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DIFFERENTIAL VELOCITY AND TIME PREDICTION OF MOTION

By

Kent A. Kimball
Mark A. Hofmann
Richard O. Nossaman

April 1972

U. S. ARMY AEROMEDICAL RESEARCH LABORATORY

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ABSTRACT

This investigation examined the effects of differential target velocity, horizontal or vertical plane conditions and air traffic controller experience on the intersection time estimation accuracy of two converging targets. Performance accuracy on this task was not significantly affected by horizontal or vertical conditions nor by air traffic controller experience. However, accuracy in magnitude and direction was found to significantly vary as a function of cursor speed with slower speeds producing the poorer performance. A differential effect for various speed combinations was also noted. Estimation accuracy on the slowest cursor speed when paired with the two faster speeds was decreased while accuracy on the intermediate speed was degraded when combined with either slower or faster speeds. Estimations on the fastest speed were not affected by differential pairings.

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INTRODUCTION

Time predictions about future positions of moving objects are made many times a day by virtually everyone. Of these predictions, perhaps the most important are those made about controllable moving objects having a common intersection point with other objects. This situation can involve a moving object having a point of intersection with a fixed body, or two moving objects having a common intersection point. In either case, error in estimating the future positions of such objects, with respect to their point of intersection, can produce undesirable consequences. For example, in aviation where a collision is incorrectly judged to be eminent, the unnecessary implementation of avoidance procedures could create a situation which in itself would be hazardous. On the other hand, not recognizing a collision course can be of greater consequence. This error in judgment can result in the failure to initiate necessary corrective actions in time to avoid or lessen the severity of a collision and its resultant effects.

Since judgments about the future positions of objects with common intersection points are prevalent, and since errors in these judgments can be, and often are costly in both lives and property, it is highly appropriate that man's capacity to perform this function be investigated.

If accurate assessments are to be made of man's ability to predict intersection times, pertinent variables influencing this type of task must be explored. One such variable is velocity. Velocity will, for a given heading determine the future position of moving bodies. Thus, laboratory situations have been utilized which modify velocity in various ways and note the effects of such modifications on prediction performance.

Several general conclusions can be drawn from these laboratory investigations:

a. Absolute error of prediction decreases as speed increases. [2 5 6 7 11]

b. Variability of error in prediction increases with increased target velocity. [1 3 5 7]

c. Subjects tend to underestimate future target positions at high velocities and overestimate them at low velocities. [1 3 7]

Both the Kimball[7] and Gerhard[5] studies, referenced previously, utilized two target displays. Kimball used two inferred moving targets approaching a common intersection point at equal velocities on a given trial, but varied velocity across trials. This task was a monitoring task which required subjects to estimate target intersection time. Gerhard, on the other hand, used a tracking task with real moving targets. The subject's task was to adjust a variable speed target to intersect with a target which moved at a prescribed velocity for any given trial. It is evident that the results of these studies were in consonance with one another as well as with other investigations which used various one target displays and tasks. Thus, it would appear that this list of general conclusions is applicable to one or two target displays, real or inferred movement and tracking or monitoring tasks.

However, there is one important variable with respect to velocity whose possible effects on time estimation of motion were precluded by the designs of the above studies. This variable is differential velocity. Common to many intersection situations are two moving objects approaching each other at different speeds. If collision avoidance is of concern, a person must make independent estimates as to the future positions of both objects with reference to their intersection point. These estimates are based on the headings of the objects and the person's estimate of the two velocities involved. There is some evidence from studies conducted with static displays in which velocity was extrapolated, that this differential speed variable does have an effect. [8 9 10 12] The nature of this differential velocity effect on judgments made about dynamic targets still remains a question to be answered by research.

In addition to the effect of the differential velocity variable, little is known about the effect of occupation on time judgments. Some occupational groups may well be able to perform this function better than others. Accuracy of judgments may also be affected by the target vector's approach to the intersection point.

In an attempt to provide information relating to the resolution of these questions, this study investigated the effect of differential target velocity on time predictions of motion. Further, it permitted a comparison of the accuracy of judgments made utilizing horizontal and vertical target vectors. Finally, this investigation provided data on intersection time estimates from two potentially different populations.

METHOD

Subjects

Subjects for the present investigation consisted of twenty (20) males possessing normal or corrected vision. Ten of these subjects had an average of 11.5 years experience as air traffic controllers. The other ten had no controller experience.

Apparatus

The apparatus was an inferred movement display patterned after that utilized by Kimball[7] and Morin, et al[11]. This display consisted of a row and a column of lights mounted directly behind a 4' by 4' translucent panel (see Figure 1). Each contained seven lights spaced evenly along a distance of 16.5 inches. The last light in both the row and the column was mounted so that it was located 16.5 inches from an intersection point on the display. Thus, both the display distance for the lights and the concealment (no light) distance measured 16.5 inches, determining the 33 inches distances of inferred cursor movement. The column and row formed a 90° angle at the point of intersection. This point was designated by a light similar to those in the vector displays. The vector lights were programmed to flash on and off in serial order with one light being activated until the onset of the next light in the sequence. Perceived motion proceeded from right to left for the row and from the bottom to the top of the panel for the column of lights.

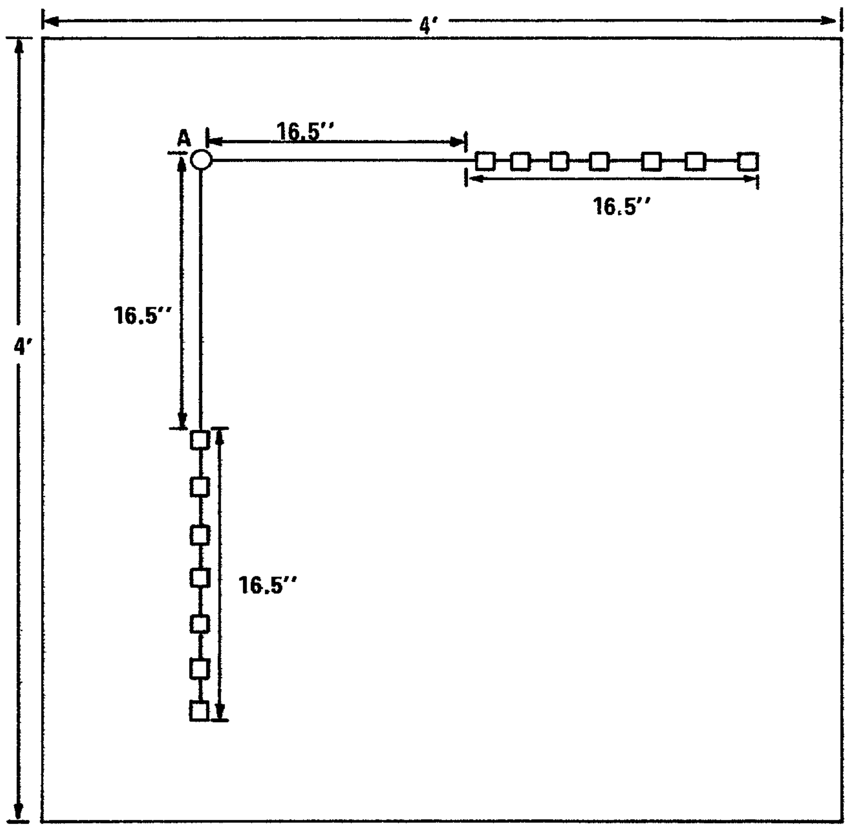

Figure 1

Schematic Front View of the Visual Display

The flash rate of the lights was varied, thus changing the speed of the perceived movement. The lights were programmed so that they traversed the 16.5 inch display distance in either 5.24 seconds, 1.31 seconds, or .66 seconds. Since the display subtended a visual angle of 5.25° at a distance of 15 feet, these respective speeds in terms of traversed visual angle were .91°, 3.61°, and 7.22° per second. Throughout the remainder of this paper these speeds will be referenced as speeds 1, 2, and 3 respectively. Apparatus instrumentation permitted the horizontal and vertical stimulus vectors to be operated independently on any combination of the three speeds specified above.

The subject's task consisted of pressing two microswitches, one response switch for the intersection time estimations of the horizontal target vector and the other for the vertical target vector. The subject activated the appropriate switch when he estimated its corresponding target cursor had reached the intersection point. After both response switches had been pressed, designating that an estimate had been made for each vector, the intersection point light was extinguished and the two judgment times were automatically recorded. An interval of three seconds was observed between trials. In the latter two seconds of this time interval, the intersection point light was again activated serving as a ready signal for the start of a new trial. The apparatus instrumentation made extensive use of a digital logic system for logic contingencies, time bases and data recording.

Procedure

Subjects were brought into a darkened test room and seated 15 feet in front of the display panel. A standard set of instructions was read to each subject. After the instructions were completed and all questions pertaining to the requirements of the task were answered, a pretest was administered. This pretest consisted of presenting one trial of each of the possible combinations of the two plane conditions and the three speeds. At the conclusion of the pretest, the experimental session was begun. This session lasted 20 minutes and included ten randomized presentations of each combination of the two planes and three speeds to each S. Thus, each subject was required to make a total of 180 judgments as to the arrival time of a target to the intersection point.

RESULTS

Performance was measured by error in time estimation. Time error measures derived and utilized in the analysis were:

a. Constant error (CE) scores comprised of the algebraic difference between each estimated intersection time and the actual computed time of intersection.

b. Absolute error (AE) scores consisting of the absolute difference between each estimated and computed real intersection time.

In an effort to keep the results maximally interpretable, a sequential analysis paradigm was employed. First, two three way analyses of variance with repeated measures on two factors were performed on the measures described above. That is, both CE and AE scores were subjected to separate analysis for intersection time estimates for the horizontal and for the vertical display cursors. The structure of the statistical design model followed in these analyses is presented in Table 1.

TABLE 1

Analysis of Variance Model for CE and AE for Each Vector

		B_1			B_2			B_3		
		C_1	C_2	C_3	C_1	C_2	C_3	C_1	C_2	C_3
	Subjects									
	1									
	:									
A_1	:									
	:									
	10									
	11									
	:									
A_2	:									
	:									
	20									

Factor A = Groups

Factor B = Time Estimations

Factor C = Speed Conditions

The analysis of variance for AE scores on intersection time estimations for the horizontal cursor is summarized in Table 2. The test for the main effect for group differences (A) failed to be significant. However, this analysis did yield a significant time estimation effect (B) ($F_{2,36}$ = 53.76, p <.01). Figure 2 represents a plot of mean absolute error scores in seconds across the three speed conditions. It can be noted from this plot that there was a decrease in error as a function of increased target velocity for both groups of subjects. The speed condition effect was also a significant source of variation ($F_{2,36}$ = 23.12, p <.01). Similarly, the time estimation by speed condition interaction (BxC) was significant ($F_{4,64}$ = 14.05, p <.01). This significant interaction indicates that the changes in speed of the vertical cursor produced a differential effect on intersection judgments made on the horizontal plane. However, the general trends plotted for the B effect were found to be appropriate irrespective of this interaction. The interactions; groups by time estimations (AxB), groups by speed condition (AxC), and groups by time estimations by speed condition (AxBxC), failed to attain significance.

TABLE 2

Summary of Analysis of Variance for

Absolute Error Scores for Horizontal Display Cursor

Source	SS	df	MS	F
Between Ss	1099200.77	19	57852.67	
A (Groups)	108290.14	1	108290.14	1.97
Ss Within Groups	990910.63	18	55050.59	
Within Ss	5718285.56	160	35739.28	
B (Time Estimations)	3754792.21	2	1877396.11	53.76**
AB	166789.35	2	83394.68	2.39
B x Ss Within Groups	1257287.33	36	34924.65	
C (Speed Condition)	119739.21	2	59869.61	23.12**
AC	2204.41	3	734.80	.29
C x Ss Within Groups	93241.94	36	2590.05	
BC	149061.06	4	37265.27	14.05**
ABC	5427.85	4	1356.96	.51
BC x Ss Within Groups	169742.20	64	2652.22	

** p < .01

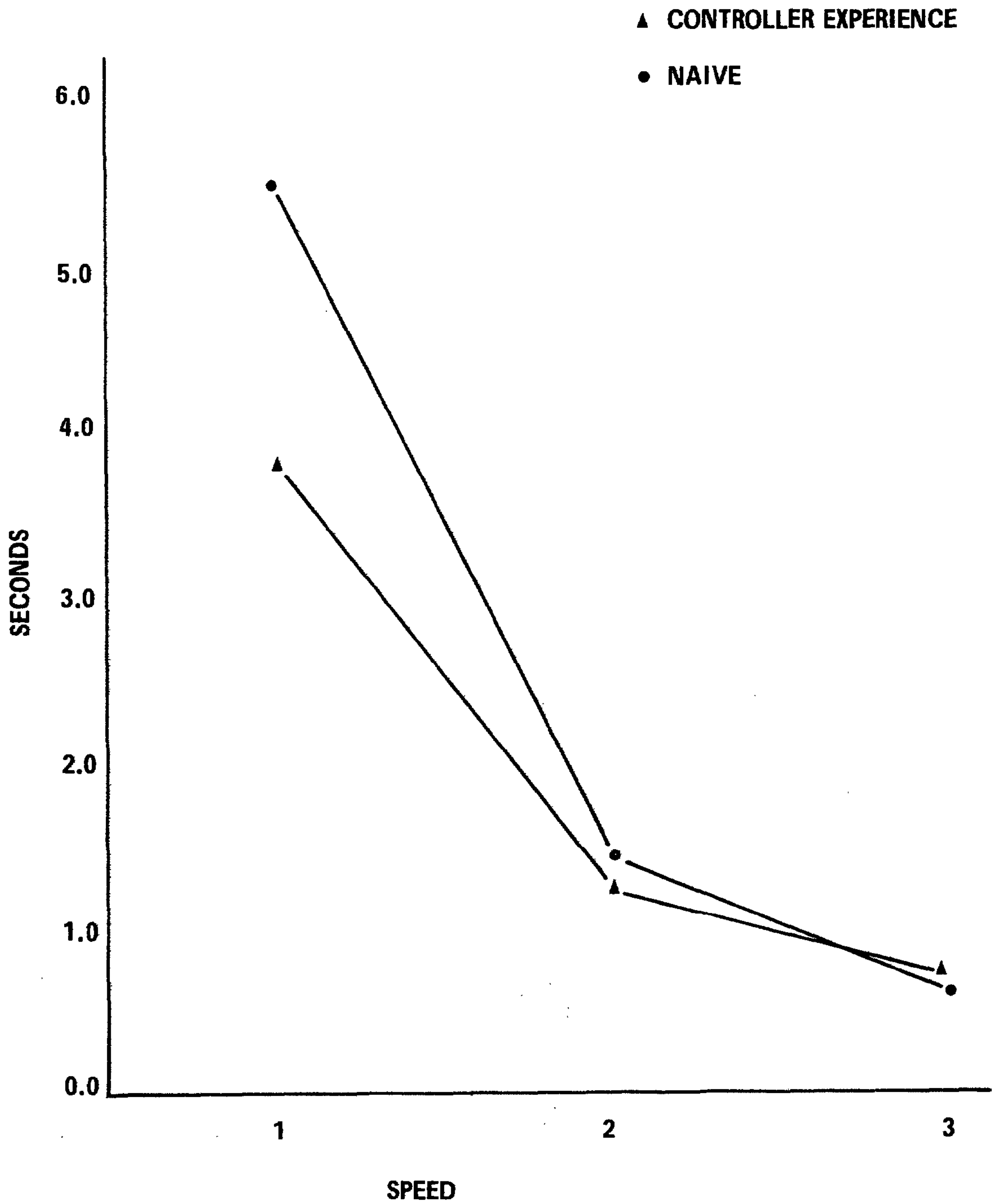

Figure 2

Mean Absolute Error in Seconds for Intersection Estimations on Horizontal Cursor

Similar results were obtained from the analysis conducted on the CE scores for horizontal judgments. The summary data for this analysis is presented in Table 3. Again the A main effect was not a significant source of variation, nor were any of the first and second order interactions with this variable. There was a significant B effect ($F_{2,36}$ = 85.59, p <.01). A plot of mean constant error scores (see Figure 3), denotes the same trend as for absolute error means across speed conditions. Subjects improved their overall intersection prediction accuracy with increased horizontal target speed. It can be noted that this increase in accuracy resulted from a reduction in overestimating the cursor speed at the slower velocities to slight underestimation at highest velocity. Speed condition was also a significant source of variability ($F_{2,36}$ = 19.20, p <.01) as was this variable's interaction with time estimation (BxC) ($F_{4,64}$ = 20.36, p <.01).

TABLE 3

Summary of Analysis of Variance for

Constant Error Scores for Horizontal Display Cursor

Source	SS	df	MS	F
Between Ss	1485546.22	19	78186.64	
A (Groups)	111801.09	1	111801.09	1.46
Ss Within Groups	1373745.13	18	76319.17	
Within Ss	7132919.78	160	44580.75	
B (Time Estimations)	5135662.43	2	2567831.22	85.59**
AB	176401.81	2	88200.91	2.94
B x Ss Within Groups	1080114.21	36	30003.17	
C (Speed Condition)	127774.63	2	63887.32	19.20**
AC	6173.75	3	2057.92	.62
C x Ss Within Groups	119784.07	36	3327.34	
BC	264766.74	4	66191.69	20.36**
ABC	14139.15	4	3534.79	1.09
BC x Ss Within Groups	208102.99	64	3251.61	

** p < .01

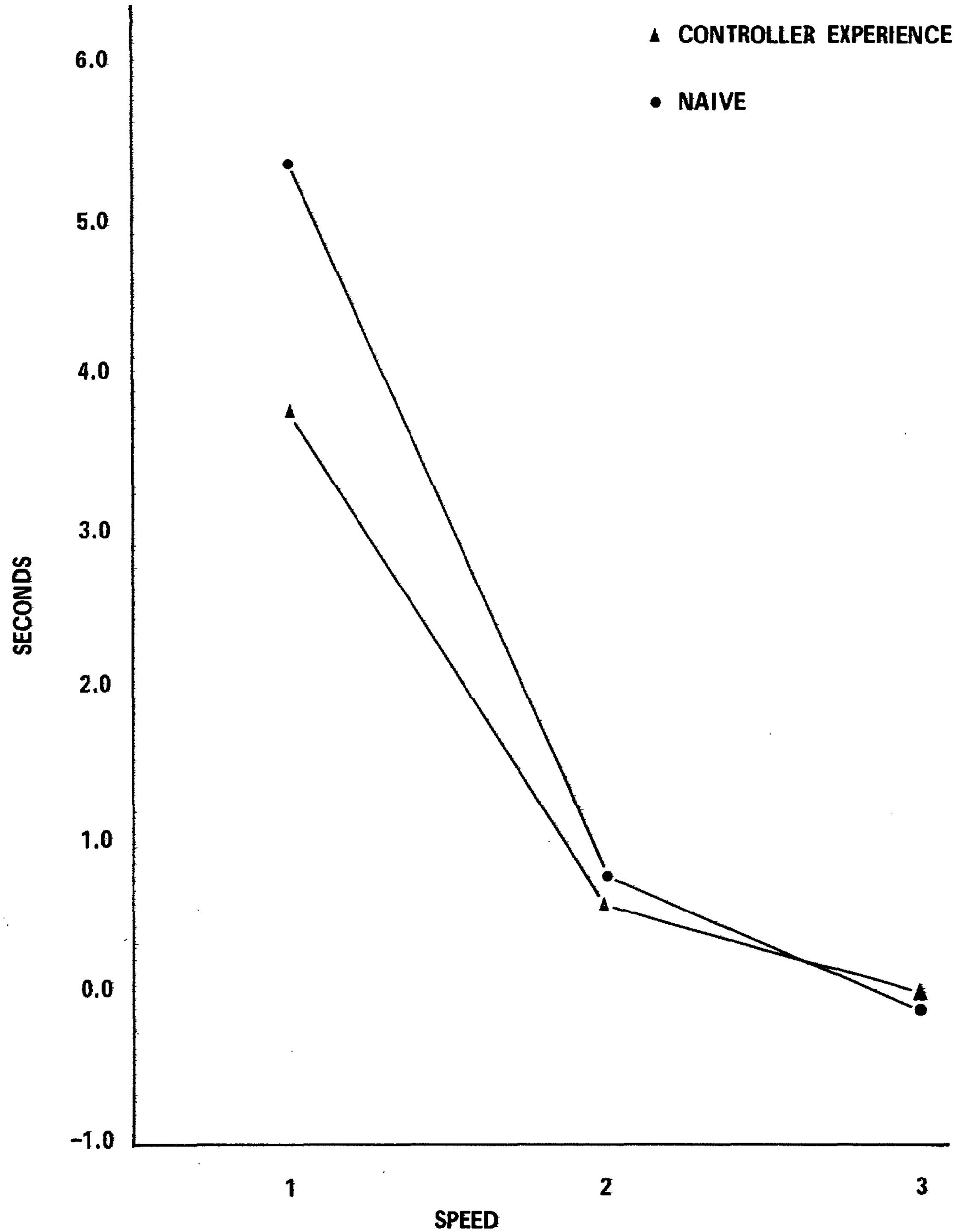

Figure 3

Mean Constant Error in Seconds for Intersection
Estimations on Horizontal Cursor

Table 4 summarizes the results of the analysis of variance performed on absolute error scores for vertical intersection time estimations. The test for the A effect was again not significant in this analysis, indicating that for this particular task, controller experience did not significantly affect performance. This analysis did produce a significant B effect ($F_{2,36} = 62.23$, $p < .01$). The mean absolute error plot across speed conditions (see Figure 4) again demonstrates a decrease in estimation error with increased vertical target velocity. A significant C effect was also present in this analysis ($F_{2,36} = 17.48$, $p < .01$) as well as a significant BxC interaction ($F_{4,64} = 14.47$, $p < .01$). As in the previous analysis of error scores on horizontal cursor time estimations, interactions with the group variable (A) failed to attain significance.

TABLE 4

Summary of Analysis of Variance for

Absolute Error Scores for Vertical Display Cursor

Source	SS	df	MS	F
Between Ss	865780.25	19	44567.38	
A (Groups)	130465.09	1	130465.09	3.19
Ss Within Groups	735315.16	18	40850.84	
Within Ss	5108133.33	160	31925.83	
B (Time Estimations)	3503564.48	2	1751782.24	62.23**
AB	236720.01	2	118360.01	4.20
B x Ss Within Groups	1013445.51	36	28151.26	
C (Speed Condition)	67536.88	2	33768.44	17.48**
AC	3006.88	3	1002.29	.52
C x Ss Within Groups	69564.24	36	1932.34	
BC	101520.22	4	25380.06	14.47**
ABC	495.42	4	123.86	.07
BC x Ss Within Groups	112279.69	64	1754.37	

** p < .01

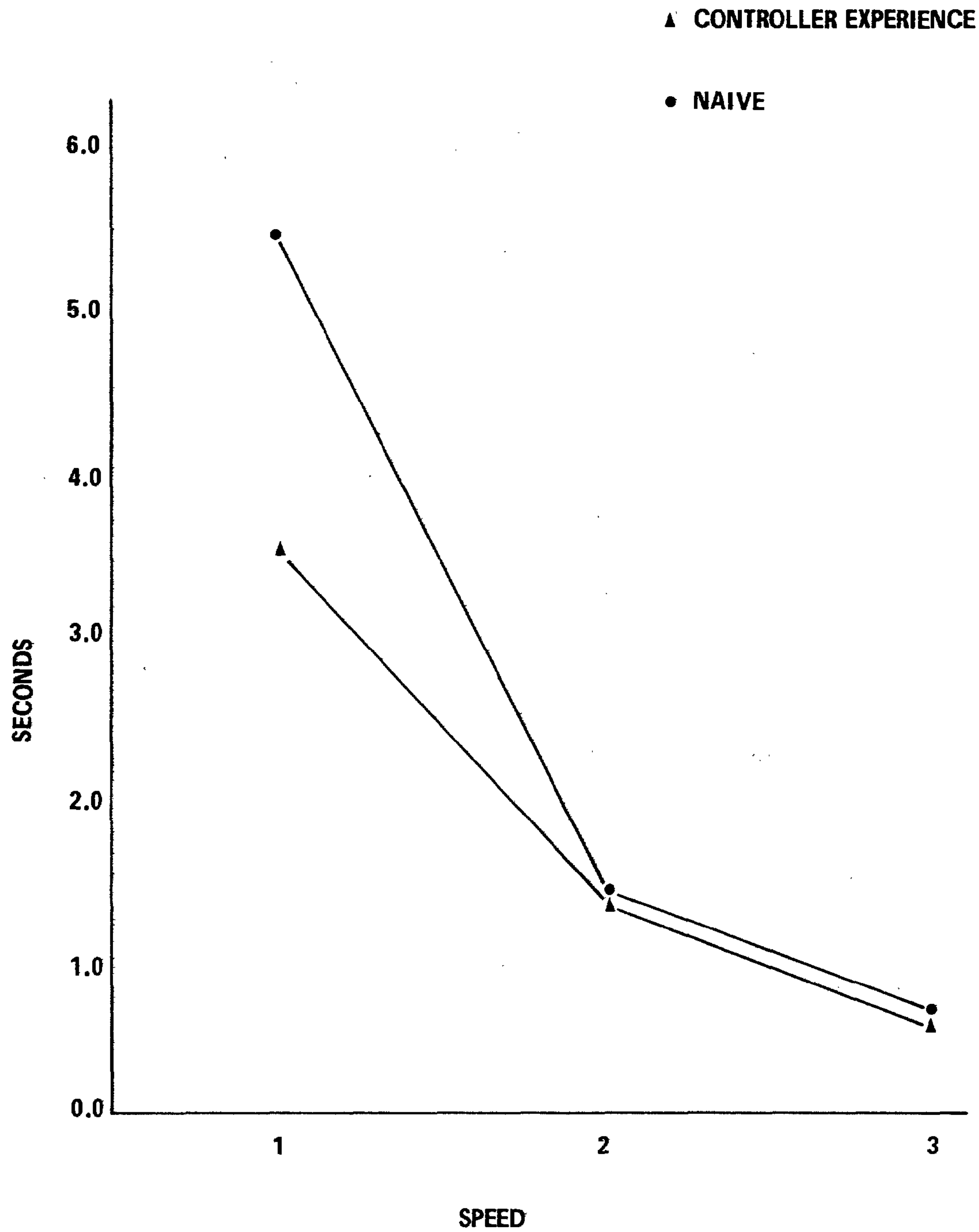

Figure 4

Mean Absolute Error in Seconds for Intersection Estimations on Vertical Cursor

The results of the analysis are similar for constant error scores on vertical intersection times (see Table 5). The group A effect was not significant nor were any interactions with this factor. There was a significant B effect ($F_{2,36} = 69.23$, $p < .01$), C effect ($F_{2,36} = 13.66$, $p < .01$), and a BxC interaction ($F_{4,64} = 24.04$, $p < .01$). A plot of mean constant error in seconds for vertical intersection estimates is presented in Figure 5.

TABLE 5

Summary of Analysis of Variance for

Constant Error Scores for Vertical Display Cursor

Source	SS	df	MS	F
Between Ss	1572151.98	19	82744.84	
A (Groups)	105705.80	1	105705.80	1.30
Ss Within Groups	1466446.18	18	81469.23	
Within Ss	6235361.33	160	38971.01	
B (Time Estimations)	4280206.14	2	2140103.07	69.23**
AB	153028.44	2	76514.22	2.48
B x Ss Within Groups	1112902.08	36	30913.95	
C (Speed Condition)	84515.48	2	42257.74	13.66**
AC	2568.10	2	856.03	.28
C x Ss Within Groups	111353.75	36	3093.16	
BC	279960.89	4	69990.22	24.04**
ABC	24534.26	4	6133.57	2.11
BC x Ss Within Groups	186292.19	64	2910.82	

** p < .01

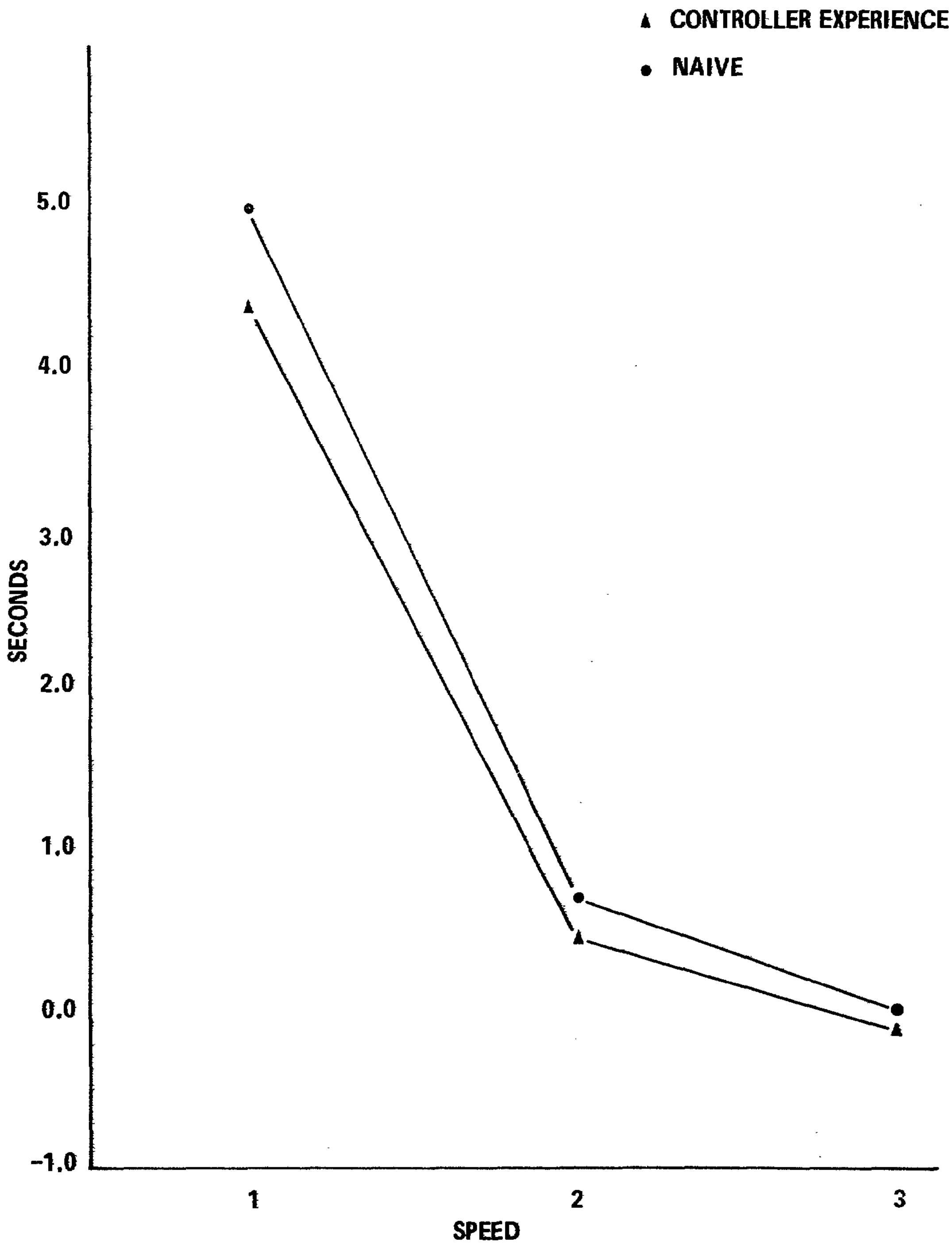

Figure 5

Mean Constant Error in Seconds for Intersection Estimations on Vertical Cursor

Since the previous four analyses failed to demonstrate a significant difference in performance between the two groups of subjects (A), and these interactions with other factors, the error scores for groups were combined. Further tests were then conducted on these data to determine if error differences in intersection time estimates with respect to horizontal or vertical plane conditions were present. Tables 6 and 7 represent summaries of the analyses performed on these combined scores. In these tables, Factor A represents vertical and horizontal time estimation error.

TABLE 6

Summary of Analysis of Variance for

Constant Error Scores for Estimations on

Vertical versus Horizontal Display Cursors

Source	SS	df	MS	F
Between Ss	3071412.88	39	78754.18	
A	13714.68	1	13714.68	.17
Ss Within Groups	3057698.20	38	80465.74	
Within Ss	13368281.11	320	41775.88	
B (Time Estimations)	9395569.04	2	4697784.52	141.54**
AB	20299.54	2	10149.77	.31
B x Ss Within Groups	2522446.53	76	33190.09	
C (Speed Condition)	208100.11	2	104050.06	34.50**
AC	21933.95	2	10966.98	3.64
C x Ss Within Groups	229191.72	76	3015.68	
BC	496207.74	4	124051.94	42.49**
ABC	30775.93	4	7693.98	2.64
BC x Ss Within Groups	443756.55	152	2919.45	

** $p < .01$

TABLE 7

Summary of Analysis of Variance for

Absolute Error Scores for Estimations on

Vertical Versus Horizontal Display Cursors

Source	SS	df	MS	F
Between Ss	1966004.48	39	50410.37	
A	1023.46	1	1023.46	.02
Ss Within Groups	1964981.02	38	51710.03	
Within Ss	10826418.89	320	33832.56	
B (Time Estimations)	7256008.86	2	3628004.43	103.11**
AB	2347.83	2	1173.92	.03
B x Ss Within Groups	2674242.20	76	35187.40	
C (Speed Condition)	180905.00	2	90452.50	40.91**
AC	6371.09	2	3185.55	1.44
C x Ss Within Groups	168017.47	76	2210.76	
BC	241892.49	4	60473.12	31.92**
ABC	8688.79	4	2172.20	1.15
BC x Ss Within Groups	287945.16	152	1894.38	

** $p < .01$

The analysis for the constant error scores for horizontal versus vertical plane conditions failed to demonstrate a significant main effect. That is, constant error scores were of the same approximate magnitude regardless of plane conditions. In agreement with the data previously reported, significant effects for time estimations ($F_{2,76} = 141.54$, $p < .01$), speed condition ($F_{2,76} = 34.50$, $p < .01$) and their interaction ($F_{4,152} = 42.49$, $p < .01$) were present in this analysis.

Referring to the summary data in Table 7, it can be noted that the analysis of variance for combined AE scores produced similar results. No significant horizontal versus vertical plane condition effect was demonstrated, but again the B and C effects ($F_{2,76} = 103.11$, $p < .01$, $F_{2,76} = 40.91$, $p < .01$) and their interaction ($F_{4,152} = 31.92$, $p < .01$).

A plot of the significant interaction for CE can be seen in Figure 6. In this graph, mean constant error in seconds has been plotted for all possible combinations of target speeds. The particular speed of a target on which the estimate has been made is referenced by a number. Speed 1 equals the slowest speed, .91°/second; speed 2, the medium speed of 3.61°/second; and speed 3 equals a speed of 7.22°/second. For purposes of discussion and clarity, when a particular combination of speeds for both cursors is referenced, two consecutive numbers will be used. For example, 1-1 refers to the condition in which both cursors are travelling at the .91°/second rate. Selected F tests were also performed on the differences in constant error between certain speed combinations. The summary data for these tests is presented in Table 8.

TABLE 8

Summary of F Tests on Constant Error

Differences for Cursor Speed Combinations

Combinations		F (4,152)	
1-1	1-3	75.21	**
1-1	1-2	100.17	**
1-2	1-3	1.79	
2-1	2-3	15.52	**
2-1	2-2	5.55	**
2-2	2-3	39.65	**
3-1	3-3	.46	
3-1	3-2	2.05	
3-2	3-3	.57	

** $p < .01$

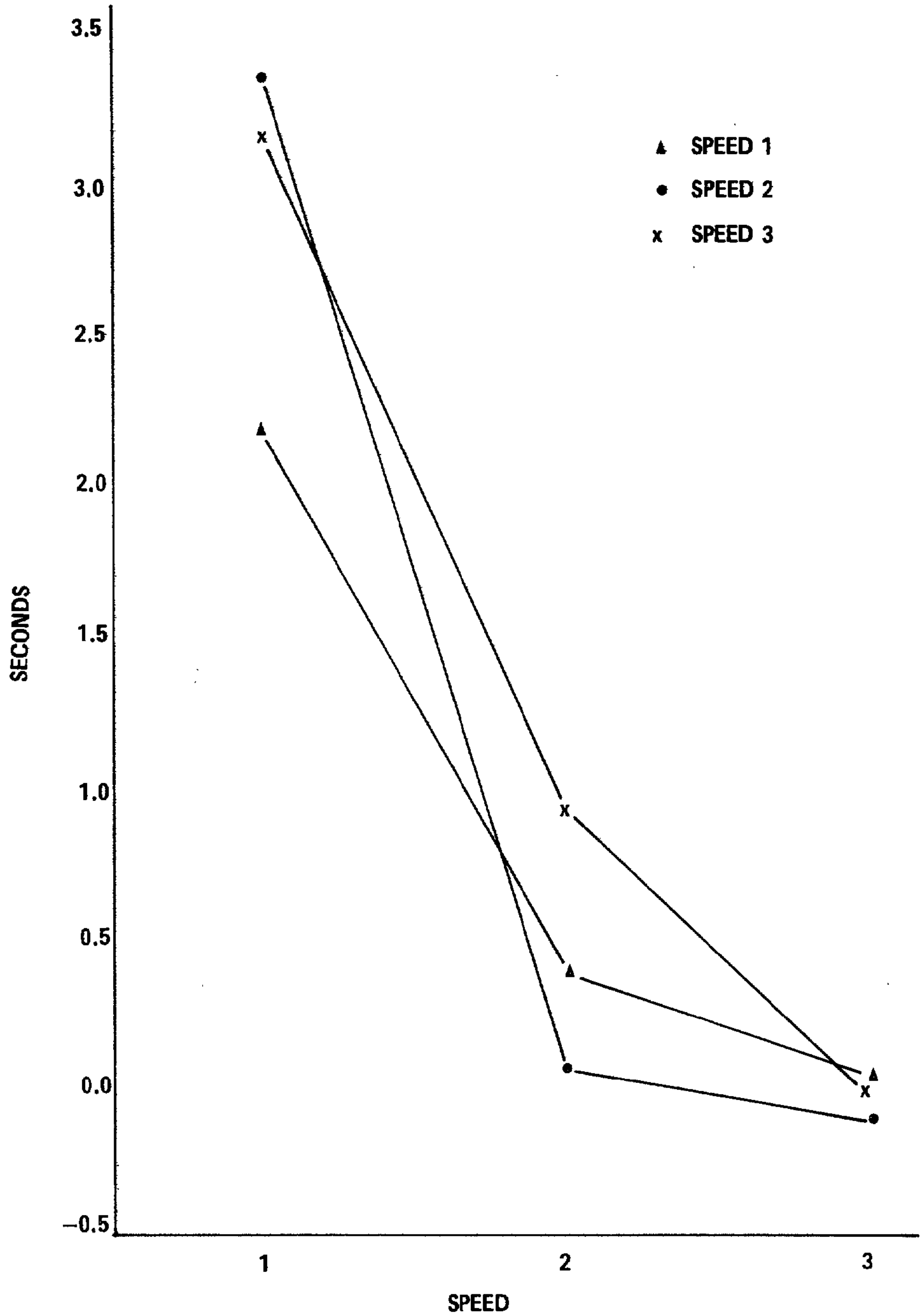

Figure 6

Mean Constant Error in Seconds for Combined Plane Conditions

When absolute error is plotted for the various combinations of speed conditions, somewhat similar effects are evident. Figure 7 is a graphic representation of these scores and selected F tests in error differences between various speed combinations are presented in Table 9.

TABLE 9

Summary of F Tests on Absolute Error

Differences for Cursor Speed Combinations

Combinations		F (4,152)
1-1	1-3	92.96 **
1-1	1-2	111.65 **
1-2	1-3	.86
2-1	2-3	10.12 **
2-1	2-2	.31
2-2	2-3	6.90 **
3-1	3-3	.09
3-1	3-2	.04
3-2	3-3	.26

**$p < .01$

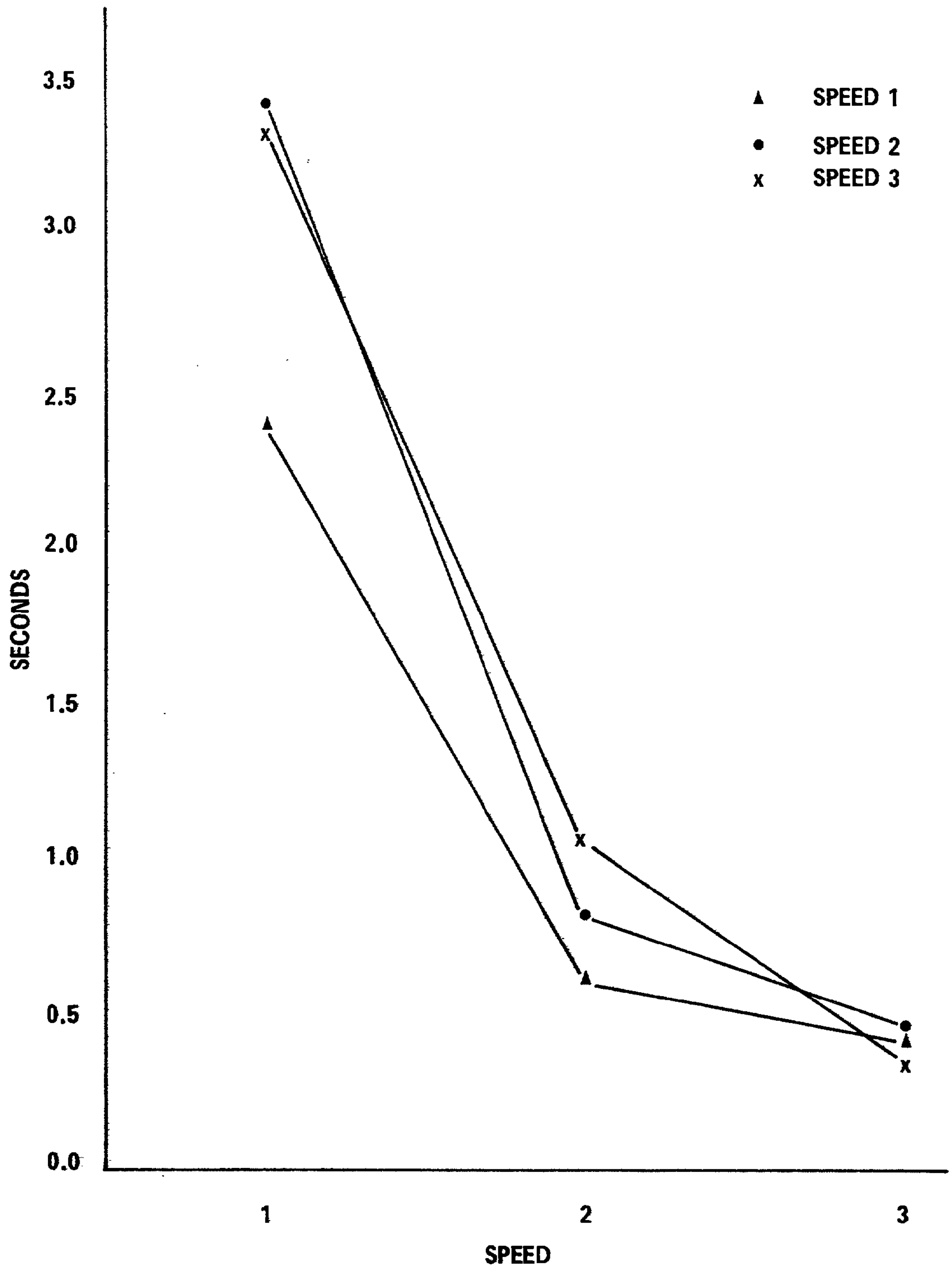

Figure 7

Mean Absolute Error in Seconds for Combined Plane Conditions

These analyses reveal that neither plane condition nor controller experience contributed to response accuracy or the task. However, time estimations (B) and speed condition (C) did contribute to response accuracy. Also these factors interacted providing a significant differential effect.

DISCUSSION

Previous research has demonstrated the speed of a target's movement to be a significant factor in man's ability to accurately predict its intersection time with other objects. In most cases, increases in time estimation accuracy have been noted to relate directly to increases in target speed. This general finding has been further substantiated by the data of the present study, independent of the differential speed effect. Mean absolute error plots for intersection time estimations on both horizontal and vertical cursors illustrate that the magnitude of intersection time estimation error diminished with increased cursor speed.

A number of explanations have been advanced for this finding in previous literature, but perhaps the most tenable one is the "temporal duration hypothesis," first posited by Dembitz[2], and later amplified by Gerhard[5]. Briefly, this hypothesis proposes that individuals do not reference velocity as it is usually physically measured such as a traversed distance per unit of time, but for tasks such as this one, determine a time interval for an object to cover a certain unit of distance. Time duration, according to these researchers, is the important dimension to be considered in this type of task. This idea has merit, especially when consideration is given to some of the operational requirements of the subject's task in the current study. First, although several speed combinations were used, there was no variation in the speed of either cursor during any one trial. Each cursor moved at a constant speed until its perceived intersection point was reached. Second, the physical distances of cursor display and concealment were equal and constant in length across all trials, and third, the point of perceived intersection was not varied and was present on every trial.

The subject's task then, required only that an estimation of time be made as the cursor traversed the display distance and that this time interval be reproduced for the concealment distance, for an accurate intersection time estimate. For fast speeds and their consequent short time intervals, the task was relatively simple. However, as the concealment time increased due to the slower target speed, maintaining an accurate reproduction of the time interval became more difficult. This situation, in turn, contributed to the increased magnitude of error in intersection time estimations.

The speed of a target has also been shown to affect the direction of error on intersection time estimates. For fast target speeds, subjects have been shown to be late in their estimations of intersection times. Conversely, when slower target speeds are used, subjects have estimated intersections to be earlier than computed intersection times. Although the effect is not as pronounced in this study as has been described in some of the earlier literature, mean constant error plots (Figures 1 and 2) do demonstrate this trend for the current investigation. Subjects underestimated the rate of movement for fast speeds and overestimated that movement for the slower speeds. This finding, too, relates to the temporal duration hypothesis in that with slower cursor speeds and increased concealment times, a breakdown in the accurate reproduction of the concealed time interval occurs. This results in less accurate intersection time estimations. However, this hypothesis does not offer much aid in explaining the changes in direction of error which result when cursor speeds are altered.

Brown[1], has suggested that this phenomena can be viewed as similar to the "range effect" noted in manual responses during a tracking task. First demonstrated by Ellson and Wheeler[4], the range effect is simply man's tendency to average the magnitude of his corrections for deviations from the track. When a large error is displayed, the operator's response is typically less than adequate to correct it. On the other hand, small errors create the tendency for overcorrection.

Whether this idea has merit for explaining the findings of the present work is open to question as most forms of tracking are directly feedback linked and this particular task was not. Nonetheless, the tendency toward response smoothing in tracking behavior has been repeatedly observed, and the present task can realistically be viewed as one which necessitates a form of visual tracking. Allowing this possibility would lead to the assumption that the same critical cues necessary for the performance of both types of tasks were present and were utilized by the subjects in the current experiment.

Perhaps the most interesting aspect of this research was the differential effect of the speed that one cursor had on the intersection time estimations of the other. This significant interaction between time intersection estimates and speed conditions was evident in all of the analyses.

Since the comparison of error scores between time estimations on horizontal and vertical plane conditions revealed no significant differences, it was possible to combine group scores. It is evident from the results of the analysis and subsequent plots of significant interaction on these combined scores that pairings of similar speeds resulted in the lowest constant error. The increased accuracy associated with these three combinations can be viewed as resulting from a simplification of the subject's task. For these conditions, once the decision was made that the two cursor speeds were equal, the subject was required only to monitor one cursor's progress during the displayed time interval and, by simultaneously activating both response switches, give his best intersection time estimate for both targets. The task then, was essentially reduced to an estimation of a single cursor's movement.

When the speed differential between targets was introduced, the task requirements increased. Unlike the prior stimulus situation where monitoring only one target was required, it was necessary for the subject to monitor both target movements and to estimate the difference in their displayed time intervals. Having accomplished this, the subject then had to reproduce these intervals during the concealment time to obtain accurate intersection times for each cursor.

The decreased accuracy in intersection time estimations supports this idea of increased task difficulty. For intersection judgments at the slowest speed, the 1-3 and 1-2 combinations resulted in significantly greater error than the 1-1 combination. Estimations of intersection times on the medium cursor speed seem to be completed with less difficulty. Although significant increases in error can still be noted for the 2-1 and 2-3 speed combinations as opposed to the equal speed condition, they are not as pronounced as with the slowest speed. Judgments on the fast speed show no differences among any of the three combinations.

Absolute error produced similar results with estimations on intersection times at speed 1 still producing the least amount of error for the 1-1 pairing and this error differing significantly from both the 1-2 and 1-3 combinations.

Results for the medium speed pairings are not as clear cut. Rather than the 2-2 combination resulting in the least error, the 2-1 pairing produced better estimation accuracy. An F test on these pairings, however, revealed this difference to be insignificant. Pairing 2-3 still produces a significantly larger error than 2-2 and 2-1 for this judgment condition. For the fast speed conditions, the trend is similar to that for constant error. No significant differences in error magnitude were found between any of these pairings.

Several trends are in evidence from the inspection of these data. First, pairing slower speeds with faster speeds on displays of this type, results in an accentuation of the underestimation effect on slow cursor intersection judgments. Second, this is also the case for the medium and fast speed pairings when intersection estimations are made on the cursor moving at medium speed, but not when these judgments are made on combinations of this speed with a slower target movement. Finally, estimations made on intersection times for the fast target speed do not seem to be affected by either of the slower target speed pairings. Further study of this speed variable will be necessary to determine the critical differential necessary to produce this effect.

Significant differences in performance between controller experienced and non-experienced groups were expected. However, it is entirely possible that necessary cues which are present for judgments of this nature in a field environment were not available to the subjects in this particular laboratory situation. This may have decreased the performance of experienced subjects to a level quite similar to the naive group.

In summary, since differential speed has been shown to be a significant variable in intersection prediction accuracy, laboratory investigation which systematically links other potentially critical cues with this variable could ultimately provide knowledge as to those cues which are necessary for more accurate estimations of this type. Follow-up studies in the field will be of equal importance to provide further validation of the necessity of these selected cues for estimations in the working environment. Since there is little doubt that man must continue to make these types of judgments in environments, where inaccuracies are extremely hazardous to property and personnel, an extended program of systematic laboratory and field research in this area is justified.

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