultaneous" or "sequential" in time. The various experimental conditions were presented in a completely randomized order, and a single test session lasted approximately 35 minutes.

Results and Discussion

Perceived Simultaneity

The percent number of trials at which reports of "simultaneity" occurred at each T_1-T_2 interval was recorded for each of the two observers. The threshold for each observer was computed by a least squares solution as described in Guilford (1954, pp. 125-129). This entailed the translation of raw percentages to z scores, which were then submitted to a linear regression equation. According to this method, the threshold value is the T_1-T_2 interval at which reports of simultaneity had a .50 probability (i.e., $z = .00$) of occurring. The thresholds for each subject was found to be 34.43 msec. (S_1), and 35.16 msec. (S_2). The mean of these two values, 34.79 msec., was considered to be the overall threshold of perceived simultaneity in this study. Thus, of the three T_1-T_2 intervals used in this experiment, only one of them (i.e., 40 msec.) was above this threshold value. The frequency of velocity discriminations (below) were then computed to see if this threshold influenced velocity judgements in any discernible way.

Velocity Discriminations

In the present study, a velocity discrimination was made if an observer reported that one direction of motion appeared discernibly slower than the other one. Thus, if an observer felt that Left-Right movement appeared slower than Up-Down motion, he/she would report "Left-Right". If they could not make a velocity discrimination, "Both" directions of motion were reported. Table 4 lists the frequency with which each of the possible responses were emitted. It should be noted that these data represent corrected percentages, derived according to the formula described in Experiment I. However, reports of motion in the control condition were very infrequent, happening on less than 7% of the trials there. Thus, the corrected percentages shown in Table 4 were practically identical to the raw percentages recorded for each condition.

The data in Table 4 indicate that, when velocity discriminations were made, the slower appearing direction of movement almost always corresponded to the motion induced by the first test signal. That is, "Left-Right" motion was usually reported as the slower appearing one when T_1 was the vertical vector; and, "Up-Down" motion was almost always reported when the horizontal array was T_1. Because the objective velocity of T_1 was always slower than that of T_2, this particular finding was expected. However, on some occasions, observers reported the motion induced by

Table 4

Velocity Discriminations In Experiment II

T_2 ISI	20			50		
T_1-T_2	20	30	40	20	30	40
T_1 ISI	40	50	60	70	80	90
T_1=Vertical						
Left-Right	.71*	.92	.96	.56	.58	.71
Up-Down	.10	.02	.01	.17	.12	.11
Both	.02	.05	.02	.24	.24	.10
T_1=Horizontal						
Left-Right	.06	.04	.01	.19	.20	.18
Up-Down	.74	.85	.96	.40	.45	.56
Both	.02	.01	.03	.33	.28	.19
Mean						
T_1-Motion	.73	.88	.96	.48	.51	.63
T_2-Motion	.08	.03	.01	.18	.16	.14
Both	.02	.03	.02	.29	.26	.14

* = per cent number of trials in which discriminations were made.

the second test signal as the slower-appearing one. This later occurrence was rather infrequent, happening on an average of 10% of the trials overall. Such reports were treated as "errors" in velocity discrimination, and were therefore not examined in any great detail.

Table 4 also shows that velocity discriminations were made on a majority of trials in most conditions. When the ISI between T_2 and the grid was 20 msec. (i.e., left half of Table 4), discriminations occurred on an average of 86% of the trials. This average dropped to 60% when the T_2 ISI was 50 msec.. It is particularly important to note that in some conditions where the T_1-T_2 intervals were below the threshold of perceived simultaneity, velocity discriminations still occurred on a clear majority of the trials. For example, when the T_2 ISI was 20 msec., there were discriminations on 73% of the trials with a T_1-T_2 interval of 20 msec.; and, on 88% of the trials when T_1-T_2 was 30 msec.. These results fail to support the previously-explained contention of "temporal integration" of T_1 and T_2 at those brief intervals. The concept of temporal integration, it should be recalled, implied that the two test signals would be combined in time within intervals shorter than the threshold of perceived simultaneity. If this had, in fact occurred in the present experiment, velocity discriminations would have probably occurred with a much lower frequency, if at all.

Overall, the data in Table 4 indicate that the threshold of perceived simultaneity was unrelated to the frequency with which discriminations were made. In fact, on the basis of the above data, it is also fair to say that the T_1-T_2 interval *per se* had no consistent influence upon the discriminability of movements investigated here. Notice in Table 4, that when conditions with identical T_1-T_2 intervals are compared, velocity discriminations are found to vary considerably. For example, when the T_1-T_2 interval was 20 msec., discriminations varied from 48% (when the T_2 ISI was 50 msec.) to 73% (when the T_2 ISI was 20 msec.). Thus, it seems that some other factor or factors, other than the T_1-T_2 interval, governed the frequency with which movements were discriminated.

Some further analyses substantiated the above idea. The percent number of velocity discriminations (in each condition) were analyzed with respect to the *proportional difference* between the objective velocities of movement induced by each test signal. This difference was computed by: (a) subtracting the objective velocity of T_1 movement from that of T_2; and, (b) dividing this differency by the T_1 velocity. Notice that in the calculation of this measure, the T_1-T_2 interval *per se* is of little consequence. Instead, it is the objective velocities of T_1 and T_2, determined by their respective ISIs, that are the salient components. Graham (1965) refers to this measure as the _velocity_ _differential_, or, v/v. Relatively large values of this differential indicate a fairly large difference between the velocities (objective) of the two test signals. Likewise, relatively small values indicate a small difference between the objective velocities of the movements.

Table 5 lists the percent number of velocity discriminations, and the v/v value in each experimental condition. This table clearly indicates that velocity discriminations were directly related to the differential in each condition. As the differential increased in value, discriminations became more and more frequent. To better assess the consistency with which those two measures were related, velocity discriminations were plotted against values of the differential. The resulting function, which can be found in Figure 5, closely resemble a linear one. This means that the percent number of velocity discriminations increased at a fairly constant rate, as the velocity differential became larger. Thus, velocity discriminations were _consistently_ related to the velocity differential among the various conditions of this study.

To summarize thus far, the threshold of perceived simultaneity was unrelated to the frequency with which velocity discriminations were made in this experiment. Instead, the velocity differential was found to be the primary determinant of velocity discriminations here. In this respect, the present findings are in basic agreement with

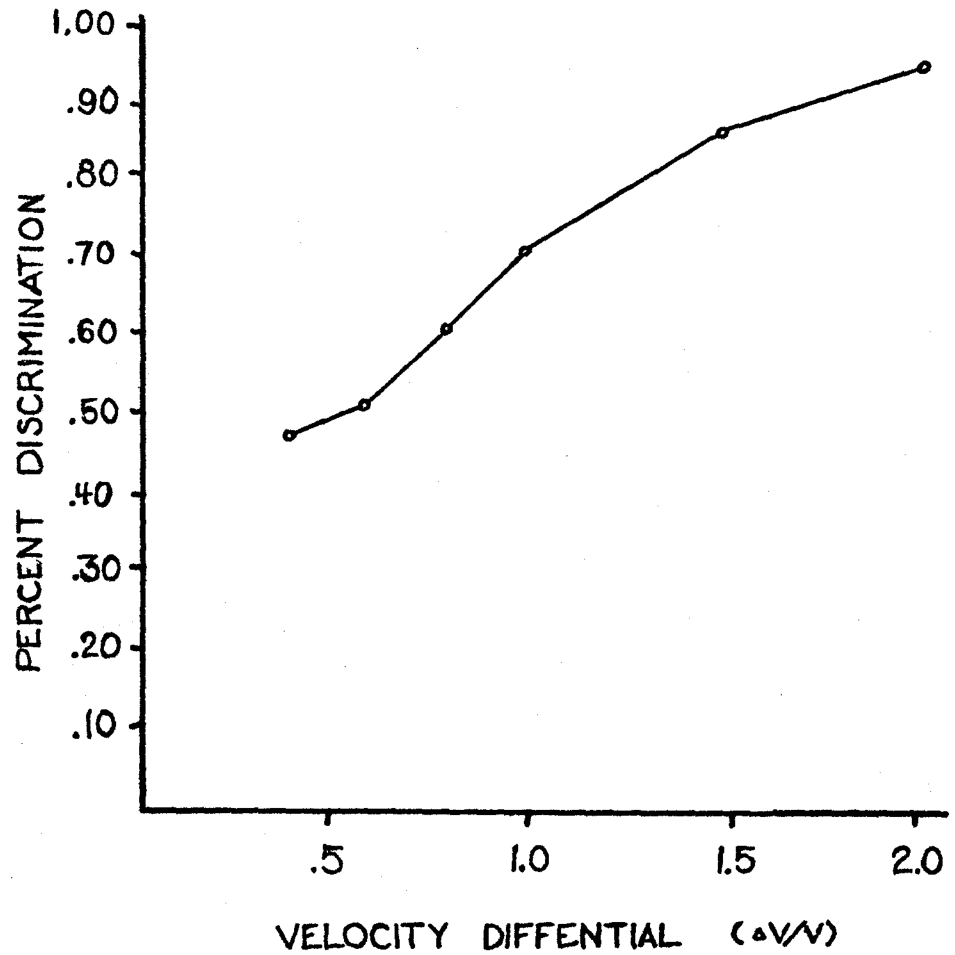
Table 5

Velocity Differentials and Discriminations

In Experiment II

T_1 ISI	T_2 ISI	Velocity Differential	Percent Discrimination
40	20	1.00	.73
50	20	1.50	.88
60	20	2.00	.96
70	50	.40	.48
80	50	.60	.51
90	50	.80	.63

FIGURE 5



1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
PERCENT DISCRIMINATION
.5
1.0
1.5
2.0
VELOCITY DIFFENTIAL (ΔV/V)

previous studies of velocity discrimination in real movement situations. Graham (1965) noted that in investigations of real motion, the velocity differential, as it was calculated here, has usually been found to be consistently related to the discriminability of two velocities. The present findings therefore imply that the same might be true under conditions of apparent motion.

Perceived Velocity

The mean velocity ratings for movement induced by the first test signal were computed. It should be reiterated that "T_1 movement" refers to situations in which "Left-Right" motion appeared discernibly slower when T_1 was the vertical vector; and, when "Up-Down" motion appeared discernibly slower when the horizontal array was the first test signal. Thus, the velocity judgements represent ratings for the slower-appearing movements only. Overall, there were no differences in ratings for "Left-Right" and "Up-Down" motion. Therefore, only the combined ratings among the four observers will be presented.

The velocity data, which can be found in Table 6, are quite similar to the trends described in the first experiment. As the ISI between T_1 and the grid increased, the velocity of motion appeared to become slower. This trend was clearly evident among all four observers when the ISIs were between 40 and 60 msec.. However, between 70 and 90 msec., there was some divergence among the participants in

Table 6

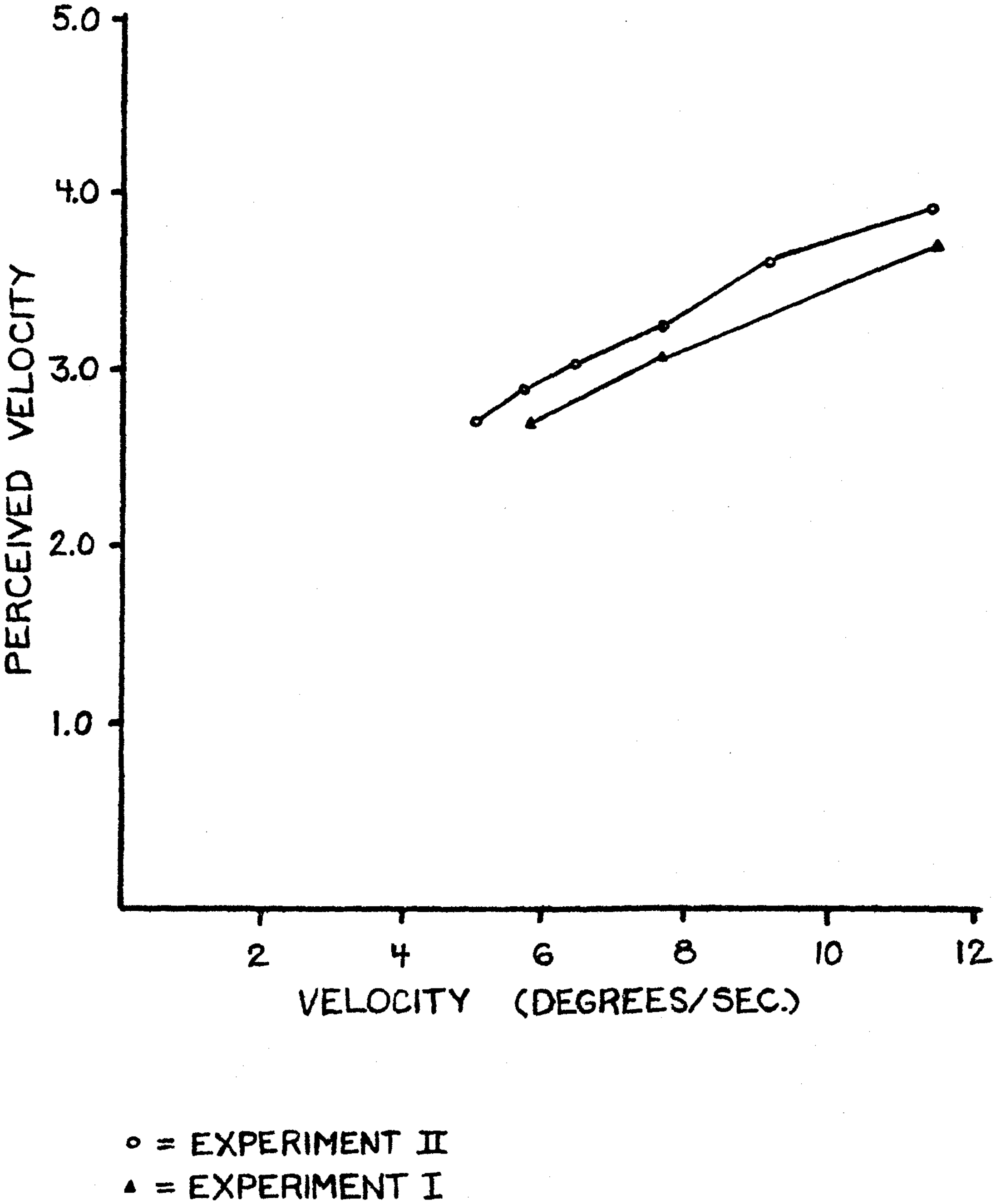
Perceived Velocity of T_1 Movement In Experiment II

T_2 ISI	20			50		
T_1 ISI	40	50	60	70	80	90
OBSERVER 1	4.49	4.02	3.41	2.96	2.83	2.15
OBSERVER 2	3.77	3.43	3.07	3.03	2.90	2.68
OBSERVER 3	3.79	3.72	3.57	3.84	3.48	3.58
OBSERVER 4	3.38	3.22	2.83	2.23	2.31	2.46
MEAN = II	3.86	3.60	3.22	3.01	2.88	2.72
MEAN = I	3.68		3.18		2.70	

this study. Observers 1 and 2 continued to show the trend described above at those larger ISIs (i.e., ratings continued to decline). The judgements of observers 3 and 4, however, began to increase somewhat at those larger values. It should be emphasized that those increases at the larger ISIs were not large enough to offset the overall trend of a decline in perceived velocity with ISIs.

The mean velocity ratings given in Table 6 were plotted against the objective values of velocity prevailing in each condition. This function is depicted in Figure 6. At this point, it should be recalled that by examining this particular function, one can assess the degree to which perceived velocity conformed to an objective, distance/time rule. Figure 6 indicates that a linear function would fit the present data extremely well. Further, this figure also displays the function for perceived velocities recorded at equivalent objective velocities in Experiment I. Notice that the two functions are very similar to one another. However, the ratings from Experiment II tended to be slightly higher than those from the first experiment. This might stem from the fact that in Experiment II, T_1 movement was frequently observed in the presence of a faster-appearing motion induced by the second test signal. Quite possibly, the observers incorporated the faster-appearing motion into their overall rating of T_1 movement, thereby inflating the perceived velocity measures from what they would have been if T_1 motion was observed alone (i.e., as in Experiment I).

FIGURE 6


5.0
4.0
3.0
2.0
1.0
PERCEIVED VELOCITY
2
4
6
8
10
12
VELOCITY (DEGREES/SEC.)
○ = EXPERIMENT II
▲ = EXPERIMENT I

Further research will be needed to further substantiate that explanation.

Summary and Additional Comments

This experiment was conducted to see if the velocity of apparent motion would conform to a distance/time rule under conditions of intermittent stimulation. The results of this study indicate that this is, in fact, the case. The perceived velocity of motion induced by one test signal (i.e., T_1) obeyed a distance/time rule, even when it was followed by a second test signal presented shortly after it. This was true, irrespective of the temporal interval between the two signals. In otherwords, the velocity of motion (of T_1) was found to be a very stable and predictable percept, even in the midst of movements induced by another stimulus. Thus, in the present study, apparent motion was again objectively equivalent to real motion because it conformed to a basic, distance/time rule.

In order to make a velocity rating for T_1 motion in this experiment, an observer had to first discriminate whether one of the movements appeared discernibly slower than the other. In this experiment, such discriminations occurred on a majority of trials in most conditions. The T_1-T_2 interval appeared to have no influence upon this latter measure. Instead, the velocity differential, which is a measure of the proportional difference between objective velocities, was found to be the primary determinant of the frequency with which discriminations were made here. This latter finding is a particularly interesting one, for it implies yet another type of equivalence between real motion and apparent motion phenomena. Namely, in studies of real movement velocity discrimination, the velocity differential has also been found to correlate consistently with velocity discriminations. However, more research will have to be done to further substantiate the idea that the velocity differential in apparent movement situations operates as it does in conditions of real motion.

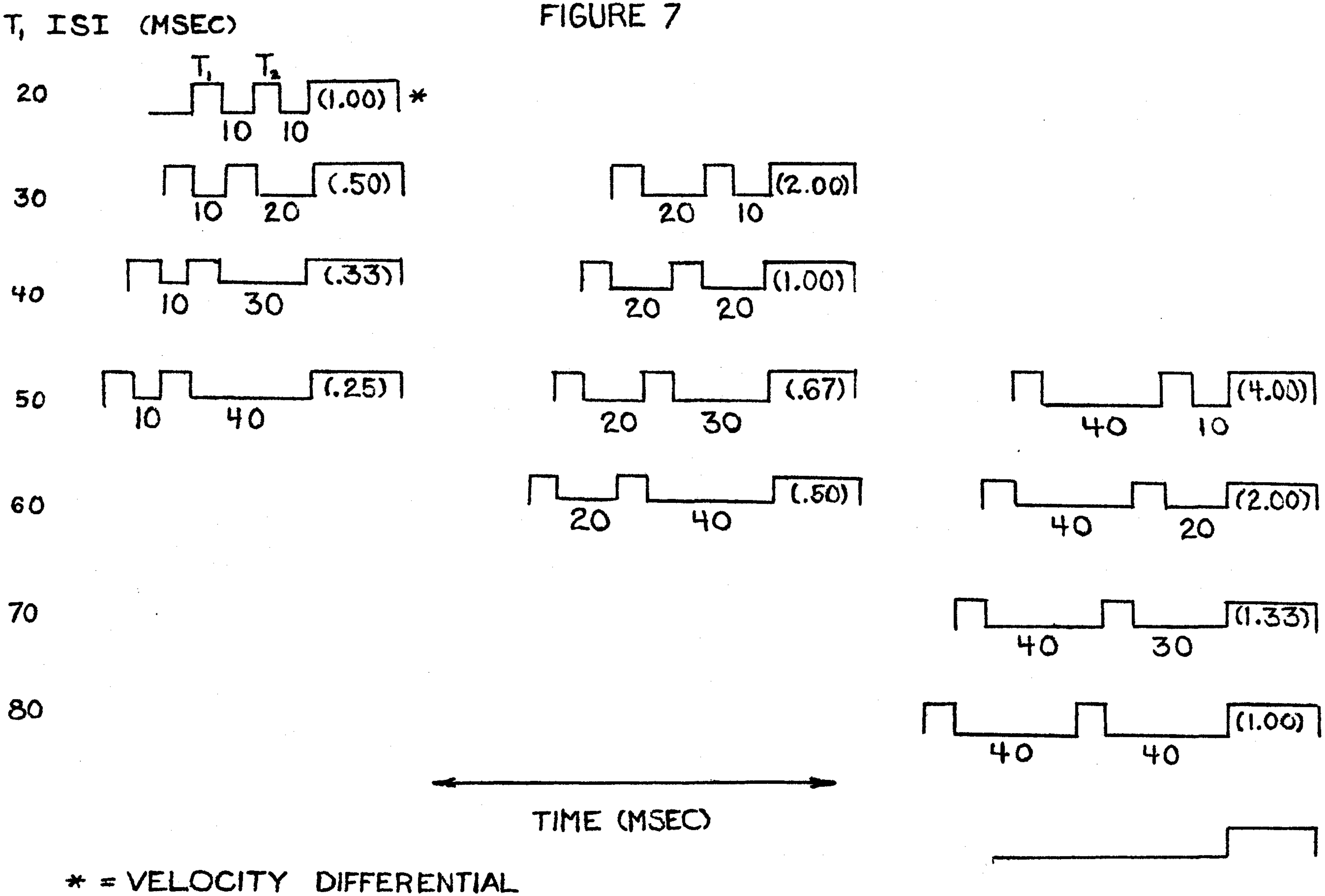
The following experiment was conducted with the above idea in mind. It was identical to the present experiment, except for the fact that a much larger sample of values for the velocity differential (in experimental conditions) was manipulated. The primary focus of this next experiment was to see how well the velocity differential would predict the discriminability of two "apparent" movements. Moreover, measures of perceived velocity (of T_1 motion) were also taken to see if the results of Experiment II would replicate there.

EXPERIMENT III

Figure 7 depicts all of the experimental conditions manipulated in this study. As was the case in Experiment II, T_1 was either a vertical vector followed by a horizontal one; or, vice-vera. Three different values of the T_1-T_2 interval were varied (i.e., 10, 20, 0r 40 msec.); and, the major columns in Figure 7 represent the various conditions in which the respective T_1-T_2 intervals were observed. The three T_1-T_2 intervals were factorially combined with 4 different ISIs between T_2 and the grid (i.e., 4 different T_2 ISIs). This factorial combination produced a fairly wide range of values for the velocity differential among the various experimental conditions. In this study, the differential ranged from .25 to 4.00, indicating that in some conditions, the objective velocities of T_1 and T_2 were only slightly different from one another. Whereas, in other conditions, the objective velocity of the first test signal was considerably larger than that of the second.

As mentioned previously, a primary focus of this experiment was to see if the frequency of velocity discriminations would be consistently related to the velocity differential. Notice that the differential within each column of conditions in Figure 7 decreases in value, as one moves from the top to the bottom in each one. On the

FIGURE 7



T_1 ISI (MSEC)
20
T_1 T_2
10 10
(1.00) *
30
10 20
(.50)
20 10
(2.00)
40
10 30
(.33)
20 20
(1.00)
50
10 40
(.25)
20 30
(.67)
40 10
(4.00)
60
20 40
(.50)
40 20
(2.00)
70
40 30
(1.33)
80
40 40
(1.00)
TIME (MSEC)
* = VELOCITY DIFFERENTIAL

basis of the previous experimental findings, we can expect velocity discriminations to become less frequent among those latter conditions within each column in Figure 7.

It should also be noted that some values of the differential were replicated in several conditions. Namely, differentials of .50, 1.00, and 2.00 were repeated among the various columns in Figure 7. The columns depicted their differ from one another chiefly with respect to the objective velocities (of T_1) inherent in each one. In the left-most column, objective velocities are relatively high, ranging from 9 degrees/sec. to 22 degrees/sec.. In the middle column, the range is between 7.5 degrees/sec. to 15 degrees/sec., indicating a somewhat lower range of values. The right-most column has the slowest velocities of motion, from 5 degrees/sec. to 9 degrees/sec.. Notice that with each replicated value of the differential, the objective valocity of T_1 motion varies from relatively high to relatively low basic rates of movement.

With this particular arrangement, the present experiment was able to ascertain the similarity between real motion and apparent motion discriminations of velocity. In studies of real motion, the discriminability of two movements having a fixed proportional difference (i.e., fixed velocity differential) has been found to vary, depending upon the objective velocities of movements being discriminated (Graham, 1965; p. 577). Generally speaking, when the objective velocities are rather high, a given v/v will result in _fewer_ discriminations than when the velocities are slower. In the present study, comparisons among repeated values of a differential were made to see if the same would be true here.

Besides looking at velocity discriminations, this experiment also took measures of the perceived velocity of T_1 movement. The data from the previous study suggested that the velocity of T_1 movement remains quite stable, irrespective of the amount of time between it and the second signal. In the present experiment, a more rigorous test of that idea was possible. Notice, from Figure 7, that several values of the T_1 ISI were also replicated among several columns of conditions. On the basis of the previous data, we can expect the perceived velocities to be equivalent among the replicated T_1 ISI conditions. This is because the objective velocity of T_1 movement is identical in each of those repeated conditions. If the present experiment should find an equivalency among the repeated ISI conditions, it could be viewed as even further evidence that T_1 motion conforms to a distance/time rule under the present circumstances.

Method

Subjects

The same four observers from the previous two experiments participated in the present study.

Procedure

The stimuli and procedures were identical to those described in the preceding experiment. Each observer was given 80 trials in each of the 12 conditions depicted in Figure 7. Sixty catch trials, in which the grid was presented without the test signals, were also included. Each observer was tested in a single session lasting approximately 2 hours, including a 15 minute rest period.

Results and Discussion

Velocity Discriminations

The percent number of trials in which T_1 movement appeared discernibly slower than T_2 motion was found for eac observer. These data were corrected in the manner described in the previous experiment. Overall, there were no discernible differences among the four observers, or between conditions in which T_1 was the vertical array, and when it was the horizontal array. Hence, only the average number of discriminations (in each condition) will be discussed. These data can be found in Table 7. It should be explained that each consecutive group of 4 rows in that table represents a column of conditions depicted in Figure 7. The first group refers to the left-most column, the next one the middle column, etc..

Two major points can be drawn from the data in Table 7. First, from the last column of data shown there, it is

Table 7

Velocity Discriminations In Experiment III

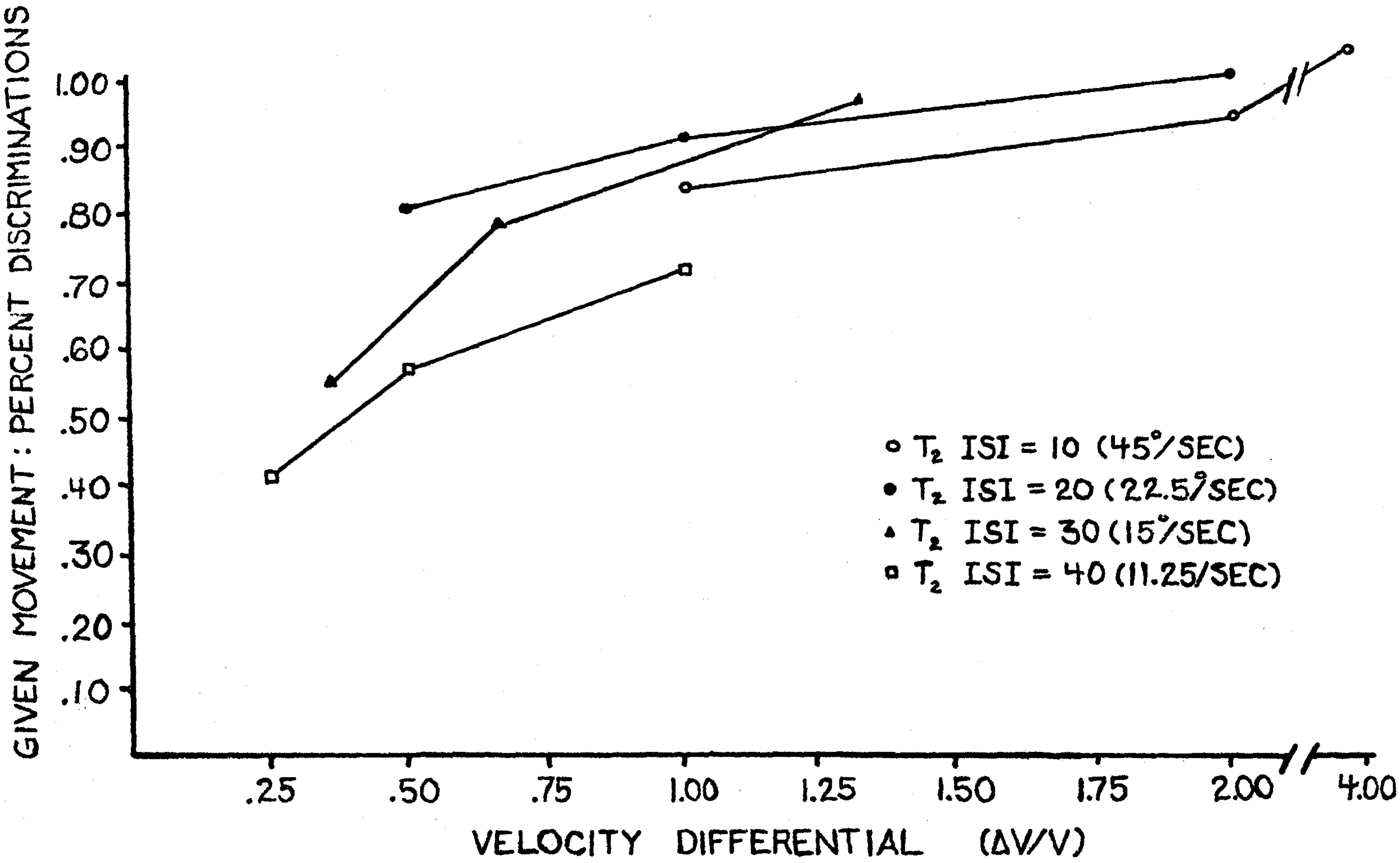
T_1 ISI	T_1-T_2	T_2 ISI	v/v	Total o/o Motion Detections	o/o T. Discrimination	Given Movement: Discrimination
*20	10	10	1.00	.32	.26	.81
30	10	20	.50	.67	.54	.80
40	10	30	.33	.83	.45	.54
50	10	40	.25	.89	.36	.40
30	20	10	2.00	.74	.66	.89
*40	20	20	1.00	.88	.78	.88
50	20	30	.67	.94	.73	.78
60	20	40	.50	.97	.55	.57
50	40	10	4.00	.95	.93	.98
60	40	20	2.00	.97	.94	.96
70	40	30	1.33	.96	.87	.91
*80	40	40	1.00	.96	.68	.71

clear that velocity discriminations were made on a majority of trials in which motion was actually detected. In this study, observers had the option of reporting whether or not they actually detected motion among the grid points. There were some extreme differences among the experimental conditions with respect to the total number of movement responses (column 5 in Table 7). For example, when the T_1 ISI was 20 msec. (first row of the table), motion was reported on only 32% of the trials. (Recall from Experiment I, that a 20 msec. ISI was slightly below the threshold of motion detection in this paradigm). At a T_1 ISI of 50 msec., however, movement was detected on approximately 90% of the trials. Because of this disparity, velocity discriminations were measured in terms of the percent number of movement responses in which one movement was reported to be slower. Table 7 shows that such discriminations occurred on a majority of those trials, even when the T_1-T_2 interval was as low as 10 msec..

A second point to be drawn from Table 7 is that within each group of 4 conditions (i.e., rows) depicted there, velocity discriminations increased as the differential became larger. As explained previously, this was what was expected to occur. However, the frequency of velocity discriminations also varied among conditions with identical velocity differentials. For example, the differential value of 1.00 produced discriminations ranging from 71% to 88% of the movement trials. (Those conditions are marked with an asterisk in Table 7). Similar variations can be observed for the other replicated differentials. Thus, in the present study, the velocity differential did not operate as a constant with respect to the discriminability of movements. In this respect, these findings are congruent with the research for real motion discrimination (cf. Graham, 1965). However, the manner in which the discriminations varied in this experiment did not correspond with the previously cited research. Table 7 suggests that discriminations were more frequent among conditions with higher objective velocities. In studies of real motion, the converse has usually been the case.

Figure 8 demonstrates the above idea much more clearly. In this figure, velocity discriminations were plotted against the differentials inherent in each condition, and a separate function is shown for each of the four T_2 ISI conditions. This was done because the T_2 ISI in each condition represents the fastest objective velocity prevailing in each one (the T_1 ISI was always larger, hence, its objective velocity was always slower than that of T_2 movement). T_2 ISIs of 10, 20, 30, and 40 msec. represent velocities of 45 deagrees/sec., 22.5 degrees, 15 degrees, and 11.25 degrees/sec. respectively. By making comparisons among those conditions, one can get some ideas as to how discriminations varied among conditions having fixed differentials, but differing with respect to basic levels of

FIGURE 8


GIVEN MOVEMENT: PERCENT DISCRIMINATIONS
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
.25
.50
.75
1.00
1.25
1.50
1.75
2.00
4.00
VELOCITY DIFFERENTIAL (ΔV/V)
○ T_2 ISI = 10 (45°/SEC)
● T_2 ISI = 20 (22.5°/SEC)
▲ T_2 ISI = 30 (15°/SEC)
□ T_2 ISI = 40 (11.25/SEC)

objective velocity.

The data depicted in Figure 8 indicate that velocity discriminations were most prevalent among conditions having T_2 ISIs of 20 msec. (conditions with the fastest objective velocities in this study). This might be due to the fact that T_2 ISIs of 20 msec. or less are below the threshold of motion detection. It is, therefore, highly unlikely that T_2 motion was seen, along with T_1 motion, on a majority of trials there. Hence, it is highly unlikely that observers were actually making discriminations between velocities in those conditions. Instead, they might have been merely responding to a single motion, induced by T_1, in the aforementioned conditions. This poses a considerable problem in the interpretation of the "discrimination" data. Comparisons among the various differentials cannot be made validly unless it is known that both T_1 and T_2 movements were detected on a majority of trials in the conditions to be compared (i.e., that true discriminations were being made in the conditions to a comparable degree).

For all of the above reasons, further analyses were restricted to conditions in which it could be assumed that both movements were being detected on a majority of trials. In effect, this restricted the analyses to only two functions in Figure 8 (i.e., the one for T_2 ISI of 30 msec., and the one for 40 msec.). When one compares those two functions, it is still clear that discriminations were more prevalent for the faster-objective velocities in the 30 msec. function. Again, this particular finding is exactly contrary to the findings for real motion discrimination. However, it must be stressed that although it is reasonable to assume that both movements were detected on a majority of trials in those functions, it is still possible that T_2 motion detection was somewhat lower in the 30 msec. function. In which case, the discriminations listed for those conditions would still not be comparable. Clearly, further research is needed to see how T_2 motion detection varies among the conditions listed in Figure 8. Only then, will we be able to clearly evaluate the findings of the present study.

Perceived Velocity

The mean ratings in each of the experimental conditions are shown in Table 8. It should be mentioned that judgements of T_1 motion were equivalent for Left-Right and Up-Down movements. Hence, only the average ratings for these movements are shown for each T_1 ISI condition. Of particular importance, notice that the mean ratings among replications of T_1 ISIs were quite similar to one another. These ratings never varied by more than .20 points among identical T_1 ISIs. This suggests that for any given T_1 ISI, the perceived velocity of T_1 motion remained fairly stable, irrespective of when another test signal was introduced after it.

As was done in the previous two experiments, perceived

Table 8

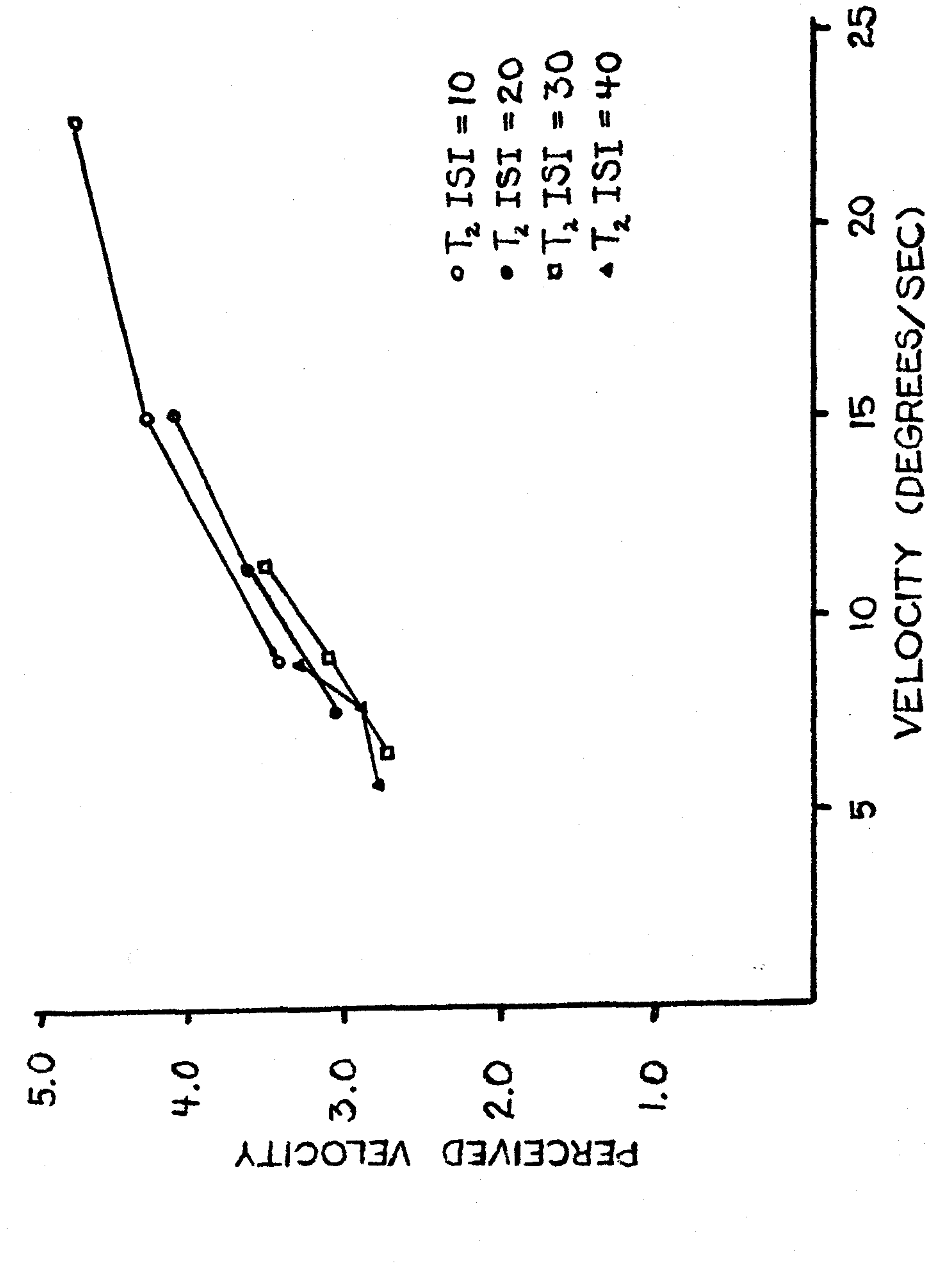
Perceived Velocity in Experiment III

T_1 ISI	T_1-T_2	T_2 ISI	$\overline{X}$ Velocity
20	10	10	4.77
30	10	20	4.15
30	20	10	4.34
40	10	30	3.60
40	20	20	3.73
50	10	40	3.43
50	20	30	3.19
50	40	10	3.45
60	20	40	2.92
60	40	20	3.07
70	40	30	2.75
80	40	40	2.80

velocities were plotted against objective velocities in each condition. A separate function was drawn for each of the T_2 ISI conditions in this study. Figure 9, which shows these functions, clearly indicates that all but one of them was linear. The single exception was when the T_2 ISI was 40 msec.. Notice that the right-most point of this function offset the linearity. That particular condition was the one with the smallest number of velocity discriminations in the entire experiment (see Table 8, row 4).

Figure 9 also shows that velocity ratings varied slightly among the four T_2 ISI conditions. Specifically, ratings were somewhat lower (i.e., T_1 movement was rated as somewhat slower) among the larger T_2 ISIs. At this point, it should be recalled that larger T_2 ISIs correspond with a slower objective velocity for T_2 motion. Moreover, at slower objective velocities of T_2 movement, there is a greater likelihood that T_2 motion would be detected on most trials. Quite possibly, the trend for lower ratings at slower T_2 velocities is due to an incorporation of T_2 velocity into the T_1 movement rating. That is, perhaps the observers' rating for T_1 motion was influenced by their perception of the velocity of T_2 movement. However, given the very slight differences in overall ratings, it can be inferred that any effect of T_2 motion velocity upon T_1 ratings is rather minimal.

FIGURE 9



$\circ\ T_2$ ISI = 10
$\bullet\ T_2$ ISI = 20
$\square\ T_2$ ISI = 30
$\blacktriangle\ T_2$ ISI = 40
PERCEIVED VELOCITY
5.0
4.0
3.0
2.0
1.0
5
10
15
20
25
VELOCITY (DEGREES/SEC)

Summary And Additional Comments

In this experiment, the perceived velocity of T_1 motion was agin observed to conform to a distance/time rule. Of particular importance, perceived velocity remained quite stable among repeated values of objective velocity for T_1 motion. That is, as long as the objective velocity of T_1 movement was maintained at a constant value, perceived velocity was also found to remain stable, irrespective of when the second test signal was presented. These findings can be viewed as even further evidence that the velocity of apparent motion (induced by the first test signal) is a very orderly and predictable percept.

The primary purpose of this experiment was to assess how well the velocity differential could predict the frequency with which movement discriminations were made. As was the case in the previous experiment, the velocity differential in each condition appeared to be systematically related to velocity discriminations. On the whole, the percent number of discriminations was found to increase as the differential became larger in each condition. Furthermore, the differential did not behave in a constant manner in that there were marked differences among conditions with fixed values of the differential. In this respect, the findings of this study agreed with the research of real motion discrimination. However, in the present study, fewer discriminations were observed at the slower objective velocities; and this contradicts the research for real motion phenomena. Unfortunately, a clear interpretation of this latter finding is not yet possible because we cannot be sure that motion detection (particularly for T_2 movement) was comparable among the slower and faster objective velocities. Thus, more research is needed to clearly ascertain the levels of motion detection under conditions similar to those observed here. Only then, will we be able to assess the possible similarity or dissimilarity between apparent movement and real movement velocity discriminations.

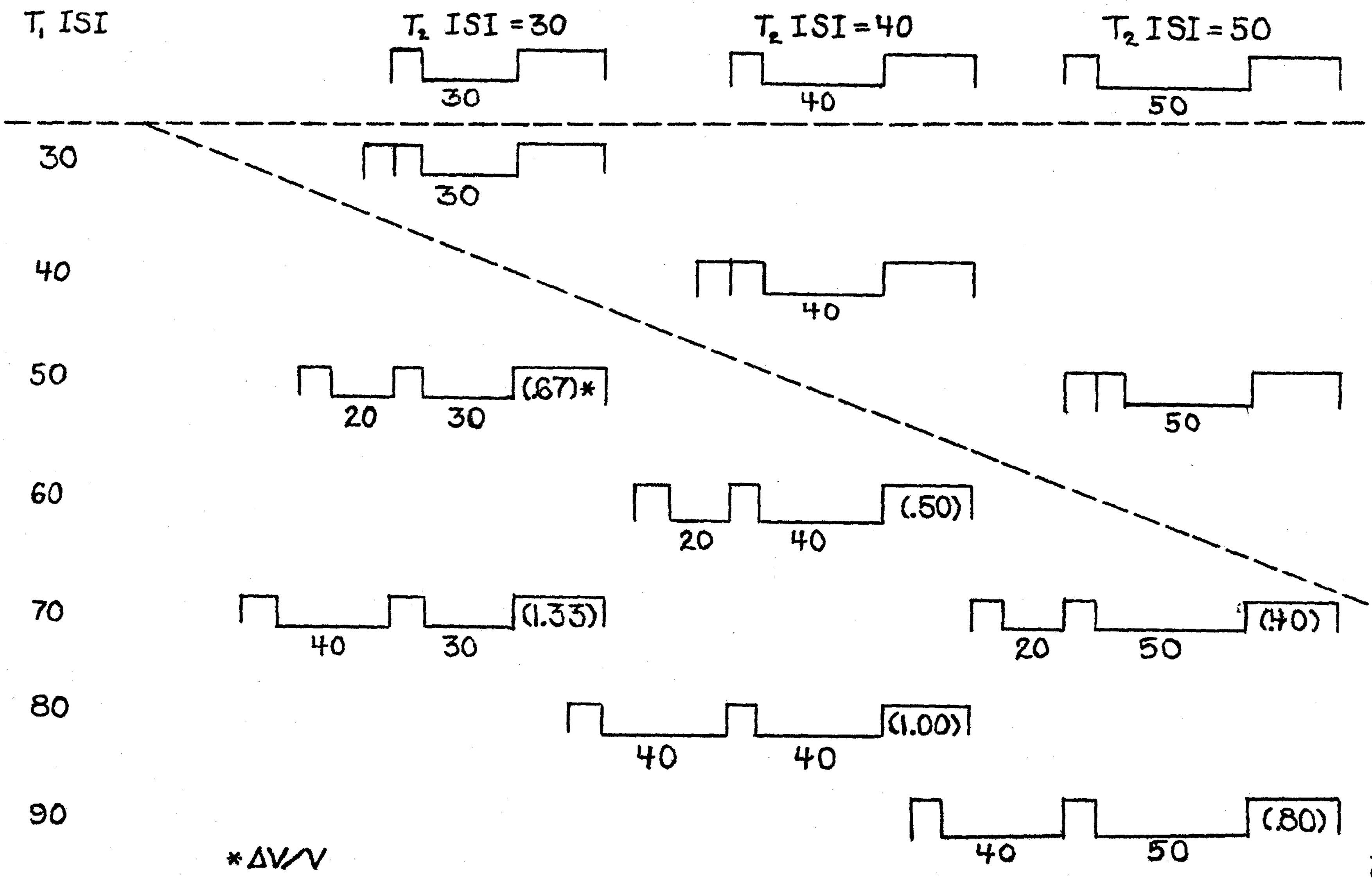
The next experiment was conducted with the above problem in mind. The laboratory arrangements were very similar to those described in Experiments II and III, but no measures of perceived velocity were taken. Instead, observers were merely asked to report the movement or movements which they detected on any given trial. Detection levels for T_1 and T_2 movements were found, and the results were used to clarify some of the findings of Experiments II and III.

EXPERIMENT IV

In this experiment, movement detection was measured under three basic modes of test signal presentation. Figure 10 graphically depicts each of these modes. The first one will be referred to as the "single mode", and it is represented by the first row of conditions in Figure 10. In this particular mode, a single test signal (either a horizontal vector or vertical vector) was flashed either 30, 40, or 50 msec. prior to the grid. (1)In the second mode, which can be found along the diagonal line in Figure 10, a horizontal and a vertical vector were presented, with zero msec. between the offset of the first one and the onset of the second one. (2)This mode was termed the "cross signal" mode, and the order in which the signals were flashed was completely counterbalanced. (3)Finally, the third mode will be referred to as "intermittent", because a brief interval of time separated the first and second test signals. This third mode is represented below the diagonal in Figure 10.

The single and cross signal modes described above are essentially identical to the arrangements previously described in Experiment I, and the intermittent mode is similar to the conditions observed in Experiments II and III. Motion detections in the intermittent mode were compared with those from the other two modes. This was done

FIGURE 10



T_1 ISI
T_2 ISI = 30
T_2 ISI = 40
T_2 ISI = 50
30
40
50
60
70
80
90
20
(.67)*
(.50)
(1.33)
(.40)
(1.00)
(.80)
*ΔV/V

because, as yet, there is no basic detection data for the intermittent mode (observers in Experiments II and III were only asked to report the "slower" motion, thereby precluding whether or not they actually observed two movements). Moreover, detection rates from the first experiment (single and simultaneous modes) have been assumed to be representative of detections in the other experiments (i.e., intermittent mode). Comparisons among the three modes were made to see if that assumption has been a valid one.

In this study, movement detections were measured separately for T_1 motion and T_2 motion. It should be recalled that "T_1" refers to the first test signal flashed before the grid, and "T_2" to the second signal (i.e., in cross signal and intermittent modes). As mentioned earlier, a primary interest in this experiment was to see how T_1 detection and T_2 detection varied with different intermittent arrangements. Namely, the level of T_2 detection was compared among the intermittent conditions with T_2 ISIs of 30, 40, and 50 msec. (i.e., the three columns in Figure 10). The first two of those are identical to some of the conditions described in the preceding experiment. In order to clarify the discrimination data from that study, it was of great interest to see if T_2 detections were equivalent among those conditions. If they are, in fact, found to be equivalent, the data from Experiment III could be viewed as evidence that velocity discriminations are quite different under conditions of real and apparent motion.

Method

Subjects

Two of the volunteers from the previous studies, plus two naive observers, participated in this experiment. The two new observers (one male, the other female) were both graduate students in psychology, and they were recruited to control for any practice effects from the previous studies. Since all of the previous studies required the observers to focus primarily upon T_1 movement, the veterans from those studies might be prone to "overlook" T_2 motion here. Comparisons between the veterans and the naive subjects were made to see if such practice effects did occur here.

Procedure

The stimuli were as described in the previous studies. Each test signal was flashed for 1 msec., and the grid for 500 msec. On each trial, observers reported if they saw "Left-Right", "Up-Down", "Both" movements, or no motion at all. In order to expedite observers verbal reports, they responded with "Vertical" for Left-Right; "Horizontal" for Up-Down. Otherwise, their verbal reports were as described above. Each observer was given 30 trials in each of the conditions depicted in Figure 10. All trials were presented in a completely randomized order, and each observer was tested in a single session lasting approximately 1 hour and 30 minutes, including a 15 minute rest session.

Results and Discussion

T_1 Detection

In this experiment, "T_1 motion" refers to Left-Right movement when T_1 was a vertical vector, and Up-Down movement when T_1 was the horizontal vector. The percent number of trials in which T_1 motion was detected was computed for each observer. There were no differences between Left-Right and Up-Down movements, or between the veteran or naive observers. Thus, only the overall averages will be discussed, and these data can be found in Table 9.

Table 9 shows that, overall, T_1 detection was fairly stable for any given ISI value between T_1 and the grid. The detection levels never varied by more than 10 percentage points within a single ISI. However, T_1 detection was usually slightly lower in the cross signal mode than in either of the other two. For example, when the T_1 ISI was 50 msec., T_1 detection in the cross signal mode was 10 percentage points lower when it was presented singly; and, about 4 percentage points lower than in the intermittent mode. This slightly lower level in the cross signal mode was also observed in Experiment I, and it reflects the fact that on some occasions, observers only reported seeing a single movement that did not correspond with the first test signal.

Table 9 also indicates that T_1 detection was slightly lower in the intermittent mode than it was in the single

Table 9

Percent T_1 Detections In Experiment IV

T_1 ISI	Single	Simultaneous	T_1-T_2=20	T_1-T_2=40
30	.68	.62		
40	.87	.81		
50	.95	.85	.89	
60			.92	
70			.90	.87
80				.88
90				.88

mode. But, the disparity between those two modes did not seem to be as great as it was with the cross signal mode. This might be due to the fact that, in the intermittent mode, T_1 always had a slower objective velocity than T_2, making it easier to perceive on a subjective level. Despite this slight disparity between the modes, however, the data do suggest that overall, there is no marked difference in T_1 detection among the three modes of presentation. Generally speaking, as long as the T_1 ISI is 40 msec. or greater, T_1 motion will be detected on at least 80% of the trials, irrespective of the mode of presentation. As will be shown below, this was not the case for T_2 motion.

$\underline{T_2}$ Detection

In this study, "T_2 motion" refers to Up-Down movement when the second signal was horizontal; and Left-Right movement when it was vertical. Overall, there were no discernible differences between the detectability of Left-Right or Up-Down motion. Hence, only the combined ratings for these motions will be discussed. However, unlike the data for T_1 detection, there were some discernible differences between the veteran and naive observers here. The averages for each group can be found in Table 10.

Table 10 clearly indicates that the average level of T_2 detection varied considerably among the three modes of presentation. Notice that the highest level of detection was in the single mode. However, when a test signal is preceded by another one in the intermittent mode (i.e., T_2),

Table 10

Percent T_2 Detections In Experiment IV

Condition	T_2 ISI = 30 Veteran	Naive	$\overline{X}$	T_2 ISI = 40 Veteran	Naive	$\overline{X}$	T_2 ISI = 50 Veteran	Naive	$\overline{X}$
Single (No T_1)	.67	.70	.685	.83	.91	.87	.93	.97	.95
Simultaneous	.71	.65	.68	.83	.75	.79	.82	.89	.86
T_1-T_2=20	.44	.62	.53	.59	.85	.72	.78	.93	.85
T_1-T_2=40	.29	.55	.42	.48	.80	.64	.56	.82	.69

detection levels dropped rather precipitiously. When the T_1-T_2 interval was 40 msec. (last row of table), detection levels were usually about 25 percentage points lower than the highest levels achieved in the single mode.

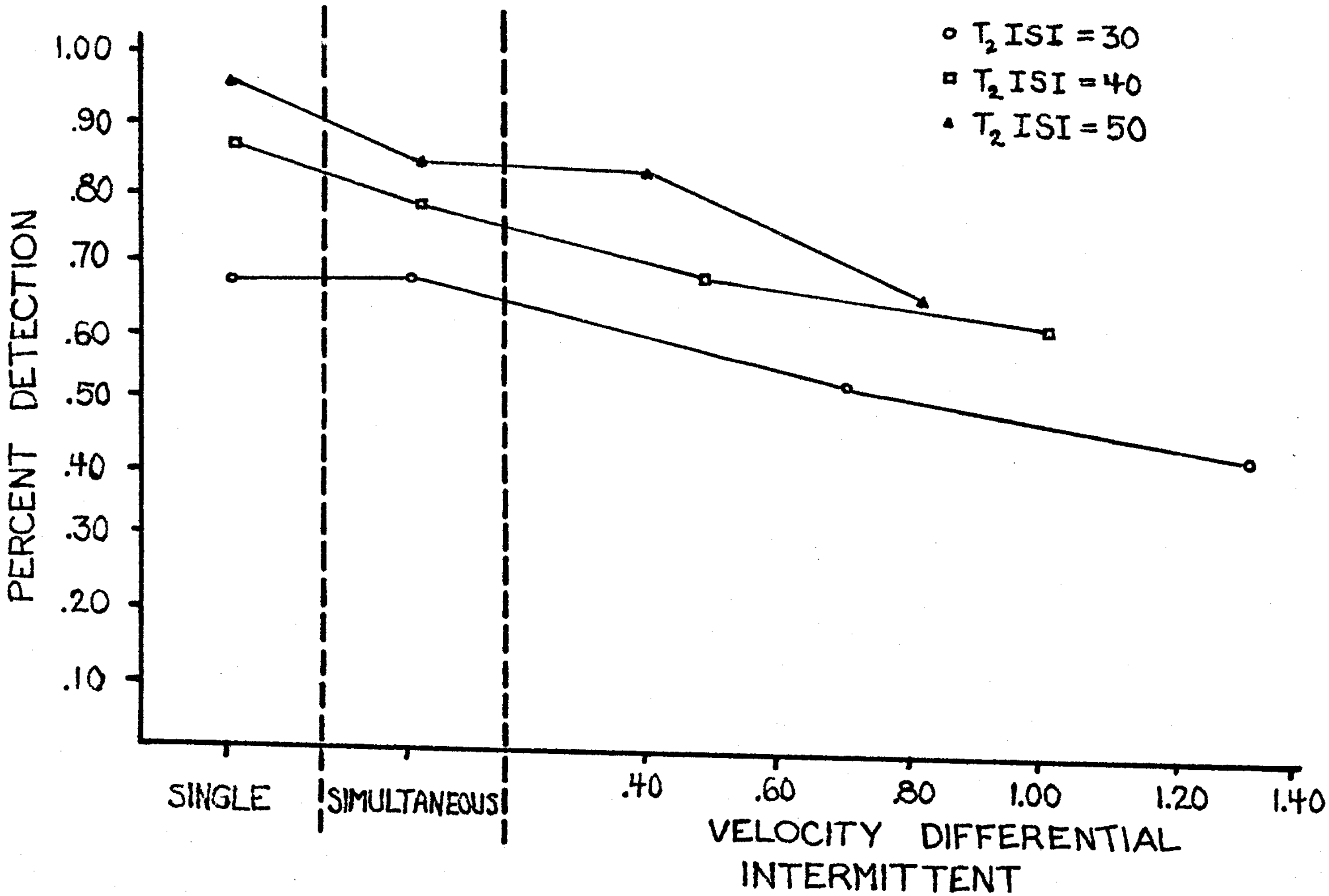
The above trend was more pronounced for the veteran observers. Their decline in detection was approximately twice that of the naive observers. Quite possibly, the marked differences between them stemmed from a "bias" for T_1 motion which they acquired in the previous two experiments. It should be recalled that in those two studies, the veterans were required to focus upon T_1 movement (i.e., the slower appearing motion). Moreover, the present experiment was conducted within 48 hours after each veteran had participated in Experiment III. Perhaps if the present study had been conducted at a much later interval of time after Experiment III, the two veterans would have approached the higher detection levels of the two naive observers. At the present time, however, it is important to stress that, although there were differences between naive and veteran observers here, both groups did show a marked decline in T_2 movement detection in the intermittent mode, particularly when the T_2 ISI was 30 msec..

The averages listed in Table 10 are graphically depicted in Figure 11. This figure imparts the previously described trends in a much clearer fashion. A separate function was drawn for each of the three T_2 ISI conditions.

The conditions within the intermittent mode are expressed in terms of their inherent velocity differential. This was done to relate the present findings to the discrimination data from the previous study (see Figure 8). It should be explained that the right-most point in each function refers to conditions in which T_1 preceded T_2 by 40 msec.. The next point (to the left) from the last one refers to conditions in which the first signal preceded the second one by 20 msec.. Because of the varying T_1 ISIs among the intermittent conditions, the velocity differentials also differed among them.

Figure 11 clearly discloses that in the intermittent mode, T_2 detection is not comparable between conditions in which the T_2 ISI is 30 msec., and when it is 40 msec.. T_2 detection was usually 20 percentage points lower in the T_2 ISI condition of 30 msec.. It should be noted that this large a difference between those two conditions was evident among both the veteran and naive observers in this study (see Table 10). On the basis of these results, it is probably safe to say that in the preceding experiment, T_2 detectability was also not comparable between those same two conditions. That is, observers in Experiment III were probably making more true discriminations between two movements at the 40 msec. ISI (for T_2). Hence, the velocity "discriminations" data from Experiment III are not really comparable pieces of information for those two conditions.

FIGURE 11



○ T_2 ISI = 30
□ T_2 ISI = 40
▲ T_2 ISI = 50
PERCENT DETECTION
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
SINGLE
SIMULTANEOUS
.40
.60
.80
1.00
1.20
1.40
VELOCITY DIFFERENTIAL
INTERMITTENT

Future research on the question of the similarity between real and apparent movement discriminations of velocity will have to find laboratory arrangements wherein there are equivalent movement detection levels. Moreover, the above question will have to remain an unanswered one until that can be done.

Probably one of the most interesting aspects of the data in Figure 11 is the fact that T_2 detection was not constant for fixed values of the T_2 ISI. Within the intermittent mode, the decline in detection became more pronounced as the velocity differential became larger. That is, as the objective velocity of T_1 became slower, relative to that of T_2, the detection of T_2 movement became more severely impaired. In other words, T_2 motion seems to have been "masked". Perhaps this masking reflects some underlying temporal interaction in the visual system. Specifically, perhaps the effective ISI between T_2 and the grid was somehow shortened, thereby minimizing the likelihood of perceiving T_2 motion. That is, under the conditions depicted in Figure 11, the temporal processing of T_2 is somehow interfered with, or retarded. This particular explanation would also help to explain the failure to observe any discernible relationship between the threshold of perceived simultaneity and movement throughout the research described in this paper. This threshold, it should be recalled, was determined when the test signals were presented in the absence of the grid. In the presence of the grid, however, it could be that the temporal processing of T_2 is interfered with, thereby effectively lengthening the interval of time separating T_1 and T_2, above that of the threshold.

The above explanation, although a feasible one, is still highly speculative, and further research, specifically addressed to that issue, will have to be done. However, no matter what the underlying reason for the observed masking of T_2 movement, it is still clear that it would not be fair to say that T_2 movement conforms to a distance/time rule, as has been the case for T_1 movement under these same circumstances. Theoretically, the objectively defined velocity of T_2 was constant among each of the three T_2 ISI conditions investigated here. If T_2 movement conformed to a distance/time rule, its motion detection would have also remained constant in those same conditions. Thus, under conditions of intermittent stimulation, a distance/time rule does not characterize T_2 movement.

Summary and Additional Comments

In this experiment, the detectability of T_1 movement and T_2 movement were observed under three different modes of presentation. The detectability of T_1 movement was found to be rather stable at a fixed ISI, no matter the particular mode of presentation. The detectability of movement induced by the second test signal, on the other hand, was impaired in the intermittent mode. This impairment became more pronounced as the objective velocity of T_1 movement became slower. This masking of T_2 motion might reflect an underlying temporal interaction in the visual system, but further research must be done to clarify that point. Whatever the underlying cause of the masking, it can be concluded that T_2 motion, unlike T_1 motion, does not conform to a distance/time rule under the intermittent mode of presentation.

The data from this experiment were also pertinent to the question of velocity discriminations under conditions of apparent motion. By virtue of the fact that T_2 detection was markedly different among the T_2 ISI conditions, it is clear that other laboratory arrangements, in which T_2 detection is equivalent, will have to be found before we can ascertain how velocity discriminations vary among different objective velocities of motion. Thus, the question of how similarly the velocity differential behaves under conditions of real and apparent motion still remains an unanswered question.

General Discussion

The research reported in this paper was conducted in an attempt to evaluate some early speculations regarding the perceived velocity of apparent movement. In 1928, DeSilva hypothesized that the velocity of this phenomenon would obey a simple distance/time rule. The present research supports his original assertions. The perceived velocity of movement investigated here bore a very predictable and consistent relationship with objective values of velocity. This was found to be true within several different modes of presentation (i.e., single, simultaneous, and intermittent). Moreover, it was also found that, as long as the objective velocity was between approximately 3 degrees/sec. and 11 degrees/sec., motion was detected on a majority (i.e., more than 80%) of the trials. This latter finding, it should be noted, agrees with DeSilva's original assertion that there is an optimum range of velocities within which apparent movement can be perceived. Although DeSilva did not specify what the range would be, he was correct in his basic proposition.

Of particular interest, the present findings closely resemble those from similar investigations of real motion velocities. It should be recalled that "real" movement differs from "apparent" movement in that, with the former, a stimulus is objectively made to traverse the distance between two spatial locations. In a rather extensive investigation of movement produced in this fashion, Masshour (1964) measured the perceived velocity by means of a "free ratio" estimation scale. His observers were asked to rate the subjective ratio between the velocity of a standard and a comparison motion (e.g., observers reported whether one motion was twice as fast, or a third as fast as the other). With perceived velocity measured in this fashion, Masshour found that is was linearly related to objective values of velocity. This is, of course, identical to what was found in the present experiments. However, it should be noted that in Masshour's research, the variables of distance, as well as time, were varied independently to produce various values of objective velocity. In the experiments reported here, only the variable of time was varied. Hence, future research is being planned wherein perceived velocities can be compared with manipulations of both of those factors. On the basis of the present research, a distance/time rule for apparent movement is still expected to occur.

Given the similarity between real and apparent movement, I would like to propose that these two phenomena are "equivalent" with respect to their velocities. However, the type of equivalency argued for here must be understood as a purely <u>objective</u> one. In the present paper, no attempts were made to equate real and apparent movement on a perceptual level. As mentioned earlier, past research has already demonstrated that, in many situations, the two phenomena are perceptually quite dissimilar (cf. Kolers, 1972). Indeed, the type of motion described in this paper seems to be quite alien from most of our natural experiences with real motion. Yet, despite this remoteness from real motion, the apparent movement described in this paper obeyed the same distance/time rule known to characterize real motion. n the present author's view, the conformity of both phenomena to the same rule represents an objective equivalency between them.

The above idea is an interesting one, for it could be extended to mean that real motion and apparent motion are also mediated by common neurological mechanisms. This particular assertion was first proposed by Wertheimer in 1912, who attempted to explain apparent movement in terms of a cortical "short-circuit" theory of perception. According to Wertheimer, the neurological mechanisms mediating real movement are identical to those for apparent movement. In retrospect, his particular theory was highly speculative, and several of its predictions have since been disputed empirically (e.g., Higginson, 1926). However, it should be emphasized that Wertheimer's general line of thinking was prompted, in part, by his assumption that real and apparent motion are "equivalent" phenomena.

Because Wertheimer's theory had difficulty in receiving empirical support, the general notion of equivalence also lost the interest of psychologists investigating this phenomenon (Kolers, 1972; pp. 174-177). This had been the general state of affairs until recently, when Frisby and his colleagues reintroduced this idea into their particular theory of apparent movement perception. Frisby (1971, a,b) has proposed that neural motion-detecting units, analogous to those identified in lower species, mediate both types of movement in the human visual system. In one particular experiment (Clatworthy & Frisby, 1973), observers were made to gaze, for a protracted period of time, at a stimulus in real motion, before they looked at a stimulus in apparent motion. This particular arrangement is generally referred to as an "adaptation paradign", and it is frequently used to analyze the mechanisms involved in real movement perception. Frisby reasoned that with prolonged observation of the real motion, the neural mechanisms mediating it would eventually habituate and fatigue. By assuming that the same mechanisms were also involved in apparent motion, Frisby predicted that apparent movement would "break down" under the foregoing circumstances. This was actually found to be the case. Frisby therefore concluded that real and apparent motion have common underlying neural mechanisms.

In the present author's view, the research reported in the present paper tends to support the basic idea put forth by Frisby. Because the velocity of apparent movement was found to conform to the same distance/time rule which real motion obeys, it is also reasonable to assume that both phenomena are mediated by similar types of mechanisms. Moreover, the paradigm used in the present paper could be modified to examine some of Frisby's ideas even further. A considerable body of research has already suggested that real movement perception is mediated by neural elements that are selectively sensitive to narrow ranges of objective velocity (see Sekular, 1975, for an excellent review). In order to assess the degree to which this might be true for apparent movement perception, observers could be required to gaze at a stimulus in real motion before looking at the movement induced within the grid of points. In this respect, the arrangement would be identical to the one employed by Clatworthy & Frisby (1973) above. However, in addition to this, the stimuli in real and apparent motion could be made to vary with respect to their objective velocities. With this arrangement, one can see if adaptation effects are selective with respect to velocity. Selective adaptation effects could be viewed as very firm evidence that apparent motion, like real motion, is mediated by mechanisms that are sèlectively sensitive to narrow ranges of velocity.

Besides investigating possible adaptation effects in apparent motion, it is also recommended that future research focus on the comparability of perceived velocities (of real and apparent movement). As mentioned earlier, no attempts were made to compare the two phenomena on a perceptual level in the present paper. It is quite possible that, even though the two phenomena conform to the same objective rule, their perceived velocities could still differ from one another. Thus, it would be of great interest to see how comparable perceived velocities would be at equivalent values of objective velocity. After comparing these phenomena on both the subjective and objective levels, we will be in a much better position to theorize about the manner in which these phenomena are treated within the human visual system.

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The dissertation is therefore accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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