7-1967

A Study of the Accuracy of Prediction Motion in Depth

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A STUDY OF THE ACCURACY OF PREDICTION MOTION IN DEPTH

by

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A Thesis
Submitted to the
Faculty of the School of Graduate
Studies in partial fulfillment
of the
Degree of Master of Arts

Western Michigan University
Kalamazoo, Michigan
July 1967

THE ACCURACY OF PREDICTION
MOTION IN DEPTH

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Western Michigan University, 1967

The study examined the effects of five variables: knowledge of results, distance, stimulus gradient, target speed, and temporal delay (a measure of temporal relationship between the target and standard) on the accuracy with which Ss could predict the arrival of a moving target at the position of a stationary standard.

The results of an analysis of variance on the data obtained from 52 Ss indicated that the variables of knowledge of results, distance, speed, and temporal delay had statistically significant effects; but no statistical significance was indicated for effects of the gradient variable. Three statistically significant interactions were also indicated: knowledge of results x distance, knowledge of results x speed, and knowledge of results x temporal delay.

Evidence was provided which showed that the three statistically significant interactions involving knowledge of results determined, to some extent, the nature of the significant differences between the levels within the main effects of distance, speed, and temporal delay.

ACKNOWLEDGEMENTS

The author wishes to express his sincere gratitude to Dr. John E. Nangle for his advice, guidance, assistance, and patience throughout the course of the study. Also, special thanks to Dr. Frank A. Fatzinger and Dr. Paul T. Mountjoy for their constructive criticisms. In addition, the author wishes to thank the following persons who contributed their time and efforts: Dr. E. J. Asher, who assisted in the statistical analysis; Mr. David Herman, who supervised the data processing; Mr. Daniel Gelfand, who assisted in the design of the experimental apparatus; and Miss Susan J. Murphy, who typed the final manuscript.

Neal I. Gelfand

MASTER'S THESIS M-1284

GELFAND, Neal I.
A STUDY OF THE ACCURACY OF PREDICTION
MOTION IN DEPTH.

Western Michigan University, M.A., 1967
Psychology, experimental

University Microfilms, Inc., Ann Arbor, Michigan

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INTRODUCTION

There are a vast number of activities and skills in which we could describe the estimation of velocity and the prediction of motion as being of considerable importance. The operator of an automobile is almost continually faced with the problem of estimating the velocities and distances of cars preceding his, in the rear, and in opposing lanes, if he is to successfully avoid collisions. The football quarterback must observe his receiver in motion, and then on the basis of these observed motions, predict when and where his receiver will be free. After this, the ball must still be thrown so that it will meet the receiver at the predicted open point. An examination of numerous activities demonstrates the great variance in the level of skill required and acquired by persons in estimating velocity and predicting motion. For even in the simply performed task of catching a ball, we find that most people become quite competent in dealing with the seemingly complex problem of judging the speed of the ball before it is caught.

Among the first and most comprehensive experimental studies of the perception of velocity was one performed by J. F. Brown (1931). Under varying stimulus conditions Brown required Ss to adjust two moving fields on paper belts to phenomenally identical velocities. As a measure of the affect of varying stimulus conditions upon perceived velocities, Brown used the quotient Va/Vb. This was the number of times one stimulus velocity was contained in the other for identity of the perceived velocities. Thus Va/Vb=1 indicates that stimulus and phenomenal velocities of A and B are identical; Va/Vb=4 indicates that B is phenomenally faster than A and must be made 4 times as slow in order that its velocity be phenomenally the same. Among the results reported by Brown was the affect of the surrounding field in determining perceived velocity. He reported that, if in a homogeneous surrounding field, one transposes a moving field in all its linear dimensions, one must also transpose the stimulus velocity by the same amount in order for phenomenally equal velocity to result. As the linear dimensions of the field are changed from 1 to 10, the Va/Vb quotient tends to change from 1 to 10. Brown also found that velocity is perceived to be faster in an non-homogeneous field than in a homogeneous field. Another result involved the relationship between distance from the observer and perceived velocity. When distance is varied from 1 to 20 meters, Va/Vb varies from 1 to 1.56. Other factors of the moving field such as increases in length, width, or size had the reported effect of decreasing phenomenal velocity. Objects oriented in the direction of movement are perceived as phenomenally faster, according to Brown. The direction of movement relative to the observer also was shown to affect velocity perception. Movements vertical to the observer were found to be judged as phenomenally faster than horizontal, while diagonal movements were found to fall in between horizontal and vertical. Brown reports that a decrease in illumination of the surrounding field had the effect of increasing the perceived velocity, with Va/Vb= 1.23, for considerable decreases in brightness. In summarizing his findings, Brown concluded that:

> "...velocity is perceived directly and is dynamically conditioned by the structure and general properties of the visual field in which movement occurs. The visual perception of velocity follows dynamic laws that are not immediately deducible from the velocity of the stimulus as physically defined..." (p. 232).

Mandriota, Mintz, and Notterman (1962) report a study of visual velocity discrimination which indicates that J. F. Brown (1931) may have been overly restrictive in his conclusion that velocity of moving objects is perceived directly and does not depend upon indirect judgments based on implicit cues. Their study was designed to permit the comparison of Weber ratios gathered under three conditions, differing only with respect to the spatial or temporal cues which accompanied each stimulus presentation. The standard and comparison stimuli were points of light that moved across the face of a cathode ray tube. In their "isometric" condition, the standard and comparison traversed equal distances; thus the duration of the stimulus transit varied inversely with the velocity. In their "isochronal" condition, the standard and comparison were in motion for equal durations. Thus the distance traversed varied directly with velocity.

In their "heterodimensional" condition, the stimulus moved over extents and for durations which were randomly changed from presentation to presentation. In this condition, velocity could not be inferred from either the distances or the durations of the comparison stimuli (Mandriota et al, 1962). The Weber ratio functions for the two subjects tested indicated, that for the range examined, discrimination is finest when the spatial cue is present (isochronal condition), intermediate in the presence of the temporal cue (isometric condition), and poorest when neither spatial nor temporal cue is related to the stimulus velocity (heterodimensional condition). The researchers also state that both types of cues are effective in improving velocity discrimnation. It appears reasonable that the cue which is more effective is the one that can be more easily detected. As support they offer the fact that $\Delta S/S$ has been found to be smaller than $\Delta t/t$ in previous research. Thus the results of the experiment would tend to demonstrate the over-simplicity of Brown's (1931) hypothesis in that the precision of velocity judgments was found to be at least partially dependent upon the systematic presence of either spatial or temporal cues.

The findings of Mandriota et al (1962) that a spatial cue is more effective than a temporal cue in improving velocity discrimination would seem to contradict reports of investigators who have studied tasks involving the prediction of the point location of an object extrapolated from its motion. In 1927, Dembitz conducted an extensive series of experiments on velocity judgment which utilized a prediction situation (Gerhard, 1959). His moving stimulus was a mark on a continuous belt which could be driven at a variety of constant speeds. The apparatus was concealed by a screen in which was a 90 cm. horizontal slit so arranged that the mark on the belt appeared at one end of the slit, traveled to the other, and disappeared. In the experimental situation the subject was asked to press a key when he estimated the stimulus mark had reached a stationary mark on its path 72 cm. beyond the point where its path disappeared. The experiment was performed with the stimulus mark moving at three different speeds. Dembitz's results showed that the greater the speed of the marker, the smaller the error of prediction; to put it another way, the greater the time to cover unit distance, the larger the error of estimation (Gerhard, 1959). The ratio of error of estimation to the speed remained approximately constant and conformed to the Weber-Fechner law (Gerhard, 1959). From this research Dembitz drew the following conclusion:

> "...the human mind does not follow the physical definition and dimension of the concept of velocity: it does not experience velocity as cms./sec.; but rather the reciprocal value sec./cm. is valid. Consequently the velocity of movement is not estimated according to the distance travelled in a certain unit of time; but rather in accordance with the temporal duration required to travel a distance chosen empirically as a unit. Time, duration, thus appears to be the criterion for the mind when comparing motions and their dimensions."

More recently Johansson (1950) and Gerhard (1959) have reported general agreement with Dembitz, particularly with respect to the dominance of the time factor in estimating velocity.

In his own experiments, Johansson had Ss compare velocities by the adjustment method until phenomenal equality was obtained. These experiments were concerned primarily with discovering whether the experienced velocity of the moving object was influenced by the motion of another object in the visual field. His results showed that such an influence does occur to the extent that "...two objects in motion in the same field, form, if possible, a single configuration of motion and velocity"(Johansson, 1950, p.79). However, despite the finding that many physical factors can influence the nature of the configuration, it has his demonstration of the dominance of the temporal component which is most important. This demonstration was accomplished in an experiment where Ss compensated for a 1:1.50 difference in the frequency of two oscillatory moving objects by an increase in the length of the path of motion until an apparent experience of equality of phenomenal velocity was obtained. His researches led Johansson to state that it is primarily the temporal factor in the experience of motion which is decisive in determining the velocity experienced. Johansson also indicated agreement with J. F. Brown (1931) in stating that velocity appears to be immediately perceptible, "...it is a kind of absolute intensity in the motion, and is just as immediately perceived as, for example, luminous intensity in the experience of illumination" (Johansson, 1950, p.48).

In Gerhard's experiments the Ss' task was to intercept an intermittently visible moving vertical light, whose constant speed was set by the experimenter, with a subject-controlled horizontal light. Ss were also required to estimate when the moving vertical light would reach a given point. Gerhard manipulated the length of time the light could not be seen and found that a systematic relationship existed between the variability of the Ss' performance and the length of time the light could not be seen (Gerhard, 1959). The experimental condition where the stimulus light was visible for approximately the same time the light was obscured resulted in superior performance by the Ss. Gerhard's explanation for this was that in this condition all the Ss had to do in order to judge when the vertical light would reach the point of interception would be to estimate the time the light was visible and reproduce that time interval. Gerhard states of a majority of his subjects:

> "...they judged when it (the light) would appear rather than where it was...He is able, with the aid of a relatively well developed ability to reproduce time intervals plus the technique of estimating the time the object will be invisible, to cope without tracking the object with his eyes, integrating the data and making a prediction in a like manner to a radar set, using comparisons of velocity" (p. 303).

Gerhard's methodology seems to have something in common with that used by Gottsdanker (1952a, 1952b, 1955) in his studies of prediction motion, in that both Es had their Ss follow the motion of an object with something more than their eyes (a controllable light in the Gerhard work, a pencil in the Gottsdanker work). In the Gottsdanker experiments, targets were provided to the Ss to track by means of an apparatus which moved sheets of paper upon which curves had been printed. These target sheets were masked except for a narrow slit, causing the appearance of a short target moving lengthwise in the slit. The S was instructed to continue tracking after the target disappeared in a manner similar to the prediction of the motion of an airplane which had flown behind a cloud. In his first study, Gottsdanker (1952a) used constant velocity and accelerating objects and found that the velocity of an object travelling at a constant rate could be accurately reproduced by the S for 6 seconds after the object had disappeared. There was also found, however, a very slight tendency for the mean continuation rate, or reproduction of the object velocity after its disappearance, to increase along each successive second of the 6 second interval. This was not the case for the accelerating object, for which the S maintained a constant velocity intermediate between the terminal velocity of the object and its average velocity while visible. It should be noted that the continuation rate rate described only the velocity and not directional component of prediction motion behavior. Gottsdanker also reports that the mean rate of continuation of a constant velocity object deviated only 1% from the required rate, with the mean error of prediction motion being 11% of the required rate. It is interesting to note that Gottsdanker reported individual differences in the measure of prediction motion to be reliable, while the reliability of continuation rate was especially high (1952a).

Gottsdanker (1952b) performed a similar study in which accuracy of prediction motion was examined with and without vision. In this case the S was instructed to again track the target after it had disappeared from view, on half of the trials with eyes open and on the other half with eyes closed during continuation. This study also used negatively accelerating motion along with the constant velocity and positively accelerating motion used in the previous study. Gottsdanker's results indicate that the eyes-closed condition had a higher continuation rate for the constant and accelerating conditions than did the eyes-open condition. The average error for eyes-opened was 14% of the required rate, while that for the eyes-closed was 20% in the constant rate condition. The rise in mean rate on each successive second of the 6 second continuation was found to be evident to a much greater extent than in the previous study, with the rate under the eyes-closed condition increasing at a faster rate than in the eyes-opened condition. Although there were significant differences in comparisons of the eyes-closed and eyes-opened conditions, Gottsdanker stated that basically the same mechanisms of prediction work in both visual and non-visual continuation motion. His proof of this rests upon the same relative rates of continuation motion under the two conditions and by high correlations between the conditions. As to the superior accuracy of the eyes-opened condition, Gottsdanker states, "Certainly prediction motion may be expected to improve as more sources of information are added concerning the motion of the target" (p. 542). The high consistency of individual differences found in the previous study was confirmed. In his 1955 study, Gottsdanker added that there was a trend, although not statistically significant, for the average error in continuation of a constant rate to decrease as the rate increased (Gottsdanker, 1955).

In 1957, Gottsdanker modified his previous apparatus for the study of a type of collision situation. Two targets in marked orthogonal lanes approached an intersection which was not visible to the S. The centrally placed S predicted their future relative positions. One target was set at a standard velocity and the other was varied by E. It was expected by Gottsdanker that the judgments of the relative future positions of the two moving targets would reflect the error of 15 or 20% in estimating velocities as found in his earlier studies. These expectations were not realized in his findings. For both constant velocity and accelerated targets, prediction was based on the relative positions at the time just before target disappearance, rather than on their velocities or acceleration (Gottsdanker, 1957). Gottsdanker attempted an explanation for this finding in stating that the increased complexity of the predictive situation decreased the order of the predictive equation used by the Ss. Such a decrease in the order of the Ss' predictive equation refers to the used of a less complex system of analyzing the information upon which the prediction was based. It would seem, however, that an alternate explanation could also be provided. The results could indicate that the Ss used the last relative positions of the targets and transposed these positions by the given time interval required for the targets to meet. This would support the conception of the dominance of the temporal cues as maintained by Dembitz (Gerhard, 1959).

A very practical situation similar to that used by Gerhard (1959) and Gottsdanker (1957) was reported by Gibson (Gerhard, 1959). He described the "Estimation of Velocity Test" used by the U. S. Air Force. This test requires the S to observe a motion picture of an aircraft flying into a cloud, and then a shell burst appearing somewhere on the screen. The S had to respond to the shell burst by reporting its position as behind or ahead of the now-invisible aircraft. The test presented only a strictly limited number of situations, since the aircraft always disappeared when half-way across the screen; secondly, only three positions were used for the shell bursts. This laboratory "situational test" resulted in rather poor validity coefficients for the test as a predictor of everyday ability to judge velocity (Gerhard, 1959).

Knight (Gerhard, 1959) also investigated a practical case involving the estimation of velocity in the steel industry. The problem involved the stopping of steel ingots at a specified point while they were travelling at various speeds. Knight found that his subjects tended to use spatial cues as "stopping points" for the different speeds. This result is of interest because it gives an example of a skill in which the estimation of velocity is supposed to operate, but for which the S has provided himself an alternative technique which gives satisfactory results.

In a more theoretically oriented study, Slater-Hammel (1955) investigated the estimation of movement as a function of movement perception and target distance. He used the method of permitting Ss to observe a uniformly moving marker over definite distances and then requiring them to estimate when the marker would reach definite positions in space. The nine experimental conditions consisted of a factorial combination of movement display and target display distances of 2.52, 5.25, and 7.87 inches, with the movement speed of 1.75 in./sec. Slater-Hammel's results indicate that the display distance did not affect the error in time of estimating the arrival of the uniformly moving marker at the specified target. However, the error increased systematically with an increase in the target distance which the marker traversed after disappearing, although the percent absolute error showed a decreasing trend for increases in target distance. In terms of percentage of the required time, the error varied between 8.9% and 21.6%. Slater-Hammel also indicated that Ss tended to underestimate the rate of movement for the shortest display distance and tended to overestimate the rate of movement for the longer display distance.

Morin, Grant, and Nystrom (1956) have reported results similar to those of Slater-Hammel (1955) despite two basic differences in their experimental procedures. First, instead of a target which moved continuously at a constant speed, Morin et al used successive illumination of cue lights which were placed at even intervals in a horizontal row. After illumination of the last cue light, the S estimated the time it would take the imaginary moving object to reach a target light. Secondly, the object traveled at a rather slow computed speed of either 0.10 or 0.05 ft./sec., rather than the 0.15 ft./sec. used by Slater-Hammel. Results obtained confirmed the fact that error of estimating arrival increases with target distance. They also found that objective velocity significantly affected this error (Morin et al, 1956). When an analysis was made to determine the single most important factor related to the size of the errors of estimation, it was found to be computed time to reach the target. This would seem to be supportive of previously reported literature that maintains dominance of the temporal factor in velocity perception. The results show that the mean errors of estimation for the faster speed (0.10 ft./sec.) were generally less than 10% of the computed time, while for the slower speed (0.05 ft./sec.) the mean errors of estimation ranged from 25 to 53%. It should be noted that all serious errors were ones of underestimation of the correct arrival time.

Garvey, Knowles, and Newlin (1956) measured the accuracy of prediction in terms of deviations in range and bearing between estimated and actual position plots on four different radar displays. They found that the accuracy of the estimated position was a function of target speed; the faster the motion of the target the less accurate the estimates.

Although the differential speed threshold would seem to be clearly related to predictions of future position of a moving object, data on the nature of the relationship are limited. A number of investigations have been aimed at determining the difference threshold for velocity, but differences in methodology make compariosn of the results difficult.

Nine of these investigations and assoicated procedures employed are summarized by R. H. Brown (1961), who also discusses the practical value of the Weber ratio as a convenient means by which velocity discrimination may be compared with similar judgments in other modalities as well as with prediction motion and tracking performance. Brown presented measurements of the differential speed threshold ($\Delta\omega$) plotted against speed (ω) for comparison stimuli which were presented adjacent, separate, and superimposed. As a rough approximation, the threshold was shown to increase in direct proportion to speed for non-superimposed stimuli over a range from 1 to 20 degrees per second. (R. H. Brown, 1961a). Brown maintained that estimates of the Weber ratio ($\Delta\omega/\omega$) of 0.14 for adjacent stimuli and of 0.08 for separate stimuli provide a basis for error interpretation of tracking and other predictive behavior. He states that since experiments have supported the assumptions of intermittancy and predictiveness of tracking responses, error in performance may be calculated for relatively simple tasks from the Weber ratio. Brown further reports that for more complex tasks, constancy of the Weber ratio agrees with the linear relationship found between tracking error and speed of target motion.

In another work, R. H. Brown (1961b) examined the results of an experiment by W. C. Biel and E. G. Brown (1949) in terms of the significance of the difference threshold for velocity. Estimates of aircraft speed were made by ground observers during World War II in order to determine the potential adequacy of lead angle correlations for anti-aircraft fire. In an experiment by Biel and Brown, 20 army officers recorded their individual estimates of the speed of airplanes that were flown on a straight and level course at varied speeds, directions, altitudes, and ranges. The most obvious result was the relationship between the mean estimate and the actual airplane speed. On the average, the observers increased their estimates with increased speed, but not proportionately. The tendency was to overestimate low speeds and underestimate high speeds (Biel and Brown, 1949). In addition, Biel and Brown found that the type of plane being flown at the same speed influences estimates; but, direction, altitude, and range had no significant effect. R. H. Brown (1961b) examined the standard deviations of Biel and Browns' data and found that the variability of the visual estimates of airplane speed made by the Ss increases in direct proportion to the mean estimates made by himself for quite different moving objects viewed at close range in the laboratory. In addition, the standard deviation is comparable to the determination of the smallest discriminable difference in speed ($\Delta\omega$) as discussed by Woodworth and Schlosberg (R. H. Brown, 1961b). Brown makes the assumption that if $\Delta\omega \propto \sigma\omega$ then the value of $\sigma\omega/\omega$ may be compared to the Weber fraction $\Delta\omega/\omega$. Brown also points out that during a training period, where Biel and Browns' Ss were informed of the true speed immediately after they recorded their estimates, it was noted that the Weber fraction discrimination of a 12.5% difference in speed was reduced to an 8.5% discrimination in speed. In his 1960 study, R. H. Brown found that his highly trained Ss in the laboratory could discriminate a 7.7% difference in the speed of two objects when they are viewed alternately.

An experiment by D. R. Brown, J. C. Naylor, and K. H. Michels (1961) was involved with determining the relationship between threshold for movement of a point source of light and the angle of approach or retreat of the light from an S who was tracking the movement binocularly. With a speed of 3 in./min., all possible combinations of retreat and approach from left and right at angles of approach of 0, 30, 60, and 90 degrees were presented to the Ss. An examination of the results indicates that when the light was either approaching or retreating from the Ss without lateral displacement from the point of origin (angle of approach or retreat = 0 degrees), an accurate judgment was not made in any instance. In addition, their data demonstrated that the closer the angle of approach approximated the line of sight, the larger the distance the light must traverse in order to obtain a correct judgment from the S. Retreat or approach from either right or left had no effect on the perception of movement. D. R. Brown et al, point out that since the dependent variable was judgment of distance moved, and since the speed was constant regardless of the angle of approach, the major factor would seem to be rate of movement per unit of visual angle. The closer that angle to the line of sight, the less the rate of movement in terms of degrees of arc/sec. The researchers maintain that this would indicate, within the limits of the rates involved in their study, that an increase in speed of a point source of light will facilitate the perception of movement. Since other authors report a significant increase in the threshold for high speeds as opposed to low speeds, D. R. Brown _et al_, suggest that their results are not contradictory to previous research, but that the relationship between speed and threshold is a curvilinear one, with the threshold becoming lower as speed increases up to a point beyond which it begins to rise again.

In a study by Olson, Wachsler, and Bauer (1961) _S_s were evaluated on their ability to detect the direction and rate of change of the space interval separating the car in which they were riding from a preceding car. This interval was set at one of two magnitudes and could remain constant or open or close at one of three rates of closure. Olson _et al_, indicated that on the range of speeds tested, people tended to be quite accurate in determining whether the distance between their car and the preceding one was increasing or decreasing, with a better-than-chance ability at discriminating between closing and opening rates as fine as 10 mph. The researchers also found that the accuracy with which these judgments could be made increased as the distance between the vehicles decreased, with judgments being made more accurately when the gap was closing than when it was opening (Olson _et al_, 1961). There was also general agreement with several of the previously mentioned studies (Biel and Brown, 1949; Morin _et al_, 1956) in the finding that _S_s tended to underestimate the speed of the lead car by an average of 4.6 mph.

Baker and Steedman (1961) report a finding similar to that of Olson _et al_ (1961) while investigating the ability of _S_s to perceive movement in depth of a luminous object in an otherwise stimulus-free surround. Like Olson _et al_, Baker and Steedman found a statistically significant bias which indicated that when an object approached, its movement in depth was more easily perceived than when it receded. This was expected, they explain, because a slightly greater visual angle change occurs per unit time when the object is approaching than when it is receding (Baker and Steedman, 1961). The results also indicated that longer observation times are required to maintain a given level of performance in reporting whether the object was approaching or receding. At the slowest speed of 1.65 in./sec. the _S_s required 6 seconds of observation time to acquire a 75% threshold level of performance; while at the fastest speed of 13.2 in./sec. they required only 0.65 seconds.

Two studies which are interesting in their theoretical contributions to the study of the perception of velocity were reported by Ekman and Dahlback (1956) and by Cohen (1961). Ekman and Dahlback attempted to devise a subjective scale of velocity similar to the sone and veg scales for subjective loudness and weight, respectively. Ss were instructed to either equate a variable stimulus to a standard moving at one of five velocities (18, 24, 30, 36, and 42 mm./sec.), or to adjust the variable stimulus so that it seemed to be moving half as fast as the standard. Through use of their own scaling procedures they arrived at the positively accelerating function: $R=0.1340S^{1.7703}$, where R is the physical velocity and S the subjective velocity, as describing the relationship between physical and subjective velocity (Ekman and Dahlback, 1956). In addition, Ekman and Dahlback reported that data on discriminative sensitivity for the physical velocities examined demonstrated that the relationship of this sensitivity and subjective velocity was a linear one.

The question of whether the perception of velocity is centrally or retinally organized was treated by Cohen (1961) with the use of a rather interesting experimental technique. Five Ss were asked to estimate the relative and absolute velocities of two spots that were moving in 180° out-of-phase simple harmonic motion. The two experimental conditions consisted of having both spots projected onto both retinas and one spot projected onto one retina and the second onto the other. The results were quite clear in demonstrating that there was no statistical difference between the two conditions. This means that the Ss performed equally as well when the perceptual organization was purely central as when it was central and retinal, if there was any organization at the retinal level at all. Cohen points out that none of the Ss had previously experienced a situation where the moving object and a frame of reference were projected onto separate retinas; yet, it was not necessary for them to have a learning period, when put into this situation for the first time, in order to perform at a maximum level. This, Cohen strongly suggests, indicates that there is no organization at the retinal level at all, and that the organization of velocity perception is accomplished centrally.

In summary, much of the earlier work on velocity estimation and prediction motion has produced results which seem to be peculiar to the particular experimental situations used. Certain aspects of the findings, however, seem to show some relative consistency. There are various reports of the dominance of the temporal cuing aspect in velocity estimation and prediction motion. These results tend to show that it is variation in the temporal relationships of stimulus events which occur as a result of movement of an object, rather than the velocity of the object in itself, which generally produces significant changes in S's responses. Recent investigations of stimulus speed and target distance seem to demonstrate a certain consistency in the findings suggesting that as stimulus speed and target distance increase, sensitivity to velocity differences as well as accuracy of prediction motion decrease. There also seems to be rather general agreement in the research reported that the presence of various cues in the surrounding field and the moving stimulus itself can increase the accuracy in velocity judgment and prediction motion.

The purpose of this study will be to examine the effects of five variables: knowledge of results, distance, stimulus gradient, target speed, and temporal delay (a measure of the temporal relationship between the target and standard), upon accuracy of performance in a prediction motion type task. A major difference between the present study and those reported in the literature will be that the stimulus object motion being predicted will be motion in depth. It is expected, however, that this difference will not prevent the results of the experiment, with respect to the effects of the experimental variables, from being in general agreement with those reported in the literature. Therefore, the following experimental hypotheses are offered:

1. It is hypothesized that the knowledge of results

condition will result in greater task accuracy than the no knowledge of results condition.

2. It is hypothesized that the temporal delay variable will result in a comparatively greater effect in determining task accuracy than the speed variable.

3. It is hypothesized that the intermediate levels of speed and temporal delay will result in greater task accuracy than either the high or low levels.

4. It is hypothesized that the near distance condition will result in greater task accuracy than the far distance condition.

5. It is hypothesized that the high gradient condition will result in greater task accuracy than the low gradient condition.

METHOD

Subjects

The Ss used in the study were 52 male undergraduate students enrolled in Psychology classes at Western Michigan University. The vision of each S, corrected or uncorrected, was found to fall within the normal range of acuity and depth perception on the *Operator of Mobile Equipment* scale of the modified Bausch and Lomb Ortho-Rater.

Apparatus

The stimulus objects were four 3 inch construction paper squares. The low-gradient target and standard stimuli were made from a sheet of solid red paper, while the high-gradient target and standard stimuli were made by alternatively weaving 0.50 inch wide strips of red and white paper. Both the target and standard stimuli were mounted on wheeled carts which travelled on separate parallel tracks.

The 26 feet 10 inch long tracks were 8 inches apart, center to center, inside of a tunnel that was 1 foot square and 32 feet in length. The target stimuli were mounted on the track that ran along the left wall of the tunnel and the standard stimuli were mounted on the track that ran along the right wall. An endless-loop leather pulley drive belt, 0.25 inches in diameter, was positioned so that its upper portion rested on the target stimulus track and its lower portion ran in a hollow beneath the track. It was to the upper portion of the belt that the target stimulus carrier was attached. The drive belt was drawn maximally taut to prevent any slippage on the ball bearing drive mountings located beneath the beginning and end of the raised track. Uniform belt movements for the 4, 8, and 12 in./sec. experimental speeds were obtained by means of a Buchler Instruments Pulse Circuit, which controlled the slow shaft of a Bodine NSH-12R synchronous speed-reducer motor attached to drive mounting at the front end of the tunnel. The experimental speeds were calibrated by timing the stimulus carriage over a measured distance marked by two microswitches mounted in the track. These microswitches were activated by a protruding device on the bottom of the moving cart. By adjustment of the control circuit rheostat to specific dial readings, E could achieve the following reliability on each of the experimental speeds: 4 in./sec. ± .01 in./sec., 8 in./sec. ± .02 in./sec. and 12 in./sec. ± .04 in./sec. The speeds were recalibrated after each day of experimental testing by readjustment of the required rheostat dial setting. The standard stimulus was positioned along its track by hand.

The bottoms of the target and standard stimuli carts were both 0.75 inches above the track, while the tops of the carts measured 2.13 inches above the track. Each of the carts was 3.50 inches wide. The front of the carts were covered with black construction paper to minimize their differences from the flat black painted tracks. The high and low gradient stimuli were pasted on opposite sides of two 3 x 3 x .50 inch wooden blocks, each of which was attached to a target and standard cart in a manner that enabled E to swivel the blocks 360°. This permitted E to select the stimulus gradient he desired to face S by adjusting the orientation of the wooden blocks. E was able to adjust the type of stimulus being used on both target and standard, as well as hand position the standard stimulus cart, by lifting the roof of the tunnel in which they were placed. The roof of the tunnel was made of a translucent plastic-coated wire mesh and was hinged only at the right side of the tunnel. Light entered the tunnel from twenty-six 15 watt G.E. frosted white bulbs suspended at one foot intervals, 10 inches above the center of the tunnel roof. This light was diffused by the translucent plastic roof to totally eliminate shadows and provide a constant light value of 16, at an ASA setting of 100, on an Etalon Compact exposure meter.

The tracks upon which the carts traveled were mounted on wooden platforms which were raised 5 inches above the floor of the tunnel. The front of the platforms began 14.5 inches from the viewing end of the tunnel. Both the tracks and the platforms beneath them were covered with single sheets of masking tape to eliminate any seams or defects in the wood that might act as cues to distance, and then were painted flat black to match the floor of the tunnel. The 0.5 inch thick tempered masonite walls of the tunnel were covered with single lenghts of white paper to eliminate cues as well as disperse the light entering from above. The back end of the tunnel was closed with a piece of opaque white cardboard.

The front, or viewing end, of the tunnel was closed by a 4 foot square sheet of masonite that was centered across the opening of the tunnel. The size of the sheet prevented the S from observing the position of E during the experimental session. A viewing aperture 5.5 inches long and 1.13 inches wide was cut in the masonite so that it was centered at 4.50 inches above the tracks and 9.50 inches above the floor of the tunnel. The Ss' eyes were thus placed at a level of .89 inches above the center of the target and standard stimuli. Access to this aperture was controlled by a hinged aluminum door that was opened and closed by a Guardian 12 continuous duty 115 v. AC solenoid. Both the aluminum viewing door and the masonite sheet were covered with black paper to avoid any distracting reflections. A colored gummed star was pasted on the masonite sheet 0.5 inches below the center of the viewing aperture to act as a guide for S in enabling him to keep his eyes at a uniform level for each trial. This was done by asking S to place his nose at the level of the star on each trial.

The viewing door solenoid was initiated when the target stimulus cart passed over one of the two microswitches, mounted in the track 12 feet apart, that marked the two experimental starting points. E controlled the status of the microswitches, open or closed, by two switches on his control panel. The viewing door solenoid was wired into a circuit with a TD-6S industrial timer, made by the Industrial Timer Corporation, that was set to close the viewing door 3 seconds after it had been opened by the cart passing over one of the microswitches. When the viewing door closed (caused by timer deactivation of the solenoid), a Potter and Brumfield SPDT KA5AY 115 v. AC relay initiated the last contingency in the closing of a circuit that set into operation a Stoelting Co. chronometer, graduated in hundreths of a second. This initiation of the clock was contingent upon two additional operations. The first was the pressing down of a desk-chair mounted Monarch Ballbearing Speed Key KY-103 by the S, and the second was the positioning of a switch on E's control panel. The pressing down of the key was used by E as an indication that the S was ready for the next trial. Because of the nature of the circuit design, E could only fulfill the second contingency for clock operation during the 3 second interval that the viewing door was open with its solenoid activated. At the moment S released the key the clock would stop. The target stimulus cart was stopped by a switch on E's control panel after ii had been indicated that S had released the key. The cart was then returned to one of the two starting positions by either a forward or reverse movement of the motor, as required. As the returning cart passed over the microswitches a Guardian stepper relay automatically reset the microswitches for the next initiation of the viewing door solenoid. The activation of the stepper relay was also controlled by a switch on the experimental control panel.

Figure 1 represents a schematic diagram of the circuit which controlled the operation of the apparatus as described above. Several photographs of the experimental apparatus can be found in the Appendix. Included are views of the tunnel, lighting system, control panel, experimental stimuli, and S preparing for an experimental trial.

White noise was administered to each S through Calrad RH-8 earphones to mask any sounds of the motor which might act as cues to the speed or distance of the target stimulus.

The Bausch and Lomb Modified Ortho-Rater was used with slides N-1, N-2, N-3, F-3, F-5, and F-6 to test the acuity and depth perception of each S.

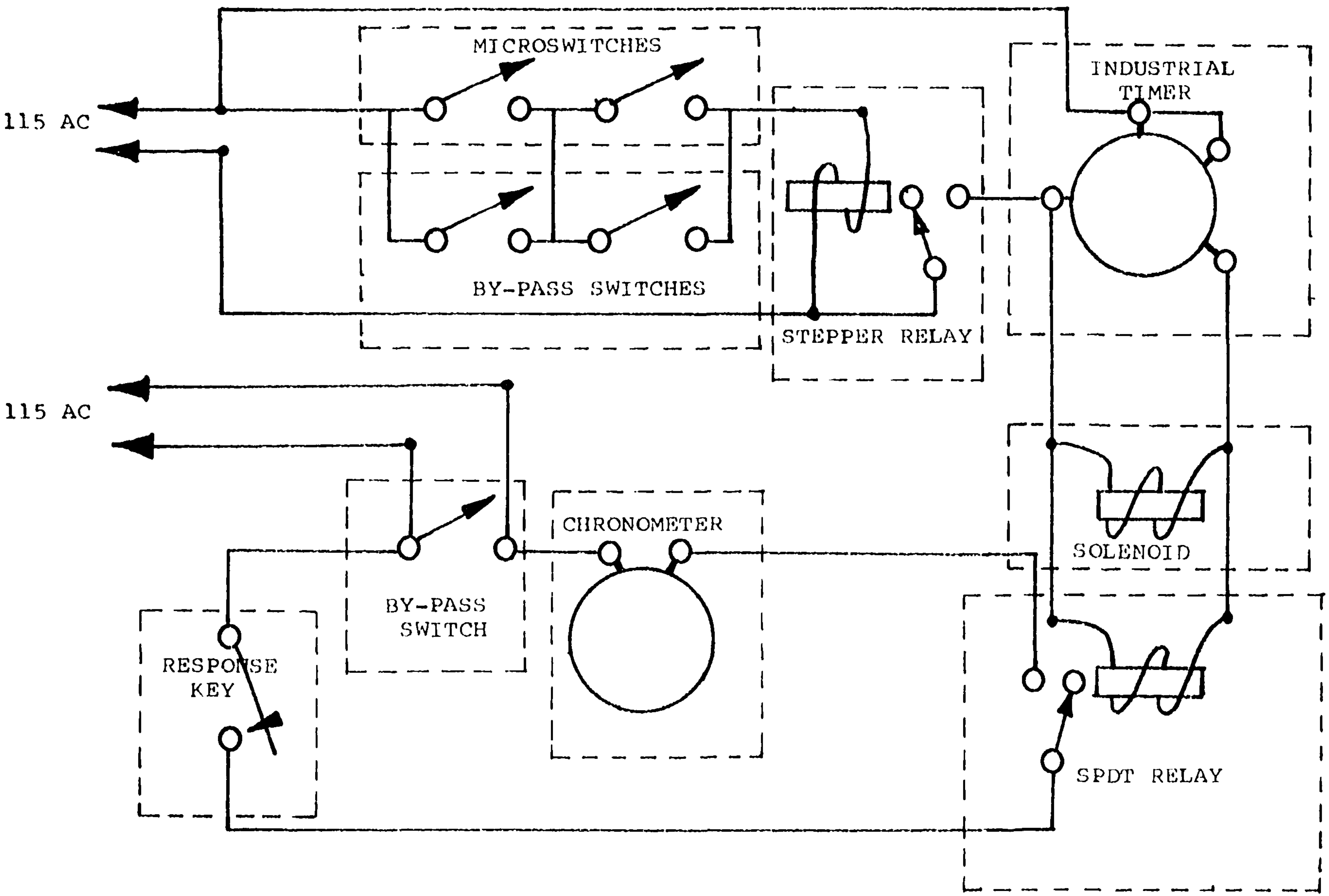

Fig. 1. Schematic diagram of the control circuit.

Procedure

The Experimental Session

When the Ss arrived, each was examined for normality of acuity and depth perception with the Modified Bausch and Lomb Ortho-Rater. This examination was accomplished in a small room adjoining the room in which the experiment was conducted. If the S's vision proved to be adequate, he was then alternately assigned, on order of appearance, to one of two experimental treatment groups. If the subject was assigned to the no knowledge of results group, he was seated at the desk-chair at the viewing end of the tunnel and given the following instructions:

> "The purpose of this experiment is to measure the accuracy with which you can estimate the movement of an object coming directly towards you. This type of movement is sometimes called closing distance. This experiment will attempt to measure this phenomena in the following manner. You will first be required to place your eyes at the viewing slot in the apparatus directly in front of you. Try to keep your nose at or near the colored star to insure that your eyes are nearly at the same level for each trial. In each of the experimental trials the door covering the viewing slot will open for only three (3) seconds. When this door is open you will be able to see two objects in the tunnel. On the left there will be a colored square on a cart moving towards you. On the right will be a similar colored square on a cart that is stationary. On your initial sighting the moving cart on the left (called the target) will always be further back in the tunnel than the stationary cart (called the standard). Thus, whenever the viewing door is open, you will see the target moving towards you and the standard

somewhere in between you and the target. Your task on each trial will be to try to estimate when the target will arrive at (be alongside of) the standard from the three second viewing of motion and position of the target and the location of the standard. You will indicate when you think the target has arrived at the standard by the following procedure. When you are given the ready signal to place your eyes in the viewing position, also press down the telegraph key mounted on the right of your chair. Hold this key down after the viewing door closes and until the time at which you think the target has arrived at the standard. You are to release the key when you think the moving target has reached and is alongside of the stationary standard. The position and appearance of the target and standard will vary on each trial, but your task will always be the same.

You will also be asked to put on the earphones at the ready signal of each trial. You may, if you wish, take them off after you have made your estimation by releasing the key. In the period in between the closing of the door and the time you choose to release the key, you are to keep your eyes open and fixate on the white spots on the viewing slot door.

There will be 3 practice trials to familiarize you with the task and the operation of the apparatus. This will be followed by 36 experimental trials. There will be a slight delay between trials so that I can set up the apparatus for the following trial."

If the S was assigned to the knowledge of results (KR) group, the following paragraph was included in the instructions described above:

"After each trial I will tell you how close you got to predicting the arrival of the target at the standard. This measurement will be to the nearest inch. When I say that you have stopped the target a number of inches short, it will mean that the target had been stopped a certain number of inches before it had reached the position of the standard. When I say that you have stopped the target a certain number of inches long, it will mean that the target had passed the standard by that number of inches when you stopped it."

Any questions the S had about the instructions were then clarified by E. When it was certain that the S understood his task the E administered the 3 practice trials. Since the purpose of the practice trials was only to famiarize the S with the operation of the apparatus as well as the experimental task, no knowledge of results was given in these trials. After the practice trials E proceded to the actual experimental trials.

The entire experimental session lasted approximately 40 minutes for the no knowledge of results Ss and 45 minutes for the Ss to which knowledge of results was given. The difference in the duration of the experimental session for the two groups of Ss represented the time that the E took in obtaining and providing feedback to the Ss in the knowledge of results group.

Manipulation of the Experimental Variables

Knowledge of results-- The knowledge of results variable was treated differently from the four other variables, in that it was the only variable in which all conditions were not presented to each S. That is, Ss were assigned to a group that received knowledge of results (designated as the KR group or treatment) on trials which represented all possible combinations with all levels of the remaining four variables, or they were assigned to a group in which knowledge of results was not given on any trial (designated as the NKR group or treatment). Those in the group that made up the KR condition were provided with immediate verbal feedback on their performance after each trial. The E accomplished this by the use of a table that converted the S's response, indicated by the clock on the E's control panel, into a measure of the actual distance between the target and the standard at the moment the response was made. The S was given the magnitude in inches of this distance as well as its direction, whether moving target had gone past or been stopped before the standard at the time of the response.

Distance-- The two conditions that composed the distance variable were determined by manipulating the S's initial viewing point of the moving target stimulus and also the range of positioning of the standard stimulus. The initial viewing point for the near distance condition was 175.5 inches from the observing S, while for the far distance condition it was 319.5 inches. For the near distance the range of standard stimulus positioning was 31.5 to 151.5 inches from the S, while the same range for the far distance was 175.5 to 295.5 inches.

Gradient-- The high and low gradient conditions were achieved by rotating the target and standard cart-mounted blocks on which were both the high and low gradient patterns. The high gradient condition was effected by rotating these blocks to a position in which the red and white checkerboard stimulus faced the S. The low gradient condition was similarly effected by rotating the blocks so that the solid red stimulus faced the S.

Speed-- The three target speeds were manipulated by varying the setting of the control circuit rheostat to the appropriate position. Speeds of 4, 8, and 12 in./sec. were chosen because they presented a presumably sufficient perceptual range as well as being within the operational limits resulting from the size of the apparatus.

Temporal delay-- The temporal delay variable was the most difficult to manipulate. Its inclusion in the experiment lies in the finding of the dominance of the temporal aspect in velocity perception and prediction motion reported in the literature. The temporal delay variable was, in effect, a methodology for separating out any of these reportedly dominant effects of the temporal factor in the velocity estimation and prediction motion demanded by this experimental situation. The variable in itself is nothing more than a measure of the time the moving target would be travelling from its last sighting to its arrival at the standard. The manipulation of this variable was accomplished by changes in the positioning of the stationary standard for each of the three experimental speeds. The rationale behind such changes is demonstrated by the following example. If the temporal delay variable had not been inserted into the experiment, a standard stimulus positioned 24 inches down the track (24 in. closer to S) from the S's last sighting of the target moving at speeds of 4 and 8 in./sec. would be reached by that target in temporal delay's of 6 and 3 seconds, respectively. In such a situation where constant distances to the standard would exist, and the temporal delay to the standard varying inversely to the speed of the target, it would be difficult, if not impossible, to ascertain whether it was the increasing temporal delay or decreasing speed, or vice versa, that was determining any affect on the accuracy of predicting target arrival at the standard. It was thus decided that the standard would be re-positioned for each of the speeds in a manner that would allow equal temporal delays for each of the three speeds. With reference to the previous example, the situation was manipulated such that the standard would be positioned 12 inches and 24 inches down the track from the last sighting of the target moving at 4 in./sec. This resulted in temporal delays of 3 and 6 seconds, respectively. The standard would then be positioned 24 and 48 inches down the track for the 8 in./ sec. target speed, again resulting in temporal delays of 3 and 6 seconds for the respective speeds.

It may seem that it can now be argued the the E has merely shifted the confounding effect of temporal delay with speed to a confounding of temporal delay with target distance from the standard. This is undeniably the case. The temporal delay variable as incorporated in the experiment is confounded with the varying target distances to the standard, making it difficult, if not impossible, to determine whether the temporal delay variable's effects resulted from the manipulation of temporal delay or the associated distances of the target from the standard. But it must be re-emphasized that one of the more important functions of this experiment was to permit an examination of the effects of the speed variable without the confounding effects of temporal delay. This has been accomplished.

Since past literature in the area has found that both temporal delay and target distance from the standard have significant effects on velocity perception and prediction motion, it would be expected that the confounding of these two factors into a single experimental variable would undoubtedly strengthen the probability of this variable producing a significant effect on the response measure. Thus, any effect resulting from the experimental variable of temporal delay would have to be attributed to either the separate effects of temporal delay and target distance to the standard, or a combination of the effects of both. It is expected, however, that the results of the experiment will provide some general indication of whether it has been temporal delay or target distance to the standard that has been the dominant aspect of the experimental temporal delay variable.

Scoring of accuracy

The accuracy with which Ss were able to estimate the arrival of the uniformly moving target stimulus at the position of the standard was analyzed in terms of a per cent of absolute error measure. This measure was obtained by application of the formula: per cent error = d/D, where d is the absolute distance between the target and standard at the moment of the S's response that the target had arrived at the standard. D is the actual distance between the target and standard at the moment they disappear from the S's view. Evidence of the tenability of a per cent error measure in the analysis of an experiment of this type exists in its use by Slater-Hammel, 1956; Gottsdanker, 1952a, 1952b, 1955, 1957; Morin et al, 1956; and Gerhard, 1959.

A per cent error measure was also chosen because of the varying distances of the target to the standard that existed on each of the trials. It was believed in such a situation a per cent error measure based on absolute distances would be a far more descriptive as well as valid indicator of accuracy of the Ss' estimations.

Experimental design

The basic experimental design is illustrated in Table 1. Each S was randomly presented with a total of 36 trials, with each trial representing one of the 36 possible combinations of one of the two knowledge of results treatments to which he had been assigned and all levels of the remaining four variables. The 52 randomizations of the 36 possible treatment combinations were prepared by an IBM 1620 computer system at the Western Michigan University Computer Center.

Table 1

The Experimental Design

			(D1)			(D2)			(D3)		
			(E1)	(E2)	(E3)	(E1)	(E2)	(E3)	(E1)	(E2)	(E3)
(A1)	(B1)	(C1)									
		(C2)									
	(B2)	(C1)									
		(C2)									
(A2)	(B1)	(C1)									
		(C2)									
	(B2)	(C1)									
		(C2)									

RESULTS

The means and other descriptive data for the error scores for the 26 subject entries in each cell of the experimental design are presented in Table 2. The statistical analysis of variance provides some insight into some of the sources contributing to the differences in errors of estimation found in Table 2. The study was essentially a 2 x 2 x 2 x 3 x 3 factorial experiment (2 levels of knowledge of results x 2 levels of distance x 2 levels of gradient x 3 levels of speed x 3 levels of temporal delay) with repeated measures on the the last 4 factors (Winer, 1962). The analysis of variance was performed by an IBM 1620 computer system at the Western Michigan University Computer Center. The results of the analysis, as summarized in Table 3, show that statistically significant differences in accuracy were produced by the four main effects of: knowledge of results ($F=31.02$, $df=1, 50$; $p < .001$), distance ($F=10.89$, $df=1, 50$; $p < .01$), speed ($F=36.38$, $df=2, 100$; $p < .001$) and temporal delay ($F=4.04$, $df=2, 100$; $p < .05$). As a main effect, gradient proved to be statistically non-significant ($F=0.66$, $df=1, 50$; $p > .05$). In addition, three of the various interactions among the main effects resulted in significant F values. These were the interactions of : knowledge of results x temporal delay ($F=22.31$, $df=2, 100$; $p < .001$), knowledge of results x distance ($F=4.09$, $df=2, 100$; $p < .05$) and knowledge of results

Table 2

The Means and Standard Deviations for the Per Cent Error Scores of All the Treatment Combinations of Knowledge of Results (A), Distance (B), Gradient (C), Target Speed (D), and Temporal Delay (E).

			(D1) 4 (E1) 3	(D1) 4 (E2) 6	(D1) 4 (E3) 9	(D2) 8 (E1) 3	(D2) 8 (E2) 6	(D2) 8 (E3) 9	(D3) 12 (E1) 3	(D3) 12 (E2) 6	(D3) 12 (E3) 9	
(A1)NKR	(B1)NEAR	(C1)HIGH	47.77	55.82	53.94	33.98	36.74	47.49	37.00	39.38	34.96	MEAN
			22.06	21.07	18.53	22.80	19.07	20.33	20.19	22.17	19.15	S.D.
		(C2)LOW	43.33	49.15	50.93	39.02	45.43	50.33	35.07	42.24	38.47	MEAN
			22.11	21.00	24.51	21.31	18.34	16.30	22.80	19.34	20.11	S.D.
	(B2)FAR	(C1)HIGH	53.02	56.91	56.75	35.50	39.70	48.19	25.81	35.65	45.05	MEAN
			28.16	22.31	22.31	26.41	20.24	17.76	19.04	22.13	30.60	S.D.
		(C2)LOW	56.15	58.69	57.85	42.03	43.71	44.97	32.51	36.95	38.75	MEAN
			25.42	16.24	21.38	24.53	30.38	21.82	19.56	18.23	22.71	S.D.
(A2)KR	(B1)NEAR	(C1)HIGH	32.34	24.73	37.37	19.73	20.57	27.25	21.84	25.97	24.53	MEAN
			23.56	18.95	17.43	15.07	14.92	17.85	16.02	18.70	18.06	S.D.
		(C2)LOW	36.00	25.56	35.93	22.15	17.03	34.39	30.05	21.64	21.12	MEAN
			32.59	17.94	17.78	19.98	12.47	12.79	43.87	13.75	14.54	S.D.
	(B2)FAR	(C1)HIGH	47.64	29.07	35.55	44.17	24.68	27.52	43.74	22.73	22.20	MEAN
			31.10	14.86	27.99	30.52	20.03	14.27	35.81	16.34	12.39	S.D.
		(C2)LOW	53.70	33.19	35.60	31.93	27.35	24.55	43.32	23.11	22.43	MEAN
			55.39	22.69	21.88	26.43	21.53	20.59	40.16	17.31	13.15	S.D.

Table 3

Summary of the Analysis of Variance

Source	SS	df	MS	F
Between subjects	253362.00	51	4967.88	
Knowledge of results (A)	97008.90	1	97008.90	31.02***
Within subjects	930573.00	1820	511.30	
Distance (B)	7252.50	1	7252.50	10.89**
Gradient (C)	304.70	1	304.70	.66
Speed (D)	54961.80	2	27480.90	36.38***
Temporal delay (E)	4184.40	2	2092.20	4.04*
A x B	2723.90	1	2723.90	4.09*
A x C	73.50	1	73.50	.15
A x D	5080.30	2	2540.15	3.36*
A x E	23055.60	2	11527.80	22.31***
B x C	3.90	1	3.90	.00
B x D	2136.00	2	1068.00	.14
B x E	6979.80	2	3489.90	.43
C x D	98.20	2	49.10	.00
C x E	448.80	2	224.40	.02
D x E	3620.80	4	905.20	.25
A x B x C	145.10	1	145.10	.00
A x B x D	1029.10	2	514.55	.06
A x B x E	8145.50	2	4072.75	.51
A x C x D	1470.30	2	735.15	.09
A x C x E	163.60	2	81.80	.00
A x D x E	2387.90	4	596.97	.16
B x C x D	1669.70	2	834.85	.13
B x C x E	590.90	2	295.45	.04
B x D x E	2462.40	4	615.60	.20
C x D x E	557.70	4	139.42	.04
A x B x C x D	145.70	2	72.85	.01
A x B x C x E	1668.40	2	834.20	.12
A x B x D x E	1191.00	4	297.75	.09
A x C x D x E	1401.10	4	350.27	.11
B x C x D x E	196.00	4	49.00	.01
A x B x C x D x E	1214.60	4	303.65	.10

*Significant at .05 level
**Significant at .01 level
***Significant at .001 level

x speed (F=3.36, df=2, 100; $p<.05$).

The means and other descriptive data of the various levels of the main effects for all experimental data are presented in Table 4 and graphically depicted in Figure 2. As is illustrated in the table and figure, there are several relatively large differences between the mean error scores of the levels within the four main effects indicated to be statistically significant by the analysis of variance. These differences between the levels within the main effects were tested for statistical significance by the use of a series of t tests. It can be seen that there was a statistically significant difference in the two levels of knowledge of results, with the NKR condition having a higher mean error score than the the KR condition (t=12.97, df=936; $p<.001$). Statistical significance was also found in the difference between the two levels of distance, the near distance having a lower mean error than the far (t=3.36, df=936; $p<.001$). In the examination of the two levels of gradient, the finding that the high gradient condition resulted in a slightly lower mean error score than the low gradient condition was shown to be non-significant (t=0.59, df=936; $p>.05$). Both Figure 2 and Table 4 indicate that the mean error score increased as the experimental speeds decreased, with the velocity of 4 in./sec. having the highest mean error score, the velocity of 8 in./sec. having an intermediate mean error score, and the speed of 8 in./sec. having the lowest mean

Table 4

Means and Descriptive Data of Levels Within the Main Effects

Treatment	Level		Mean	S.D.	N[a]
Knowledge of results (A)	NKR	(A1)	44.13	23.16	936
	KR	(A2)	29.74	25.01	936
Distance (B)	Near	(B1)	34.97	22.89	936
	Far	(B2)	38.90	27.09	936
Gradient (C)	High	(C1)	36.53	24.13	936
	Low	(C2)	37.34	26.14	936
Speed (D)	4	(D1)	44.44	26.88	624
	8	(D2)	34.51	22.71	624
	12	(D3)	31.85	23.95	624
Temporal delay (E)	3	(E1)	37.81	29.53	624
	6	(E2)	34.78	22.74	624
	9	(E3)	38.21	22.43	624

[a]cumulative observations across Ss

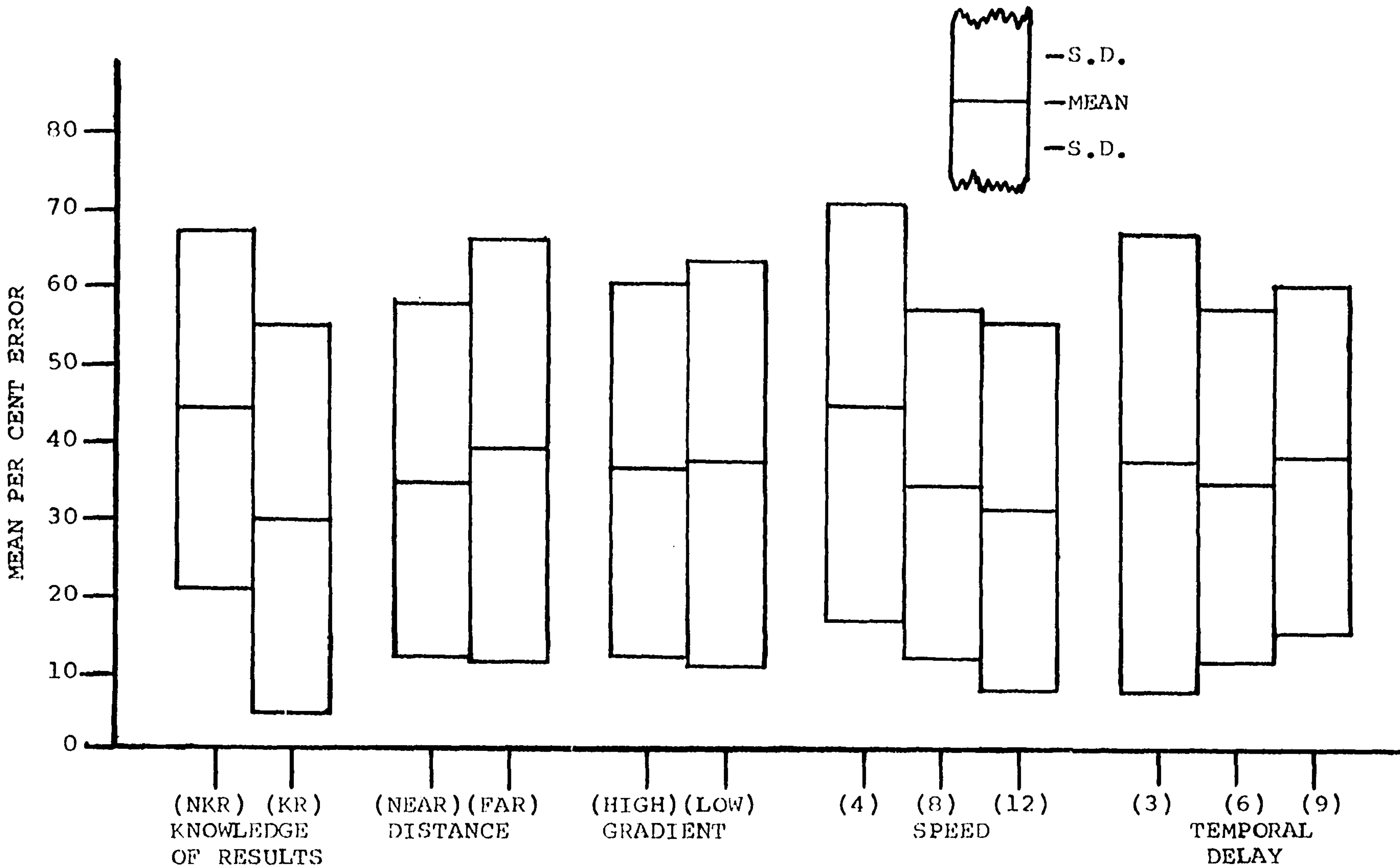

Fig. 2. Means and standard deviations of the error scores for the levels within the main effects.

error score. Significant differences were found to exist between the mean error scores for the 4 and 8 in./sec. speeds (t=7.09, df=624; $p < .001$), and between the mean error scores of the 4 and 12 in./sec. speeds (t=8.81, df=624; $p < .001$). No statistical difference was evidenced between the 8 and 12 in./sec. pairing (t=1.01, df=624; $p > .05$). It would thus seem that a large component of the differences in accuracy resulting from the main effect of speed, as indicated by the analysis of variance, resulted from the difference between the 4 in./sec. speed and the two remaining speeds of 8 and 12 in./sec., respectively.

Figure 2 and Table 4 show that the 6 second, or intermediate, temporal delay resulted in a lower mean error score than obtained for either the 3 or 9 second delays. A comparison of the mean error scores for the levels within the variable of temporal delay yielded statistically significant differences between the pairing of the 3 and 6 second delays (t=2.04, df=624; $p < .05$), the pairing of the 6 and 9 second delays (t=2.69, df=624; $p < .01$), but no significant difference when the mean error scores of the 3 and 9 second delays were compared (t=0.34, df=624; $p > .05$). This would seem to suggest that the difference between the 6 second temporal delay and the delays of 3 and 9 seconds provided a large component of the treatment effect of temporal delay which was shown as significant by the analysis of variance.

A test of trend (Winer, 1962) was used in an attempt to ascertain the nature of any functional relationship that might exist between speed and accuracy as well as between temporal delay and accuracy. In both cases it was found that no statistically significant trends of a linear, quadratic, or cubic nature were found between either the levels of speed or temporal delay and task accuracy ($F < .001$ for all trends tested).

The means and other descriptive data for the various levels of distance, speed, and delay, as partitioned by the two levels of knowledge of results, gave some insight into the nature of the three significant interactions yielded by the analysis of variance. These means and associated data are listed in Table 5. The partitioning of the levels of distance, speed, and delay are graphically presented in Figures 3, 4, and 5, respectively. The differences between selected pairings of mean error scores pertinent to the explanation of the significant interactions were tested for statistical significance with the use of a series of t tests.

The graphic representation of the knowledge of results x distance interaction depicted in Figure 3 would seem to suggest that knowledge of results had a greater effect in reducing the mean error in the near distance condition than in the far distance condition. This interpretation is a result of the observation that there was a greater decrease in the mean error score of the near distance condition as compared to the far distance condition as a function of going from the NKR condition to the KR condition. It is interest-

Table 5

Means and Descriptive Data of Levels of the Main Effects Involved in Interactions with Knowledge of Results

Treatment		Level	Mean	S.D.	N[a]
Distance (B)	NKR (A1)	Near (B1)	43.37	21.44	468
		Far (B2)	44.89	24.76	468
	KR (A2)	Near (B1)	26.56	21.16	468
		Far (B2)	32.91	28.01	468
Speed (D)	NKR (A1)	4 (D1)	53.33	22.50	312
		8 (D2)	42.25	22.19	312
		12 (D3)	36.81	21.73	312
	KR (A2)	4 (D1)	35.55	27.97	312
		8 (D2)	26.77	20.51	312
		12 (D3)	26.88	25.04	312
Temporal Delay (E)	NKR (A1)	3 (E1)	40.07	24.10	312
		6 (E2)	44.92	22.61	312
		9 (E3)	47.43	22.19	312
	KR (A2)	3 (E1)	35.55	34.00	312
		6 (E2)	24.63	17.85	312
		9 (E3)	29.03	18.59	312

[a]cumulative observations across Ss

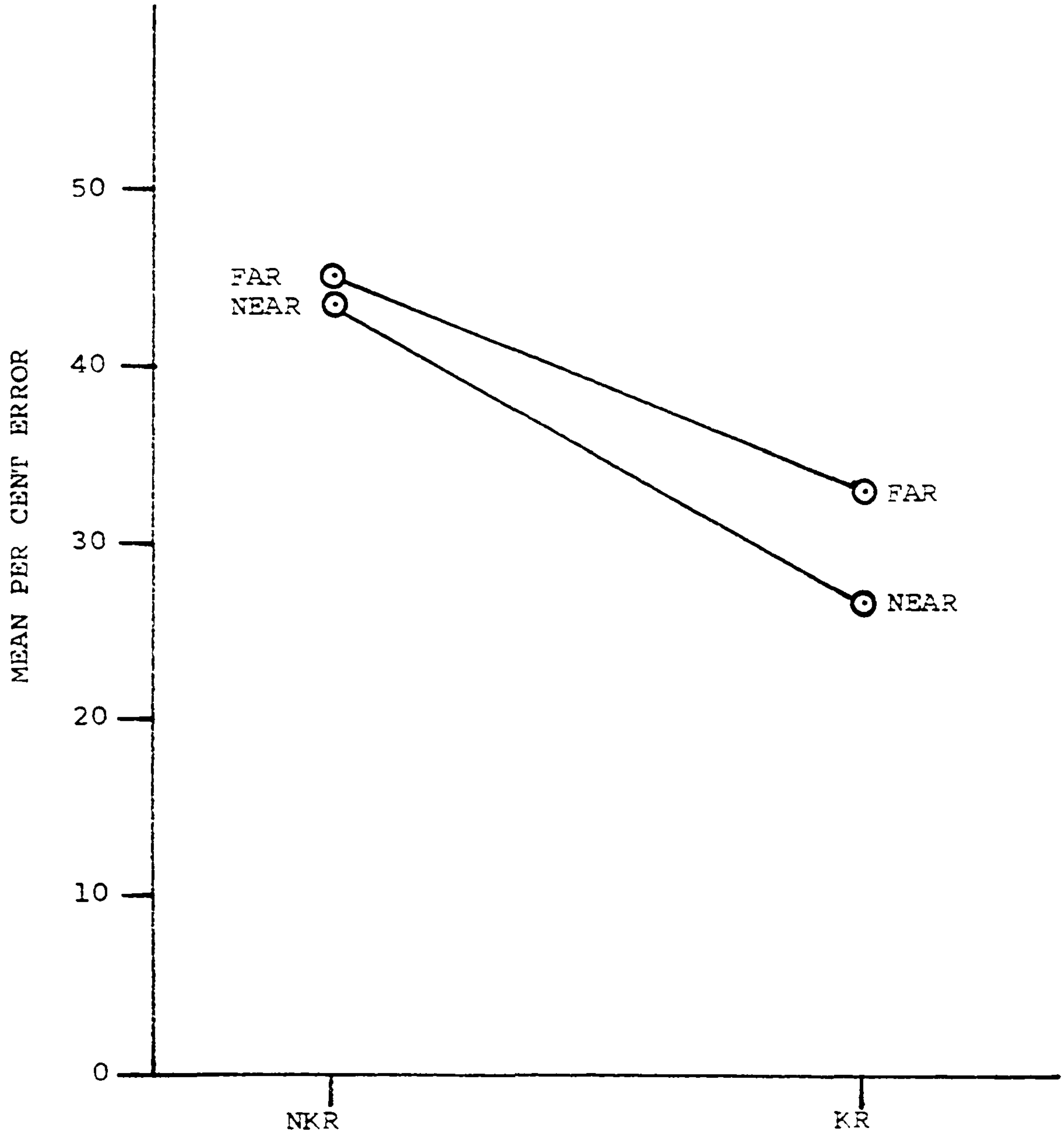

Fig. 3. The knowledge of results x distance interaction.

ing to note that there is no statistically significant difference between the mean error scores of the near and far distance in the NKR condition (t=1.00, df=468; $p > .05$), while there is a significant difference between the near and far distance error means for the KR condition (t=3.89, df=468; $p < .001$).

The graphing of the knowledge of results x speed interaction (Figure 4) suggests that the fastest speed (12 in./sec.) was not as affected, in the direction of lowering the mean error score, by the KR condition as was the low (4 in./sec.) and intermediate (8 in./sec.) speeds. From Figure 4, it can be seen that, although there is a consistent decrease in mean error score as speed increases in the NKR condition, in the KR condition the 12 in./sec. speed has a slighly higher mean error score than the 8 in./sec. speed. This would suggest that the effect of the KR treatment in reducing the mean error score was greater at the two lower speeds than it was at the highest speed. Support of a statistical nature for this interpretation is provided by various t tests between the levels of speed involved. t tests run between the three levels of speed in the NKR condition revealed statistically significant differences in pairings of the 4 and 8 in./sec. speeds (t=6.19, df=312; $p < .001$), 4 and 12 in./sec. speeds (t=9.33, df=312; $p < .001$), and 8 and 12 in./sec. speeds (t=2.09, df=312; $p < .05$). The same pairings in the KR condition yielded

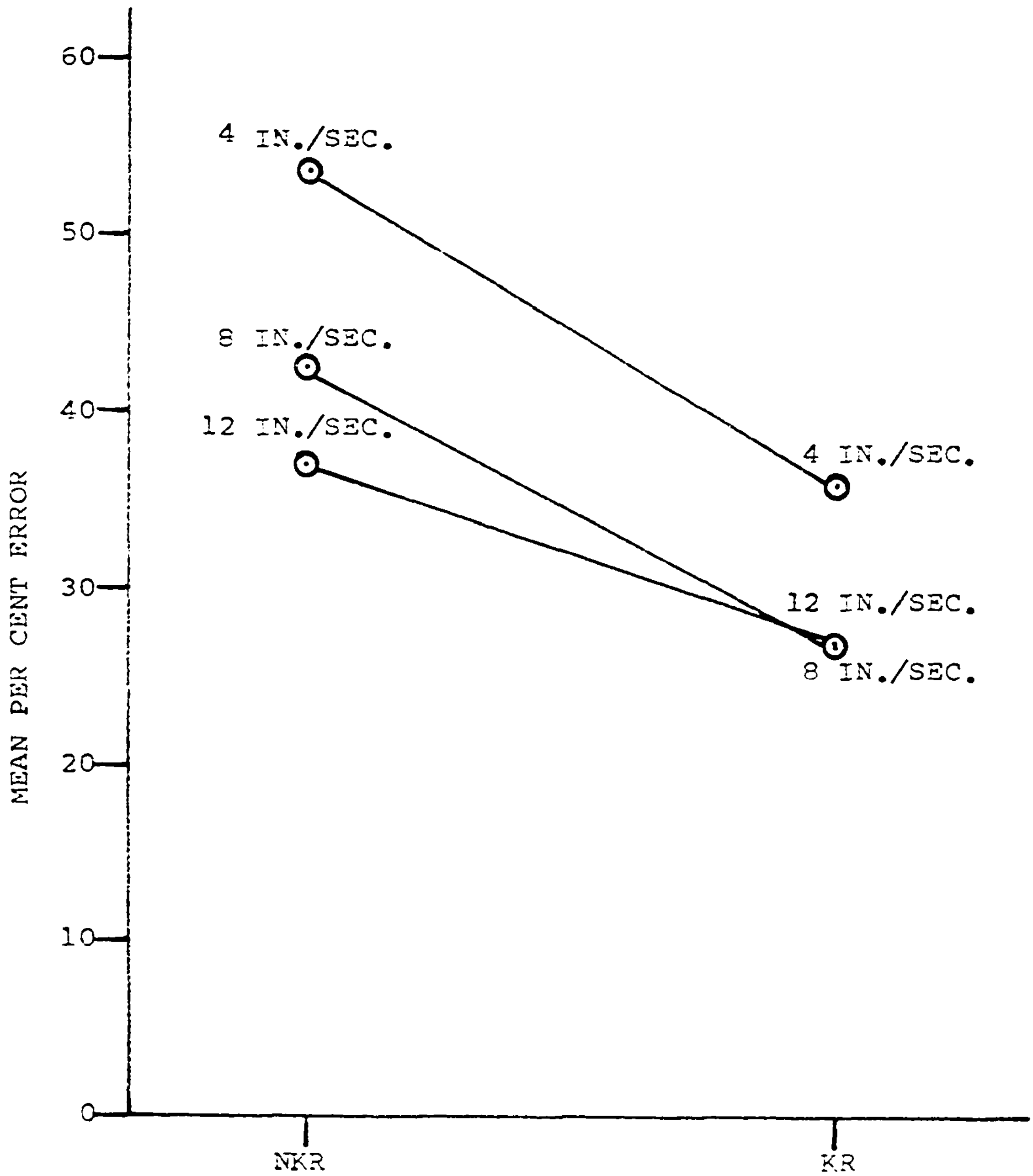

Fig. 4. The knowledge of results x speed interaction.

slightly different findings, in that statistically significant differences were found in the 4 and 8 in./sec. pairing (t=4.64, df=312; $p < .001$) and in the comparison of the 4 and 12 in./sec. speeds (t=4.07, df=312; $p < .01$); but, no statistically significant difference between the comparison of the 8 and 12 in./sec. speeds was found (t=0.06, df=312; $p > .05$).

The strength of the knowledge of results x temporal delay interaction, suggested by the large F value in the analysis of variance, is readily apparent in viewing the graphic presentation of this interaction in Figure 5. It can be seen from the graph that, although the 3 second delay had the lowest mean error score in the NKR condition, the situation was reversed in the KR condition; ie., the 3 second delay was associated with the highest mean error score. It may be suggested that the KR condition had a greater effect in lowering the mean error scores of the 6 and 9 second temporal delays than it did in affecting the same change in the 3 second delay. Statistical support for this assumption is provided by the finding that there is no statistically significant difference between the mean error scores of the 3 second delay for the NKR and KR conditions, while differences between the mean error scores of the 6 second delay at the two levels of knowledge of results (t=12.44, df=312; $p < .001$) as well as the 9 second delay (t=11.21, df=312; $p < .001$) proved to be statistically significant.

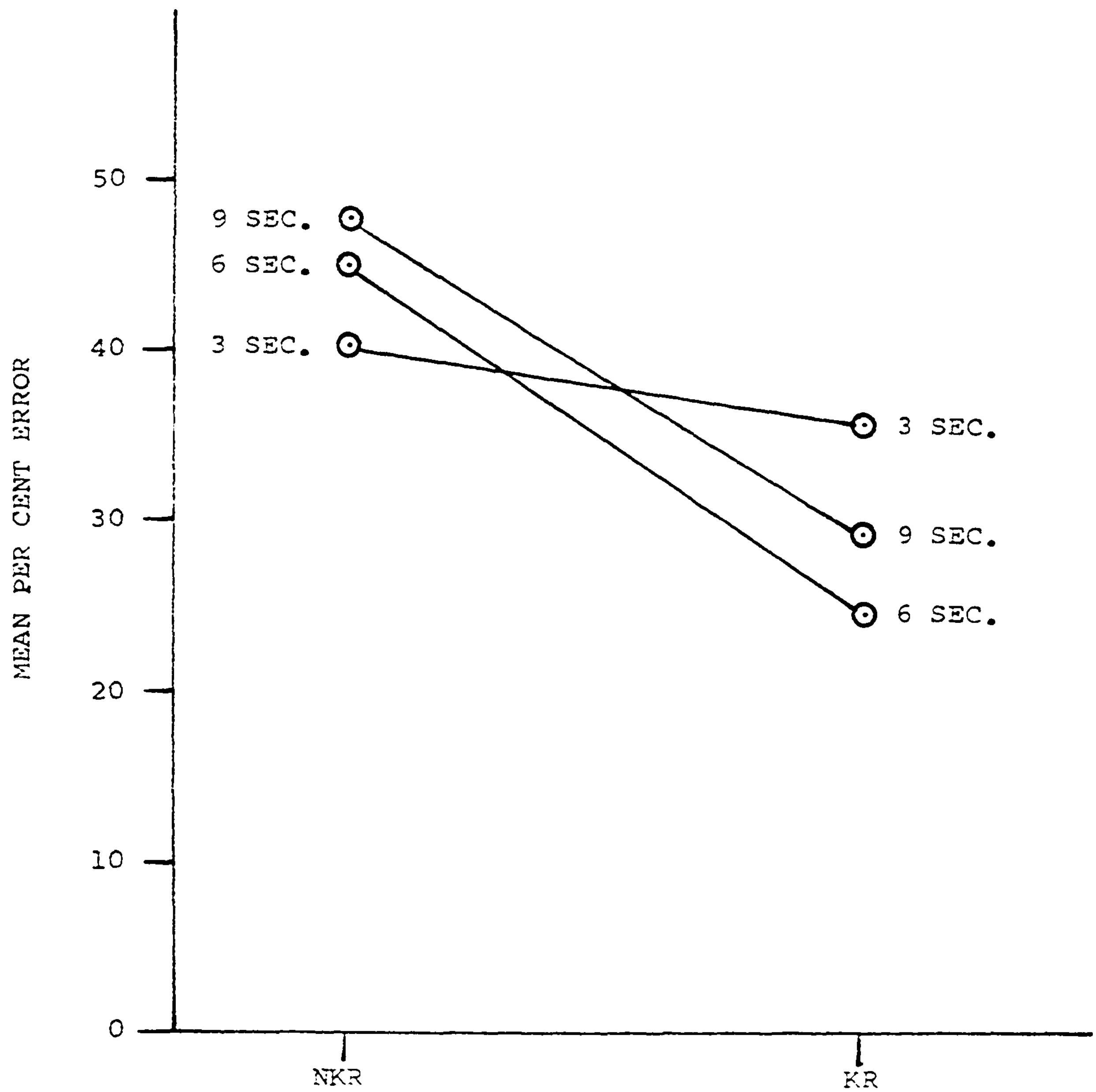

Fig. 5. The knowledge of results x temporal delay interaction.

DISCUSSION

The purpose of this experiment was to examine the effects of five variables: knowledge of results, distance, gradient, target speed and temporal delay, upon accuracy of performance in a prediction motion task. A major difference between this study and many others reported in the literature was that the motion being predicted was motion in depth rather than forms of lateral motion.

The findings of the experiment would seem to leave little doubt about the confirmation of the hypothesis that the KR condition would result in significantly greater accuracy of predicting the target arrival at the position of the standard than the NKR condition. Statistical significance of the knowledge of results main effect ($F=31.02$, $df=1, 50$; $p < .001$) was revealed by the analysis of variance. An examination of the graph of the knowledge of results main effect (see Fig. 2) indicates that the main effect was caused by the significantly lower mean error score of the KR condition as compared to the NKR condition. The KR condition resulted in a lower mean error score than that of the NKR condition. This finding would confirm, to some extent, the affect of knowledge of results on velocity perception as reported by Biel and Brown (1949).

It had been hypothesized that the intermediate level of target speed would result in greater task accuracy than either the high or low speeds. This hypothesis must be rejected. Although target speed was shown to be a significant main effect by the analysis of variance (F=36.38, df=2, 100; $p < .001$), the graph portraying the main effect of speed (see Fig. 2) shows that as target speed increased, accuracy of performance in the experimental task increased. A comparison of the over-all differences in mean error scores between the three levels of speed indicated that most of the differences in accuracy caused by the speed main effect, resulted from a difference between the effects of the slowest, or 4 in./sec. speed, and the effects of the two faster speeds of 8 and 12 in./sec. An examination of the knowledge of results x speed interaction, shown to be statistically significant by the analysis of variance (F=3.36, df=2, 100; $p < .05$), yields additional information related to the speed main effect. An examination of the differences between the three levels of speed in the NKR condition showed statistically significant differences between comparisons of the mean error scores for the 4 and 8 in./sec. speeds, 4 and 12 in./sec. speeds, and the 8 and 12 in./sec. speeds. The same comparisons, when examined in the KR condition, yielded statistically significant differences between the mean error scores for the 4 and 8 in./sec. speeds and the 4 and 12 in./sec. speeds; however, no statistical significance was found between the difference in the mean error scores for the 8 and 12 in./sec. speeds.

This would seem to indicate that the significant difference between the mean error scores of the 4 in./sec. speed and the 8 and 12 in./sec. speeds respectively, as shown to exist in the speed main effect, was, to a large extent, determined by the difference between these speeds in the KR condition.

The results of the experiment were in support of the acceptance of the hypothesis that the intermediate level of temporal delay would result in greater task accuracy than either the shorter or longer temporal delays. The analysis of variance indicates that the temporal delay main effect significantly affected the accuracy of predicting the arrival of the target at the standard (F=4.04, df=2, 100; $p < .05$). The over-all view of the temporal delay variable, depicted by the graph of the three levels within the main effect (see Fig. 2), shows that the intermediate, or 6 second delay, resulted in a lower mean error score than the 3 and 9 second temporal delays. When the differences between the mean error scores for the three temporal delay levels were compared, it was found that the 6 second delay was significantly different from the 3 and 9 second delays, while there was no statistically significant difference between the mean error scores of the 3 second delay and the 9 second delay. This would support the observation that the main effect was a result of the difference between the effects of the 6 second delay from those of the 3 and 9 second delays. An examination of the knowledge of results x temporal delay interaction provides a further insight into this aspect of the temporal delay main effect. It can be seen from the graph of the knowledge of results x temporal delay interaction (see Fig. 5) that the 6 second temporal delay resulted in an intermediate mean error score from the three levels of temporal delay in the NKR condition, whereas it was associated with the lowest mean error score for the three temporal delay levels in the KR condition. It should be noted that the differences between the mean error scores of the three levels of temporal delay were found to be statistically significant in both the NKR and KR condition. Thus, when the levels of temporal delay are examined across the two conditions of knowledge of results, the 6 second temporal delay was found to give the lowest average mean error score for the two knowledge of results levels. Such an examination would, in effect, be the equivalent of examining the levels within the temporal delay main effect. Support would hence be provided for considering the finding that the 6 second temporal delay resulted in the lowest mean error score to be largely a consequence of the knowledge of results x temporal delay interaction.

One of the basic purposes of this experiment was to compare the relative effects of the temporal delay and target speed variables in determining the accuracy with which the prediction motion task could be performed. The literature in the area definitely pointed in the direction of emphasizing the dominance of the temporal aspect of stimulus events in determining this type of performance (Dembitz, 1927; Gerhard, 1959; Gottsdanker, 1957; and Morin et al, 1956). The results of this experiment would seem to suggest that such findings cannot be generalized to explain the data in the present experimental situation. Thus, the hypothesis that temporal delay would result in a comparatively greater effect in determining accuracy of predicting target arrival at the standard must be rejected. An examination of the mean error scores within each of the levels of the main effects of speed and temporal delay (see Fig. 2) indicates that relatively much larger differences in mean error scores resulted from the three speed treatments than for the three temporal delay treatments. It must be remembered, however, that the statistically significant F value for the mean error scores related to the temporal delay main effect, indicated by the analysis of variance, cannot be considered to have conclusively indicated that a significant effect of temporal delay existed in this experiment. This is because the temporal delay main effect in the experiment is confounded with the target distance from the standard. This would mean that the temporal delay main effect could have no greater effect than that indicated in the analysis of variance, but there is a possibility that it had less than the indicated effect. Such a situation would become clarified if the effects of target distance to the standard could be partitioned out. This cannot be accomplished, but reports of previous research indicate that target distance to the standard does significantly affect accuracy of performance in a prediction motion type task (Gerhard, 1959; Slater-Hammel, 1955; and Morin et al, 1956). Thus, it would seem that there is evidence that the effect of the temporal delay variable was caused by a combination of the effects of both temporal delay and target distance from the standard. Since the experimental effect of temporal delay was indicated by the analysis of variance to be statistically significant by only a small margin, it is possible that there would have been no significant temporal delay main effect had either temporal delay or target distance to the standard operated alone. This would strengthen the case for the rejection of the experimental hypothesis concerning the comparative effects of temporal delay and target speed as well as the interpretation that the target speed variable was, to a comparatively greater degree, more instrumental than temporal delay in affecting the accuracy of task performance.

The analysis of variance indicated that there was a statistically significant effect for distance (F=10.89, df=1, 50; $p < .01$). The graph of the two levels within the distance main effect (see Fig. 2) points out that the hypothesis that the near distance condition would result in a lower mean error score than the far distance condition was confirmed. An examination of the knowledge of results x distance interaction, indicated to have been statistically significant ($\underline{F}$=4.09, df=2, 100; $p < .05$), provides some insight into the nature of the significance of the distance main effect. Such an examination points out that, while there was no statistically significant difference between the mean error scores of the near and far distance conditions in the NKR treatment, there was a statistically significant difference between these two levels of distance in the KR condition. It should be mentioned that, in both the NKR and KR conditions, the near distance resulted in a lower mean error score than the far, although the difference between the two distance conditions was significant only in the KR condition. This would suggest that the significance of the distance main effect was, to a large extent, determined by the knowledge of results x distance interaction. Thus, the manipulation of distance did not independently affect accuracy of task performance in itself, but resulted in bringing about a differential increase in accuracy through the presence of knowledge of results.

The hypothesis that the high gradient condition would result in greater accuracy in the experimental task than the low gradient condition must be rejected. Although the experimental main effect of gradient was shown by the analysis of variance not to be statistically significant ($\underline{F}$=0.66, df=1, 50; p$>$.05), it should be noted that the high gradient condition resulted in a slightly lower mean error score than did the low gradient condition. It had been expected that the use of the high gradient condition would have provided the Ss with more cue information on relative depth changes of the target as well as information on the depth of the standard. Such information would have been useful in increasing the accuracy of the Ss' performance. There are at least two possible explanations for the finding that gradient resulted in no statistical effect on task accuracy. The first is based on the physical properties of the gradient employed. The gradients were apparently inadequate in providing cue information in the experimental situation. By this it is implied that the selected size or colors of the experimental gradient did not facilitate its use as an effective information-providing cue within the range of distances and speeds presented in the tunnel. It must also be remembered that during the brief 3 second interval in which the stimuli were viewed, the Ss were being presented with information from many other sources besides gradient; some of these could well have been more dominant than information provided by changes in gradient. A second possible explanation is that the manipulation of the gradient variable has no effect on accuracy of performance in the experimental task or under the conditions presented by the experimental situation.

The results of the experiment indicate that knowledge of results operated to cause a relatively large and statistically significant increase in accuracy of performance in the experimental task. As well, it entered into statistically significant interactions which affected task accuracy that resulted from the distance, speed, and temporal delay main effects. A description of the apparent mechanism by which knowledge of results operated to cause these effects is, therefore, pertinent to the interpretation of several of the experimental findings. Such a description has its basis in the two components of information that knowledge of results in the present experiment explicitly provided to the Ss: information on the magnitude of his error and the direction of his error. This description of the apparent mechanism through which these two components of knowledge of results operated is dependent upon a conceptualization of the experimental situation as it appeared to the Ss. Such a conceptualization can be inferred from the performance of the Ss in the NKR condition, where knowledge of results did not operate to alter the Ss' conception of the experimental task. The 44.1% mean error score found in the NKR condition indicates that the Ss were having great difficulty in accurately predicting the arrival of the target at the standard. An examination of the direction in which this error was being made provides information on one of the causes of this large mean error score for the NKR condition. The Ss in the NKR group demonstrated remarkable consistency in undershooting the standard. The 26 members of the NKR group cumulatively allowed the moving target to overshoot, or move past, the standard in only 87 of the 936 total trials that the group received. An overshoot occurred on only 9.3% of the trials received by the NKR group. This would either mean that Ss were either consistently overestimating the target speed, or were consistently underestimating the distance that existed between the target and standard at the point at which the target and standard were last visible. It would seem that the latter explanation was more responsible for the consistent undershooting of the standard in the present experiment. Evidence for this is provided by the responses of the Ss when they were asked by the E to estimate the distances involved in the experimental situation. Many Ss reported that the target was, at its furthest point, from 12 to 15 feet away from their viewing point. Ss were consistent in underestimating the actual absolute and relative distances involved in the target and standard positioning. This finding is quite plausible, since the homogeneity of the tunnel environment, the lack of previous experience with the target and standard stimuli, and the brief exposure time, made judgment of the absolute and relative depths at which the stimuli were positioned a difficult task. It was this difficulty that was evident in the large mean error scores arising in the NKR condition. It can be concluded from the Ss' reports, that, when observed through the viewing door, the target and standard stimuli appeared to be considerably closer in depth than the actual physical distances involved. The Ss' reports also implied that the same effect was evident in the perception of the relative differences in depth that determined the distances between the target and standard. Such target-to-standard distances appeared to also be shorter than the actual physical dimensions. It would seem that the measured responses of the Ss confirm the verbal reports indicating an underestimation of the distances involved in the experimental situation. This would suggest that the stimulus and/or environmental deficiences in cue-provided information on depth resulted in judgments of the perception of actual depth which were faulty, and in an inaccurate conception of the distances essential to the accurate performance of the experimental task.

Since the NKR Ss were never given any feedback on their performance, they continued, through all their trials, to make task-related judgments based on what would appear to be an inaccurate conception of the distances involved. Those in the KR group, however, quickly learned from the feedback information provided by the two components of knowledge of results, that their initial conception of the distances in the task were inaccurate. On their initial trials the KR Ss made underestimation errors similar to those made by the members of the NKR group. The components of knowledge of results describing the direction and magnitude of their errors provided the Ss with information on the degree and consistency with which they were underestimating the distances between the target and the standard. Such information probably provided the basis for the learning of a different conception of the distances involved in the experimental situation. Evidence for this is indicated by the observation that the 26 Ss in the KR group cumulatively allowed the target to overshoot the standard in 340 of the 936 total trials presented. This means that overshooting of the standard occurred on 36.3% of the trials received by the Ss in the KR group as compared to the 9.3% overshooting that occurred in the NKR group.

In addition to the evidence that the conception of distances involved in the experimental situation were qualitatively different in the KR as compared to the NKR condition, there is also evidence supporting the notion that the modified conception of distance caused by knowledge of results was more accurate. This is provided by the finding that the mean error score in the KR condition was 29.7%, as compared to the 44.1% mean error score for the NKR condition. Since the underestimation of distance in the experimental situation was undoubtedly one of the major sources contributing to error in the Ss' performance in predicting the target arrival at the standard, the decreasing of this underestimation must be considered as one of the basic mechanisms by which knowledge of results increased task accuracy. It should be noted, however, that even in the KR condition there remained a rather large mean error score that provided evidence of the difficulty of the experimental task in the situation presented. This would seem to suggest that there existed an irreducible and ever-present error in the performance of the experimental task. This irreducible error probably is defined by the limitations in the capabilities of the Ss to perform beyond some given level of accuracy under the conditions provided by the experimental situation and task.

In an earlier discussion of the speed main effect evidence was presented which indicated that the significant differences between the mean error scores of the 4 in./sec. speed and the 8 and 12 in./sec. speeds respectively were, to a large extent, determined by the differences between these speeds in the KR condition. This was based upon an examination of the effects of the knowledge of result x speed interaction. A closer look at this interaction provides information on a possible mechanism that operated to result in the significant difference between the 4 in./sec. speed and the 8 and 12 in./sec. speeds. A comparison of the three target speeds in the NKR condition points out that mean error decreased as the speed increased, with statistically significant differences between each of the three target speeds, although the largest difference was, in fact, between the 4 in./sec. speed and the 8 and 12 in./sec. speeds. In the KR condition approximately equal and significant decreases were found in the mean error scores of the 4 and 8 in./sec. speeds from the mean error scores of the 4 and 8 in./sec. speeds in the NKR condition. However, the decrease in the mean error score of the 12 in./sec. speed in the KR condition, from the mean error score of the 12 in./sec. speed in the NKR condition, although significant, was considerably less. It is important to note, however, that there was no longer, in the KR condition, any statistically significant difference between the mean error scores of the 8 and 12 in./sec. speeds, although there was a large and significant difference between the mean error scores of the 4 in./sec. speed and the 8 and 12 in./sec. speeds, respectively. These findings are important for two reasons. First, as indicated earlier in the discussion, it would seem to suggest that most of the effect of levels of speed as reflected in difference between the mean error scores resulted from or were dependent upon the effects of the KR condition. In light of this finding, a more accurate reflection of the actual effects of speed on error in performance stems from an examination of the three target speeds in the NKR condition. Secondly, these findings would offer a possible explanation for the seeming inability of knowledge of results to affect a decrease in mean error score of the 12 in./sec. speed equal to that occurring for the 4 and 8 in./sec. speeds. Such a mechanism lies in the suggestion that an asymptote for the affect of knowledge of results in reducing error of performance may have been reached at or near the fastest (12 in./sec.) speed. Such an asymptote for accuracy of performance is probably defined by limitations in the perceptual capabilities of the Ss in the experimental situation. This asymptote would represent the irreducible and ever-present error in the performance of the experimental task, mentioned earlier in the discussion, for each of the three levels of speed. Thus, knowledge of results could not affect as large a decrease in the mean error score for the 12 in./sec. speed as it did in the 4 and 8 in./sec. speeds simply because, as indicated in the NKR condition, the lower mean error score of performance at the 12 in./sec. speed was already close to a presumed asymptote. In such a situation it would be the limiting properties of the asymptote that was evidenced by the interaction, rather than a diminishment of the effects of knowledge of results upon performance with increasing speed. Thus, it would seem that the relationship of target speed to accuracy of task performance is closer to the description presented in the NKR condition, in that, as speed increased, accuracy of performance at the experimental task also increased.

A basis for the above relationship is probably to be found in the differences in the amount of task related information each speed provided to the Ss. There is little doubt that in the brief 3 second viewing time the Ss were permitted for each of the three target speeds, information pertinent to accuracy of task performance increased as the target speed increased. This is primarily a result of the varying distances traversed by the target for three speeds in the same time interval. Since the distance traversed varied directly with speed, there was also with increasing speed, an increase in the rate of change in cues for the differences in the relative depth of the target from its initial appearance to its disappearance. As the magnitude and rate of change of these cues increased, more information on the changes in relative depths were provided to the Ss. Thus, the 12 in./sec. speed had provided more information on the relative depths involved; i.e., the distances between target and standard. With increased information on the depths associated with the task the Ss could be more accurate in their predictions of the target arrival at the position of the standard. It can be reasonably assumed that the magnitude of change of cues related to relative depth resulting from the 4 in./sec. speed were closer to the threshold of detection for such changes than was the situation for the two faster speeds. Because the cue changes for the 4 in./sec. speed were closer to the detection threshold, the probability of the Ss discriminating such changes and using any depth information from these discriminations was diminished. This deficiency of the 4 in./sec. speed, as compared to the 8 and 12 in./sec. speeds, in providing information on the changes in the depth of the target, may have resulted in the relatively larger difference between the mean error scores of the 4 in./sec. and the 8 in./sec. speed when compared to the difference in mean error scores between the 8 in./sec. speed and the 12 in./sec. speeds, in the NKR condition.

When the temporal delay main effect was discussed, evidence was provided which indicated that this main effect was determined primarily by the differences between the mean error score of the 6 second delay and the 3 and 9 second delays. Support was also provided for regarding these differences between the levels of delay as being determined, to a large extent, by the knowledge of results x temporal delay interaction. A closer examination of the knowledge of results x temporal delay interaction provides additional information pertinent to an interpretation of the effects of the temporal delay variable. In viewing the graph of the knowledge of results x temporal delay interaction (see Fig. 5), it becomes evident that the interaction resulted from the inability of knowledge of results to significantly lower the mean error score for the 3 second delay from the level obtained in the NKR condition. It can be noted that in the NKR condition there were significant decreases in the mean error score as the length of the temporal delay increased. Increasing temporal delay has been reported by previous researchers to result in a similar decrease in accuracy of performance in prediction tasks involving lateral motion (Gottsdanker, 1957; Gerhard, 1959; Slater-Hammel, 1956; and Morin et al, 1956). The 3 second temporal delay resulted in the lowest mean error score in the NKR condition. In the KR condition this relationship was not evidenced; the mean error score of the 3 second temporal delay was significantly larger than both the 6 second delay, which had the lowest mean error score, and the 9 second delay, which had an intermediate mean error score. There is some information which would indicate that, although there was no statistically significant difference in magnitude of the mean error scores between the 3 second delay in the NKR condition and in the KR condition, there was a difference in direction of these errors. Since the 3 second temporal delay always represented the shortest target-to-standard distances, the possibility of overshooting the standard was more likely in this delay condition than in the other two delay conditions. In the NKR condition there were more overshoots involving the 3 second temporal delay than in the 6 and 9 second delay conditions combined. Although the number of overshoots in each of the three levels of temporal delay was increased by almost four-fold in the KR condition, the relative distribution of the number of overshoots across the three levels remained approximately the same. In the KR condition there still remained more overshoots involving the 3 second temporal delay than in the other two delays combined. Errors involving overshoots occured on 58.9% of the trials involving the 3 second temporal delay in the KR condition as compared to 13.8% of the trials in the NKR condition. This would tend to suggest that Ss were making errors, under the KR condition, almost equally on either side of the standard. Because an absolute error measure was used in this experiment, it did not reflect the fact that errors in the KR condition were now being made on either side of the standard at about a 6:4 ratio. In any case, the errors being made in the KR condition, although different in the proportionality of direction from those in the NKR condition, were not significantly different in magnitude from those made in the NKR condition. One needs to note that the variance associated with the mean error score of the 3 second temporal delay in the KR condition was almost double that of the variance of the same delay period in the NKR condition. In the case of the other two delay conditions variance decreased by over one third across the NKR and KR conditions. This may suggest that the Ss in the KR condition were attempting to compensate for their errors by utilizing feedback for the 3 second temporal delay, but were unable to demonstrate any consistency in their performance. It is possible that this lack of consistency in performance can be interpreted as an indication of the difficulty the Ss had in such an attempt. The 3 second temporal delay and the target distances to the standard associated with it, may well have been too brief and too short, respectively, to allow the Ss to apply any information provided by knowledge of results to a reduction of their errors in prediction. The high variance associated with the mean error score of the 3 second temporal delay in the KR condition may then be interpreted as an indication of the Ss' unsuccessful attempt to utilize the feedback on his performance that was being provided by the E.

An explanation of why the present study did not demonstrate the dominance of a temporal aspect in prediction performance as reported in the literature exists in the basic difference between previous experimental situations and the present one. This experiment involved the prediction of motion in depth while those reported in the literature involved lateral motion of a horizontal, vertical, or angular nature. It would seem rather obvious that the accurate judgment of distance is an important element affectting the accuracy of performance in any prediction motion task. The fact that the judgment of distance is more difficult in depth than laterally is also fairly evident. This is evidenced by the larger mean error scores obtained from the present experiment in comparison with those generally reported in the literature. Gottsdanker's (1952a, 1952b) experiments yielded mean errors of from 15 to 20%. Slater-Hammel (1956) reported errors ranging from 4 to 21%. Morin _et als_' (1956) finding of errors ranging from 22 to 53% are more in line with the 17 to 58% error range found in the present experiment. Because of the difficulty in distance perception encountered in the present experimental situation, it is plausible to assume that the _S_s may have had to resort to a different type of "prediction equation" than they would have used in a situation where distance was more easily perceived. In a prediction situation where lateral motion is presented, the relationship between the factors of speed and distance are more directly perceived. In such a case it would be possible for the _S_s to integrate the information presented by these factors into a single conceptual form. Thus the information on the target arrival at the standard provided by speed and distance may be integrated into a concept represented by some temporal interval. This would explain the finding of the dominance of the temporal aspect of stimulus events in determining prediction motion behavior in previous research. The difficulty that the Ss experienced in obtaining distance information may have prevented such an integration from taking place in the present experiment. The Ss would then be forced to utilize a simpler and more elementary "predictive equation" based upon the information that was most readily available. Such information would probably be provided by the differences in the experimental speeds. As a result of this, the speed variable would be a more effective determinant of the accuracy at which the present task was performed than the temporal delay variable.

Of all the findings of the present study, the effect of knowledge of results on performance would seem to offer the most potential value for future study. It would seem that, although people have been making predictions of objects moving towards them for most of their lives, they have not yet reached an asymptote in ability to improve prediction performance in such situations. The fact that such learning is possible has been strongly indicated by the results of the present experiment. The practical implications of this finding have importance in a wide range of activities that occur with varying frequency in everyday life, from the driving of an automobile on a crowded highway to the rendezvous and docking of two space ships.

SUMMARY

The purpose of the present study was to examine the effects of five variables: knowledge of results, distance, stimulus gradient, target speed, and temporal delay (a measure of the temporal relationship between the target and standard) on the accuracy with which the Ss could predict the arrival of a moving target stimulus at the position of a stationary standard stimulus. The present study was different from most reported in the literature because the motion being predicted was motion in depth rather than any of the various forms of lateral motion.

The study was essentially a 2 x 2 x 2 x 3 x 3 factorial experiment with repeated measures on the last 4 factors. Each of the 52 Ss was randomly presented with 36 experimental trials representing the 36 possible combinations of the near and far distance conditions, the 4, 8 and 12 in./sec. speeds; the 3, 6 and 9 second temporal delays; and either the knowledge of results or no knowledge of results condition, depending upon which of the two groups he had been assigned. An absolute per cent error score based on the actual distance of the target from the standard at their last viewing by the S was used to measure errors of prediction on each trial.

The results of an analysis of variance on the data obtained indicated the variables of knowledge of results,

distance, speed, and temporal delay to have statistically significant effects; but no statistical significance was indicated for effects of the gradient variable. Three statistically significant interactions were also indicated: knowledge of results x distance, knowledge of results x speed, and knowledge of results x temporal delay.

An examination of the significant main effects yielded the following findings:

(1) The KR condition resulted in a 33% lower mean error score than the NKR condition.

(2) Accuracy of task performance increased as target speed increased. Thus, in the three levels of speed, the 12 in./sec. speed resulted in the lowest mean error score, the 8 in./sec. speed resulted in an intermediate error score, and the 4 in./sec/ speed resulted in the highest mean error score.

(3) The 6 second temporal delay resulted in greater task accuracy than the 3 and 9 second temporal delays.

(4) The near distance condition resulted in a lower mean error score than the far distance condition.

Evidence was provided which indicated that the three statistically significant interactions involving knowledge of results determined, to some extent, the nature of the significant differences between the levels within the main effects of distance, speed, and temporal delay.

The dominance of the temporal aspect in prediction motion performance reported in previous literature was not noted in the present experiment.

It was suggested that the finding of the effects of knowledge of results on the accuracy of prediction motion in depth has practical implications that warrant further investigation.

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APPENDIX

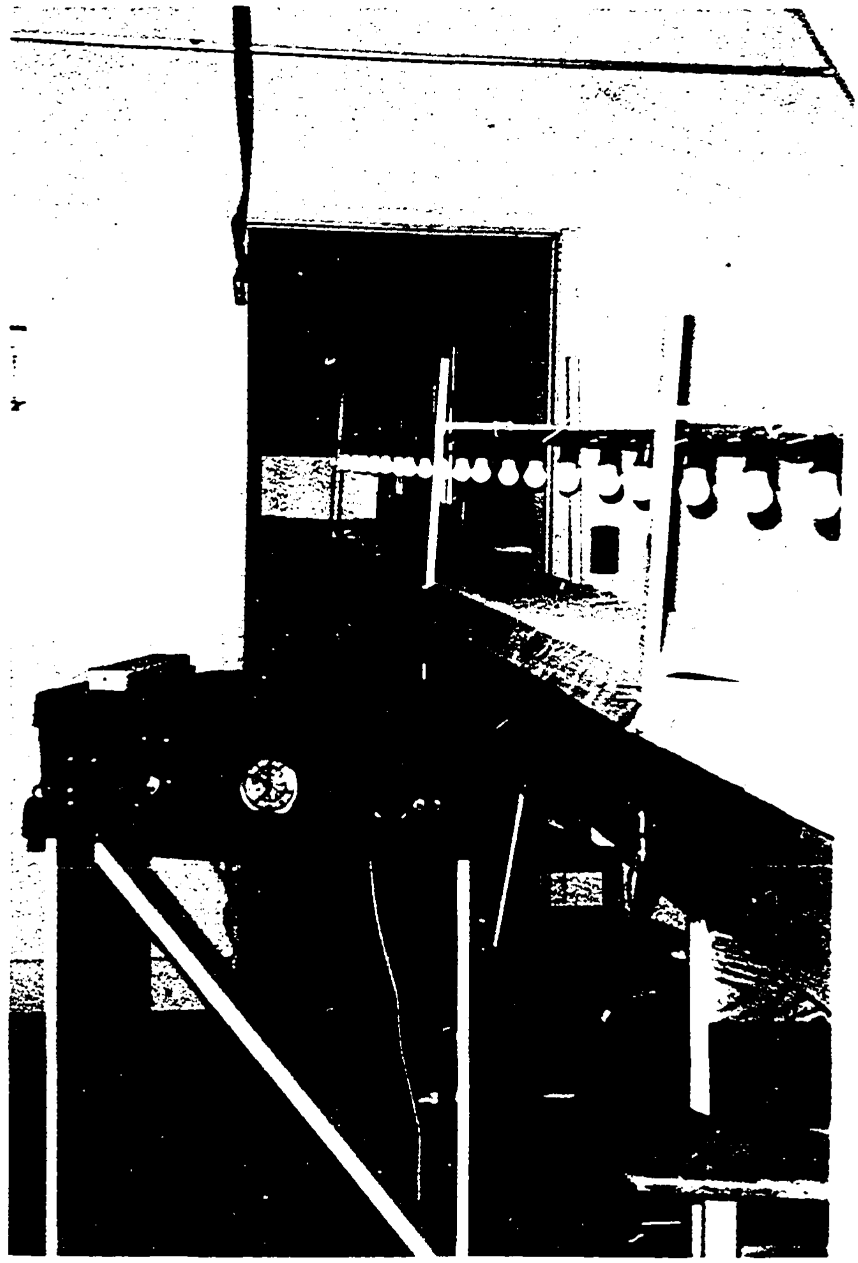

Photo. 1. A view of the tunnel, lighting system and control panel.

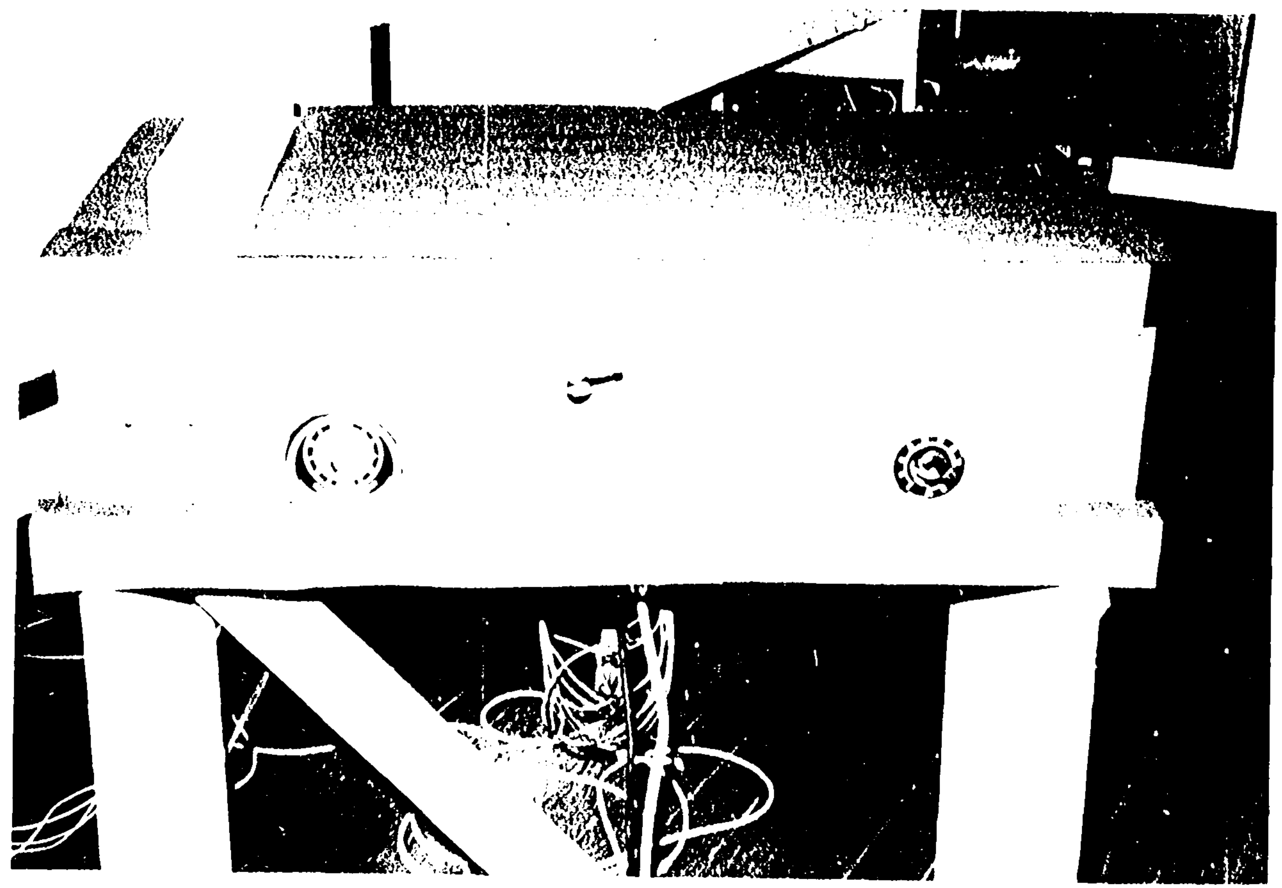

Photo. 2. A close-up view of the control panel.

Photo. 3. A subject looking through the viewing aperture.

Photo. 4. The target and standard stimuli as seen through the viewing aperture.

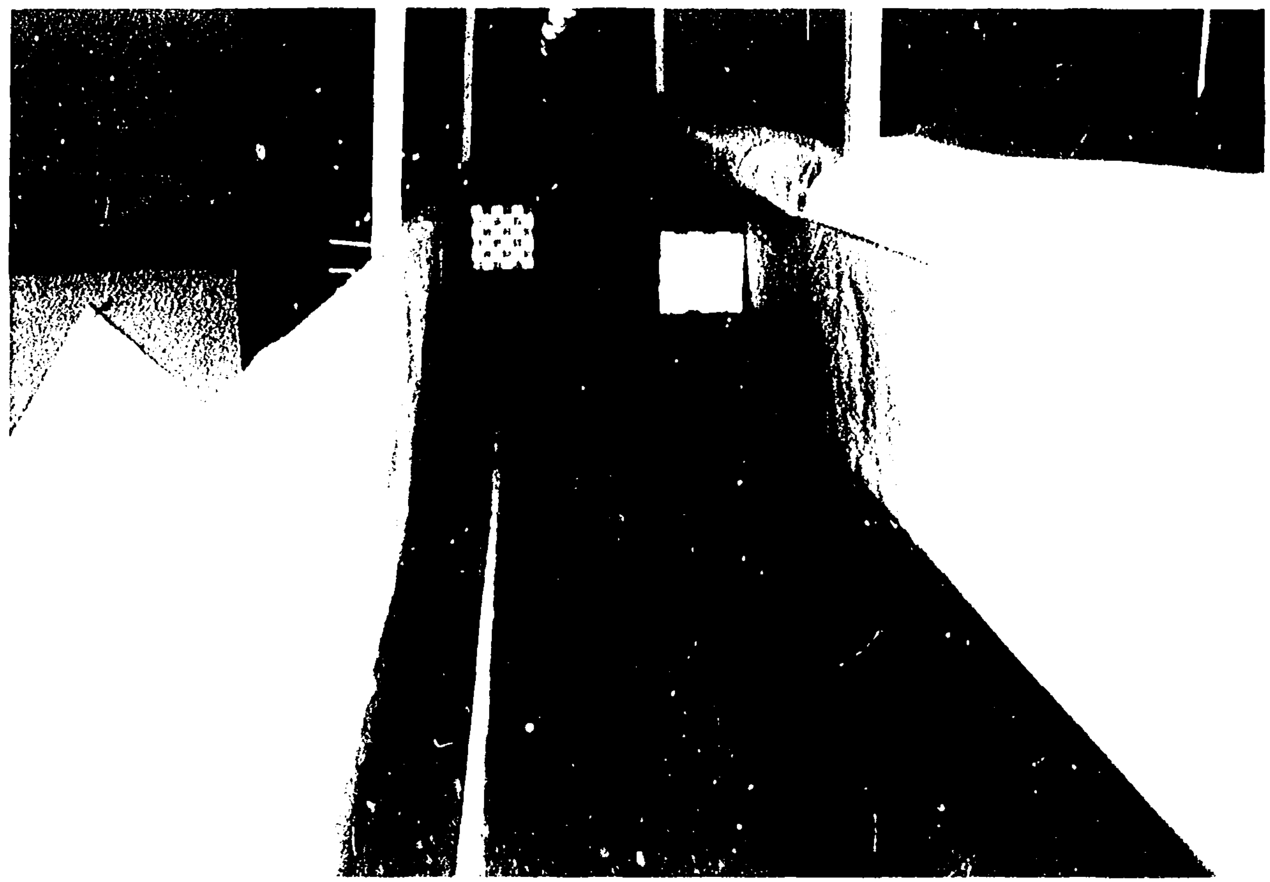

Photo. 5. A view of the target and standard stimuli with the tunnel roof opened.