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PERFORMANCE IN PURSUIT AND COMPENSATORY TRACKING TASKS AS A FUNCTION OF RATE AND PREDICTABILITY

by

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INTRODUCTION

General Problem

Two major forms of information display are used to study human tracking behavior. The pursuit mode consists of a target line and a follower or cursor line presented as stimuli. The target is controlled independently by the experimenter and the cursor is controlled independently by the subject or operator. The subject's task is to keep the cursor aligned with the target as the latter moves in the display medium--usually a cathode-ray tube (CRT). The compensatory display mode consists of a stationary target, or null, indicator and a cursor which is controlled jointly by the system input and the subject. The subject's task in this case is to compensate for displacement changes imparted to the cursor by the experimenter, or system input, thus keeping the cursor superimposed on the reference target.

Except for low frequency inputs, the compensatory tracking task has been found to be more difficult to master and to result in poorer performance than the pursuit task. The obvious interpretation of the difference in performance between these two modes of tracking is that the pursuit mode offers more direct information to the operator--target and cursor positions, rate of travel, and instantaneous error--than the compensatory display which offers only an indication of error in the deviation of the cursor from the reference target. If the subject centers his arm control and does not respond, the path of the cursor on the CRT would be the mirror image of the path of the target in a pursuit task. The subject would then receive the same information as to rate, amplitude, direction, and acceleration as would the pursuit operator. Because the operator must respond, the stimulus information is confounded with feedback of the subject's response. Most of the studies to be reviewed here were interpreted as indicating that this difference in direct information supplied to the subject accounts for the superiority of pursuit tracking.

Research comparing the pursuit and compensatory modes indicates that many experimental variables have been used in attempting to explain performance differences between pursuit and compensatory tracking. Some of the major studies and their conclusions are examined in the next section.

The purpose of this thesis was to examine two task variables, task predictability and task rate, as they affect both pursuit and compensatory tracking. Some of the previous research suggested that different levels of stimulus predictability presented at different rates of target movement might be a possible means of examining performance differences between the two tracking modes.

The necessity for examining and comparing these display modes is two-fold. First, a better understanding of human skilled performance may be obtained from results of experiments of this type. Second, in practical applications, the compensatory display mode (because of engineering or design limitations) is used more often than the pursuit display which, in most cases, yields the best performance. Therefore, any new evidence with respect to task variables affecting differences or similarities between these two displays may be both theoretically and practically useful.

Research

General Comparisons

Most sutdies showing a difference in performance between pursuit and compensatory tracking have been favorable to the former. Briggs (1962) reported that this has been the case across a wide variety of manipulated variables including display gain, control gain, and target frequency (Fitts, Marlowe, and Noble, 1953; Noble, Fitts, and Marlow, 1953), visual noise (Howell and Briggs, 1959), and target frequency (Hartman, 1957a; 1957b).

By using a combined display, Senders and Cruzen (1952) showed that a continuum exists on which the pursuit and compensatory display modes are the end points. By varying the percentage of each component, the experimenters demonstrated that, as the pursuit component increased, performance (measured by time on target scores) increased up to the 75% pursuit-25% compensatory condition. The 100% pursuit-0% compensatory condition was not significantly different from the 75%-25% condition; but later Bahrick, Fitts, and Briggs (1957) showed that this may have been due to artifacts in the scoring, and that it was probable that performance increased significantly as the pursuit component approached 100%.

Senders and Cruzen attributed the superiority of the pursuit display by the general argument given in the first section, namely, pursuit displays allow the subject to examine directly information concerning the direction, rate, and acceleration of the target course. In the compensatory display, if the subject is tracking perfectly, the only information he receives, other than his own response-produced feedback, is that he _is_ tracking perfectly. He has no display information regarding position, rate, or acceleration of either the target or the cursor. Therefore, by increasing the pursuit component in a tracking task, the subject will be able to perceive some of these changes in the target and cursor and his performance level will increase.

Recently Briggs and Rockway (1966), in a study similar to the Senders and Cruzen experiment, attempted to determine whether the amount of pursuit component influenced learning as well as performance. They used the same pursuit-compensatory percentages as the previous study and then transferred one-half of each group to either a 100% pursuit or a 100% compensatory tracking task. For the acquisition phase, they found an increase in performance with an increase in the pursuit component up to and including the 100% pursuit condition. This finding tended to bear out Bahrick, Fitts, and Briggs' (1957) conclusion that Senders and Cruzen's (1952) performance measure (time-on-target) may have been insensitive at particular levels of performance.

For the transfer condition, the authors found that all groups exhibited 100% transfer. That is, there were no significant differences among any of the groups transferred to the 100% pursuit condition, and they did not differ from the 100% pursuit control group. The same held true for the groups of differentially trained subjects who were transferred to the 100% compensatory condition.

These results were unexpected because the authors assumed that, since more information was available to the groups with a larger pursuit component, these groups would perform proportionately better during the transfer task, just as they did on the training task. They concluded that, "the percentage of pursuit component has a significant effect on performance but little or no differential effect on learning." (p. 169)

Because there was no apparent learning gradient in any of the groups, the authors pointed out "that whereas previous experiments might have obtained different (higher) performance levels with a pursuit display, it is unlikely that the fundamental aspects of skill acquisition would have been different." (p. 169)

In a follow-up of the 1952 (Senders and Cruzen) study, Senders (1953) predicted that, if tracking proficiency is determined by the <u>availability</u> of information as to direction, rate, amplitude, and acceleration, then any increase in the proportion of perceptible rates would enhance tracking performance. He used three techniques to increase the proportion of perceptible rates. The amount of pursuit component of the task was varied by using the same five combinations of pursuit-compensatory display mode as in the first study. Second, two input signals were used, one with a low rate of change and the other with a high rate. Finally, both light and dark viewing conditions were used in order to provide visual cues (edge of the CRT and grid marks) or no cues as to target rate and acceleration. Four conditions were employed: low rate input and light condition, low rate input and dark condition, high rate input and light condition, and high rate input and dark condition.

Results confirmed the data obtained in the earlier study: an increase in performance was a function of an increase in the pursuit component of the task. Further, except for the high rate-light condition in the 100% compensatory display, tracking in the light condition (perceptible visual references) was superior to tracking in the dark condition (higher threshold for rate perception). Briggs (1962) concluded that the results support Senders' original hypothesis that:

> ...the availability (perceptibility) of information as to the direction, amplitude, rate, and acceleration of the input signal is a major determinant of tracking proficiency. It follows, then, that Senders has accounted for the positive relationship between percent pursuit component in an information display and performance level. (p. 5)

Control/Display Factors

Two studies (Noble, et al., 1953; Fitts, et al., 1953) varied control and display scale factors and input frequency on both compensatory and pursuit tracking tasks. They found that the display scale factor affected pursuit performance, but was not significant for the compensatory mode. The latter finding is in disagreement with other studies which have demonstrated that compensatory tracking is enhanced by greater magnification of the error signal. These results may have been due to the narrow range of display gain used or to the relatively high input frequencies used in the pursuit study (Fitts, et al., 1953). Others (Garvey and Henson, 1958; Bowen and Chernikoff, 1958) have found that high display gain factors increased the proficiency on compensatory tasks for low and medium input frequencies, but not for high frequencies. Manipulation of the control scale factor affected both forms of tracking. The interaction between control and display scale factors was nonsignificant for both modes and indicated that these variables affected performance independently (Fitts, et al., 1953). Others who found that an increase in the amplitude of control movements gave a continuous improvement in performance on both modes were: Rockway (1955), Rockway, Eckstrand, and Morgan (1956), and Hartman (1957a).

Hartman and Fitts (1955) pursued the matter of control and display scale factors further by varying control and display scales, input frequencies, and complexity for both modes and found interactions between several of the control and display factors. This dependency indicated "that a control/display (C/D) factor ratio may be a meaningful index to quantify the gain aspects of the machine portion of the man-machine control system" (Briggs, 1962).

Control Lag

The effects of delaying feedback of the results of a control movement (control lag) on pursuit and compensatory systems was studied by Conklin (1957). Type of lag (exponential or sigmoidal), length of lag time, and input complexity (different sinusoidal combinations) were varied. Results indicated that performance on the pursuit tasks was better than on the compensatory tasks. Performance on both modes was also better with exponential lags than with sigmoidal lags. Performance deteriorated constantly as a function of lag time for all conditions and also as a function of an increase in rate and/or complexity (predictability) of the input signal.

By increasing system gain, Rockway (1954) showed that the effect of lags may be reduced and that in some cases a lag may improve performance, partly because the higher gain effectively reduced the delay in information feedback. A curvilinear function was found to describe the relation between operator performance and lag time for high gain systems. Fitts, Noble, Bahrick, and Briggs (1959) concluded:

> ...that it is erroneous to assume that any system lag is detrimental to controlling accuracy. Rather, the generalization more accurately stated holds that as system sensitivity is reduced, the presence of exponential lags may degrade performance; however, for higher levels of sensitivity, a system lag may actually improve performance due in part to the fact that the higher gain effectively reduces the delay in information feedback resulting from a particular lag. (p. 12.19)

Aiding, Quickening, and Unburdening

From the operator's point of view, aiding and quickening are identical, but from a system point of view they are different. Aiding involves taking derivatives of the controlled element, feeding them forward, and adding them to the system output. In a quickened system, derivatives of the system output are fed back to the display and added to the information fed back from the system output. As Senders succinctly puts it:

> Psychologically speaking, quickening (or aiding) permits immediate knowledge of results, provides a high degree of stimulus-response integrity, and simplifies the computation required of the operator. These effects account for the improved performance of such systems. From the engineering point of view, quickening is a process of response shaping through modification of the closed loop response of the system, resulting in stability and in meeting a criterion of performance. Aiding involves actual changes in the open loop transfer function of the system to the same end. (1959, p. 32)

Unburdening reduces the physical work required of the operator by adding an integral transformation to the machine element in a closed loop system. An example of unburdening would be adding a motor to the operator's control so that, when he manipulates the control positionally, he will obtain a rate or higher order output component. Unburdening is independent of the display output so that the operator's perceptual requirements are not affected. In other words, the subject may move an arm control positionally and impart a rate or acceleration change to his controlled element. What he sees, however, is a function of the display output and this is determined by aiding or quickening techniques. A combination of aiding and unburdening factors may reduce the operator's perceptual and physical requirements. Applications of these techniques have been fairly extensive in the research literature because of their obvious practical applications and because they offer additional variables to be used in skills research in general.

A series of studies by Chernikoff, Birmingham, and Taylor examined pursuit and compensatory paradigms using aiding and other parameters. Chernikoff and Taylor (1957) studied the effects of aided time constant and input signal frequency, and they found an interaction on both tracking modes. Fitts, et al., (1958) commented on the importance of these interactions and noted that:

> in many cases...for complex inputs with high frequencies, positional dynamics are superior to velocity or rate-aided. However, [this study] shows that this superiority holds only for the higher frequency inputs, and that the rate-aided system becomes superior for inputs in the low range and that both velocity and rate-aided systems are superior to positional dynamics in the very low frequency range. (p. 12.30)

In another study Chernikoff, Birmingham, and Taylor (1955) found that for the slowest input signal there was no difference between pursuit and compensatory displays, but for higher frequencies (over 4 cycles per minute) pursuit was better. They concluded that:

> Overall, the results lend credence to the hypothesis that pursuit tracking will be superior to compensatory in those cases where target velocity and acceleration information is required by S, but that pursuit tracking will lose its pronounced advantage when this information is not needed by the tracker. Furthermore, it appears that the inclusion

> within a display of information which is uncorrelated with the tracking behavior required of S is detrimental to performance. Thus, it would appear that recommendations as to whether pursuit or compensatory tracking should be used in specific systems must take into account the precise nature of the informational requirements of the particular tracking task involved. (p. 59)

Transfer Effects

Andreas, Green, and Spragg (1954) reported the first of two studies found which examined transfer from pursuit to compensatory and compensatory to pursuit modes. Display mode and input complexity were confounded because the input signal in the pursuit task was more complex than in the compensatory mode. The authors noted that subjects did better transferring from pursuit to compensatory modes than vice versa. This indicated that subjects learned more on the pursuit display, but no clear-cut conclusions may be drawn due to the confounding.

Briggs and Rockway (1966), in a study described earlier in this paper, found no significant differences in performance in transferring from pure pursuit, pure compensatory, or any combination of pursuit-compensatory tracking mode to pure compensatory or pursuit tasks. They stated that there appears to be no learning differences, only performance differences, between the two tracking tasks.

In summary, it must be remembered that, although the pursuit display allows better performance, the decision as to which mode to use must be tempered with consideration of the type of information processing required of the subject in a particular situation. For example, if it is a low frequency input, then compensatory would probably be equal to or better than pursuit. If the system could utilize aiding or quickening, compensatory could also suffice. If higher derivatives of the input signal are used to determine motor output, pursuit tracking would probably be better than compensatory.

Briggs (1962) noted that "in all the research comparing pursuit with compensatory displays there was no guarantee that the compensatory mode was used optimally. Thus, had display magnification been increased for the compensatory mode, the superiority of the pursuit mode might have been reduced" (p. 11). Therefore, in a system that requires a compensatory display because of engineering limitations or feasibility, use of some of the techniques described herein might enable the operator to approach the performance level which he could attain on a pursuit task.

Task Predictability and Task Rate

A series of studies (Trumbo, Noble, Cross, and Ulrich, 1965; Trumbo, Ulrich, and Noble, 1965; Trumbo, Noble, and Ulrich, 1965) have examined the effects of stimulus predictability for step-function inputs in pursuit tracking tasks. Predictability of step amplitudes or of dwell times was based either on digram sequential probabilities or on the proportion of random target events in an otherwise fixed series of targets. These studies have pointed out that a differential learning effect occurs as a function of the degree of predictability of the pattern. In other words, the fixed and highly predictable (low proportion of random targets) patterns are tracked with a high degree of skill, while performance scores on the more unpredicatble patterns are grouped at a lower level. Retention scores have shown that relatively large losses in performance were evident, especially for the tasks which manifested the greatest improvement during acquisition.

In a recent unpublished study in this series, an attempt was made to apply some of the stimulus coherency (predictability) concepts used in the step-function tasks mentioned above to a continuously moving input. In this experiment three rates of target movement were used in a factorial-design with three levels of predictability. For this pursuit task the target moved across the CRT at a constant rate of speed, reversing itself at various pre-selected positions. Three stimulus patterns were used: completely predictable in the temporal-spatial relationship; semi-predictable so that some movements were fixed while others were random, and completely random.

Results indicated that as rate increased, performance decreased, that is, higher integrated error scores were obtained for the faster rates. Within the different rates, performance was better on the more predictable patterns. As the rate of target movement increased, it was also noted that there appeared to be greater differences between levels of predictability. For example, at the slowest rate there was little difference in performance on the three different patterns. At the highest rate there were distinct differences as a function of predictability. In other words, it appeared that as the need for quicker responses increased, the necessity for relying on predictable portions of the input in order to "pre-program" responses increased.

Two retention periods were used (one week and one month), and no general pattern of loss was found during either of these periods. For the one week interval there was an apparent average improvement in performance for all patterns over all three rates, but this may have been due to insufficient training trials, since it appeared that performance levels had not asymptoted, or it may have been due to a reminescence-type recovery, for which there was some evidence between sessions of the training phase. There was a general decrement in performance for the highly predictable tasks at the one month interval, but no losses were evident for the less predictable patterns. These findings supported earlier results on step-function tasks (Trumbo, Noble, Cross, and Ulrich, 1965) in that losses were greatest for the tasks in which there were the greatest gains in performance. These results are not in accord with general retention effects reviewed by Naylor and Briggs (1961) in which they found relatively small losses in performance over comparable periods of no practice.

There has been little emphasis on the characteristics of the input stimulus in studies of pursuit and compensatory tracking. It is commonly known that an increase in the rate of movement for a continuous input results in poorer performance scores (see Senders, 1959; Noble, Fitts, and Warren, 1955) and that an increase in stimulus complexity also increases the difficulty (e.g., Conklin, 1957) on both display modes. No research has been found, however, that examines the effects of both of these variables on both tracking modes.

The fact that the above may be a valid area of study has been suggested by previous research. Two studies examined elsewhere in this paper (Senders and Cruzen, 1952; Senders, 1953) have indicated that the availibility or perceptibility of information as to the direction, amplitude, rate, and acceleration of the input signal is a major determinant of tracking proficiency. This would seem to indicate that any increase in the predictability of an input would also enhance performance on the two types of tracking tasks. The fact that this variable may have a differential effect across modes is suggested by Poulton (1952a; 1952b; 1957) who used intermittency of presentation to determine cues in both display modes. He concluded that acquired knowledge of the stimulus is important for both kinds of tracking, but that it is more important in the compensatory mode, since the stimulus pattern is confounded by the process of tracking.

The purpose of the investigation was to examine the effects of rate of target movement and predictability of the input signal on both pursuit and compensatory tracking performance. Several predictions were made:

1. Differences in performance levels between pursuit and compensatory tracking would become greater as a function of an increase in rate. This would be indicated by a mode by rate (MxR) interaction in the analysis of variance computed on the data.
2. Performance on both modes would improve as the degree of stimulus predictability increased.
3. The pursuit mode would allow higher performance levels on the predictable and semi-predictable patterns that would the compensatory mode. In other words, it was predicted that distinctly different performance scores would be attained as a function of pattern predictability on the pursuit mode, whereas the compensatory trackers would be able to distinguish only the completely predictable pattern.
4. Performance would degrade in both modes as stimulus predictability decreased and rate increased.
5. As rate is increased, the effects of increasing predictability would be greater for the pursuit mode than for the compensatory. This would be indicated by an MxPxR interaction.

The first two predictions were suggested from results of previous studies which have shown: (a) only at low rates is compensatory tracking equivalent to or better than the pursuit mode; (b) predictability enhances performance on both modes (e.g., Conklin, 1957).

The last three predictions were indicated by previous data. The third one was suggested from Senders' (1953) work on the availability of stimulus information. The pursuit tracker is able to perceive more of the pattern and, thus, should be able to discriminate the less predictable patterns better than the compensatory tracker.

Prediction 4 was a logical supposition based on studies which varied predictability (e.g., Conklin, 1957) and studies which varied rate (e.g., Noble, et al., 1955). The first found a decrease in performance with a decrease in predictability, and the second found a decrease in performance with an increase in rate. A combination of these conditions should cause performance deterioration to a greater extent than either condition separately.

The last prediction would follow from the first, third, and fourth predictions. At a higher rate of target travel, the subject may have to preprogram his response movements for several segments of the sequence in order to stay in phase with the target. If so, his performance must necessarily be poorer on the intermediate or partially predictable patterns than on the fixed patterns. His performance would also be worse on the compensatory mode because he would be receiving less information about pattern predictability. In a relative manner, his performance on a slower rate intermediately predictable pattern would be better than on its higher rate counterpart because he could pre-program fewer responses and therefore correct himself when a random stimulus interrupts the fixed portion of the pattern.

METHOD

Subjects

The subjects were 144 undergraduate, right-handed male students enrolled in various sections of an introductory psychology course at Kansas State University. The subjects ranged in age from 17-28 years. Each subject was given research participation credit and/or paid for the six thirty-minute sessions for which he volunteered to serve.

Apparatus

The subjects were required to track in a one-dimensional, zero-lag (positional) control task. Input to the system was a constant rate triangular-wave function and the display was provided by a 5-in. cathode ray tube (CRT). The subjects' arm control consisted of a lateral beam pivoted at the elbow, with an adjustable handle grip. This control, free of viscous damping and not spring-centered, was attached to the right side of an adapted army dentist's field chair. The CRT display consisted of two 0.5-in. vertical lines which overlapped 0.125 in. when adjusted for zero tracking error.

The input of the triangular-wave function was provided by means of programmed punched tapes, read out by a commercial tape reader, converted to analog voltages by a digital to analog converter and flip-flop network and displayed on the CRT. For the pursuit mode of tracking the target was the top line on the display and was the direct output of this programmer circuit. The position of the cursor was independently determined by the output of a potentiometer at the pivot of the subject's arm control. For the compensatory mode the target was the stationary upper line on the display and the lower line was the cursor. For this mode the deviation of the cursor at any point was the instantaneous difference between the input signal and the operator's response; that is, the error. Thus, when the subject was tracking perfectly the cursor was aligned with the target in the center of the scope.

Maximum travel of the target and cursor for the pursuit task and for the cursor for the compensatory task was ± 1.6 in. (± 4 cm.) along the horizontal axis. A control movement of ± 18.0 degrees was required to track the maximum amplitude of target and/or cursor movement. The subject was seated in the chair facing the scope. The distance from eyes to the scope was approximately 28 inches. Two identical subject booths were paralleled into the system so that two subjects could be run on the same pattern simultaneously.

Scoring was performed by means of an operational amplifier manifold so that the momentary error in volts was obtained as the absolute difference between the target and the cursor. This difference was integrated over each trial and read out continuously by means of two voltmeters, one for each booth.

The programming unit, integrating amplifiers, intertrial intervals, and subjects' warning buzzers were automatically controlled with Hunter interval timers. This tracking system is identical in all essential respects to the Kansas State University Versatile Electronic Tracking Apparatus (VETA) which has been described elsewhere (Trumbo, Eslinger, Noble, and Cross, 1963).

An intercom system was used to relay knowledge of results of the integrated error scores for every other trial during the 12-second rest period. The booths were fairly well sound proofed, and, in addition, white noise was piped in over loudspeakers two feet above and to the right of each subject to mask external noise.

Low ambient illumination was provided by shaded 10-watt night lights above and behind each subject.

Experimental Variables

Task

Each of the 18 groups received a continuous triangular-wave input which varied ± 4 cm. from the center along the horizontal axis of the CRT. Nine reversal positions, 1 cm. apart, produced eight distinct 1 cm. lengths of target movement from 1.0 to 8.0 cm. Trials were 72 seconds, separated by a 12-second rest period and anticipated by a 2-second warning buzzer.

Tracking Mode

Two modes of tracking were used: pursuit and compensatory. In the _pursuit_ condition the subject was presented with two slightly overlapping vertical lines called the target (top line) and the follower or cursor (bottom line). The target movement was controlled by external sources (punched tape), and the cursor was controlled by the subject's manipulation of his arm control. The subject's task was to keep the cursor aligned with the target throughout each trial period. A quail hunter following a flushed bird over his gun barrel while standing still is an example of pursuit tracking.

In the _compensatory_ condition the subject was presented with the same two vertical lines except that the target was now a stationary reference point, and the deviation of the cursor from this point represented the difference between the input signal and the subject's response. If the subject responded perfectly, the cursor would never move from the reference target. A radar operator maintaining a target pip in the center of his scope, or a motorist attempting to maintain a constant speed by keeping the speedometer needle on a certain mark are examples of compensatory tracking.

Predictability

Three levels of stimulus predictability were used: Fixed, I3X, and Random. The _Fixed_ pattern was composed of the eight distinct segment lengths (1.0 to 8.0 cm.) arranged so that the sequence began in the middle position and returned to the middle, from the opposite direction, at the end of one repetition in order that each following sequence would begin in the same direction. These limitations provided only a few possible sequences and one of these was chosen and is given in diagrammatic form in Appendix A. The total length of one sequence, which was the sum of the eight distinct line segments, was 36 cm., and this determined the minimum time for one repetition at the slowest (1.0 cm./sec.) rate to be 36 seconds. A minimum of two repetitions per trial was used thus making the trial length 72 seconds.

The I3X or semi-fixed pattern was constructed by inserting a quasi-randomly drawn segment into the basic fixed pattern at every fourth segment interval. The pattern began with the first three segments of the fixed pattern. The fourth segment, however, was randomly chosen with the restriction that its length did not exceed the ± 4 cm. range of the CRT measured from that particular reversal point. The next three segments were those of the fixed pattern--the first segment being the one which normally had its starting point at the end point of the random segment. This procedure was repeated until appropriate trial length (approximately 72 seconds) was achieved. (Appendix A gives the complete sequence for three complete trials).

For the Random pattern all segments were randomly chosen with the following restrictions: trial length equaled approximately 72 seconds and each succeeding segment was in the opposite direction of travel of the preceeding segment.

These three input programs were identical for both pursuit and compensatory tasks.

Rate

Three rates of target movement were used: one, two, and three cm. per second. These rates were controlled by a constant voltage input being fed into an integrator which gave the resulting constant rate output on the CRT. For example, a five-volt input yielded a rate of movement of 1 cm./sec. with the polarity of the voltage determining the direction (left or right) of target movement. The basic fixed pattern at the slowest (1 cm./sec.) rate repeated two times during each trial, while for the 2 cm./sec. and 3 cm./sec. rates it repeated four and six times, respectively. Thus, the basic pattern at the 1 cm./sec. rate had a frequency of 0.125 cps (nine reversal points--two repetitions) while for the 2 cm./sec. and 3 cm./sec. rates the frequencies were 0.25 cps and 0.375 cps, respectively.

Design

A 2x3x3 factorial experiment was used with eight subjects randomly assigned to each of the 18 groups (Table 1). The first factor was the tracking task with one-half of the subjects performing with the compensatory display and the other half using the pursuit display. The three levels of stimulus predictability constituted the second factor. One-third of the subjects tracked in each predictability level. The last factor was the rate of target movement, and one-third of the subjects tracked at each rate. A total of 100 acquisition or training trials and twenty retention trials were given each subject. Twenty trials were given each day for five successive days. Twenty retention trials were given on one day after a period of no practice which ranged from five to six weeks with an average interval of 5.2 weeks.

Table 1

Experimental Design

Mode 1 Compensatory	Fixed	Rate 1
		Rate 2
		Rate 3
	I3X	Rate 1
		Rate 2
		Rate 3
	Random	Rate 1
		Rate 2
		Rate 3
Mode 2 Pursuit	Fixed	Rate 1
		Rate 2
		Rate 3
	I3X	Rate 1
		Rate 2
		Rate 3
	Random	Rate 1
		Rate 2
		Rate 3

Procedure

Because of equipment limitations it was possible to run only a single tracking mode each week. Within this mode, however, all three rates and all three levels of predictability could be administered. With this restriction, all subjects were assigned by order of appearance to a randomly chosen pattern and rate within the mode which was selected for that week.

Subjects were run in pairs and both subjects were given instructions in booth 1 with the subject assigned to that booth seated in the control chair, and the subject assigned to booth 2 standing next to him with a clear view of the CRT.

Depending on which tracking mode was assigned, the pursuit or compensatory set of instructions was read to the subjects (these are given in their entirety in Appendix B). These explained the nature of the task, performance evaluation through error scores, and feedback of these scores. The strategies of anticipation of direction change and constant rate of movement of the arm control were also pointed out. Subjects were told to look for redundancies in the patterns, but were not told which pattern they would have. They were also told that the pattern would remain the same throughout training. Any questions they had were answered at the end of the instruction period. When the subjects returned for their retention session, they were briefed on pertinent points:

nature of the task, scoring, feedback, types of patterns, and number of trials.

RESULTS

Acquisition

The integrated error scores for the eighteen groups are given in Figs. 1 and 2. Acquisition and retention curves for the compensatory mode (M_1) are shown in the first, and data for the pursuit mode (M_2) are given in the latter figure. The mean integrated error scores are based on blocks of five trials with blocks 1-4, 5-8, 9-12, 13-16, 17-20 representing days 1-5, respectively, for the acquisition phase. The means for the first trial are also shown in order to indicate the relative starting positions of each group. For the retention phase, blocks 1-4 represent the 20 trials of the single retention period in five trial blocks.

In order to examine as many aspects of the data as possible, two separate analyses of variance were computed for the acquisition phase. A 2x3x3x5 complete factorial, with eight subjects per group, two modes of tracking, three levels of predictability, three rates of target travel, and with five blocks of the 20 trials conducted each day as a within-subject measure, is summarized in Table 2. Trials were grouped into blocks representing days mainly to simplify computations since interest was in the overall trend of the practice effects and their interactions with experimental variables.

The second analysis was performed on the last block of five acquisition trials in order to examine proficiency levels at the end of training.

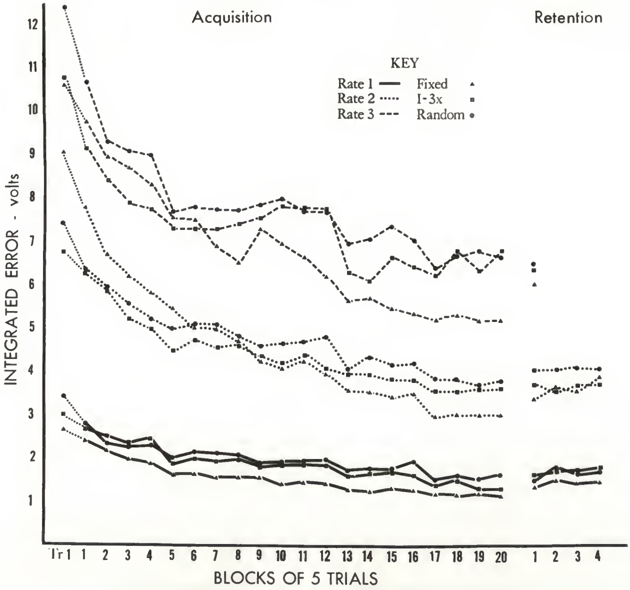

Fig. 1. Integrated error scores for the compensatory tracking mode for acquisition and retention.

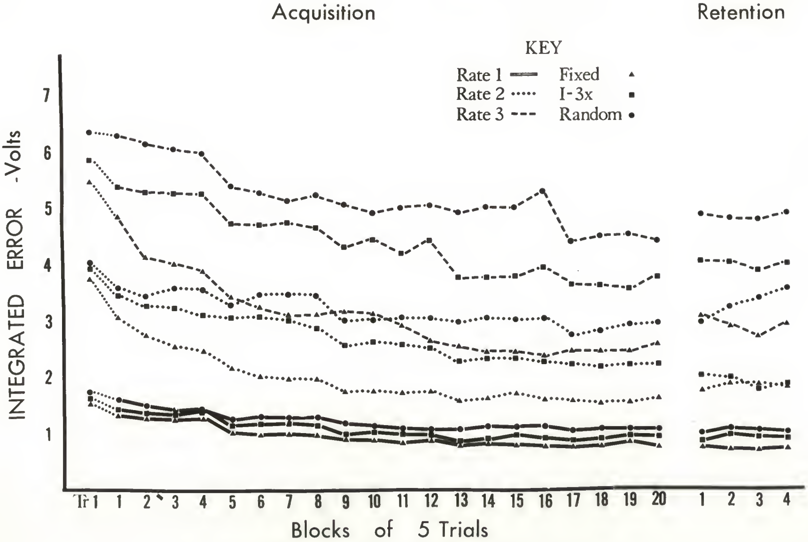

Fig. 2. Integrated error scores for the pursuit tracking mode for acquisition and retention.

Table 2

Summary of Analysis of Variance for Blocks 1 Through 5 of Acquisition Phase

Source of Variation	df	SS	MS	F
Between <u>S</u>s	143	3586.118		
M (mode)	1	653.786	653.786	219.908***
P (predictability)	2	95.971	47.986	16.141***
R (rate)	2	2231.431	1115.716	375.283***
MxP	2	11.459	5.730	1.927n.s.
MxR	2	172.096	86.048	28.943***
PxR	4	34.862	8.716	2.932*
MxPxR	4	11.561	2.890	<1.0
<u>S</u>s/gps. (error betw.)	126	374.952	2.973	
Within <u>S</u>s	576	374.036		
B (blocks)	4	214.989	53.747	410.282***
BxM	4	23.478	5.870	44.809***
BxP	8	9.245	1.156	8.824***
BxR	8	38.946	4.868	37.160***
BxMxP	8	5.892	0.736	5.618***
BxMxR	8	5.328	0.660	5.038***
BxPxR	16	5.860	0.366	2.794***
BxMxPxR	16	4.468	0.279	2.130**
Bx<u>S</u>s/gps. (error w/in.)	504	65.830	0.131	
Total	719	3960.154		

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

The lay-out of this analysis was identical to the first one except that there were no within-subject measures. The summary of the computations is given in Table 3.

As expected, all main effects were highly significant ($p < .001$) for both analyses. Integrated error scores at the end of training were higher (7.3 volt mean for the nine conditions) on the compensatory mode than the scores on the pursuit mode (3.9 volt mean for all nine conditions). This difference was also illustrated by the range of scores for each mode: the range of scores over the compensatory conditions was 9.7 volts (2.7 volts to 12.4 volts), and for the pursuit conditions was 4.9 volts (1.5 volts to 6.4 volts).

Input predictability was also a significant effect, indicating that some of the differences in performance were attributable partly to the different levels of difficulty.

Significance of the rate factor suggested that decrements in performance were caused, in part, by the increase in the velocity of the target. Effects of different levels of rate interacted with both the levels of predictability and across modes. The MxR effect is given graphically in Fig. 3 for the last block of trials, and it is almost identical in appearance to the interaction summed across blocks. Since differential effects were indicated by the significant F-term, a Fisher's LSD (Snedecor, 1956) was computed to allow individual comparisons to be made (LSD= 0.776). Results indicated that there was no difference in performance

Table 3

Summary of Analysis of Variance for Block 20
of Acquisition Phase

Source of Variation	df	SS	MS	F
M (mode)	1	73.046	73.046	125.720**
P (predictability)	2	29.292	14.646	25.260**
R (rate)	2	329.458	164.729	283.527**
MxP	2	1.079	0.539	<1.0
MxR	2	26.032	13.016	22.402**
PxR	4	9.593	2.398	4.127*
MxPxR	4	1.333	0.333	<1.0
Error	126	73.246	0.581	
Total	143	543.079		

* Significant at .005 level
** Significant at .001 level

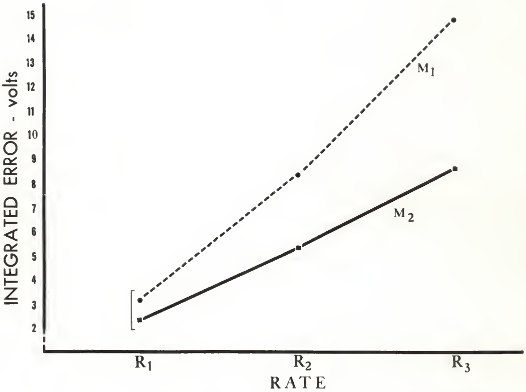

Fig. 3. Interaction of mode with rate at the end of the acquisition phase. Brackets denote non-significance between incorporated points.

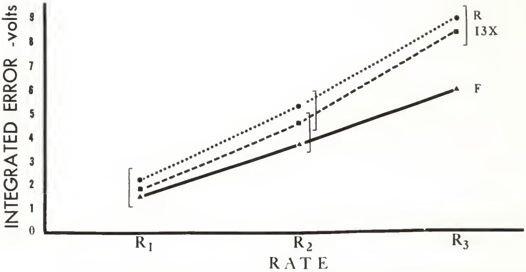

Fig. 4. Interaction of predictability with rate at the end of the acquisition phase. Brackets denote non-significance between incorporated points.

between modes at the slowest rate (R_1), but that performance was significantly different at the two faster rates.

Interpretation of the effects of the Rate and Predictability interaction (PxR) was slightly more complex (Fig. 4). Again, an LSD was computed (LSD=0.709) and comparisons were made between levels of predictability at each rate. At R_1 there was no difference in the performance among the three input patterns. At R_2, however, performance on the Fixed pattern differed from the Random pattern, while performance on the I3X pattern was not different from the other two. For the fastest rate (R_3) separations of both the Random and I3X patterns from the Fixed pattern were significant.

The effects of the independent variables and their interactions across blocks of trials are listed at the bottom of Table 2. This analysis was computed in order to establish that there were no large differences among variables during the learning phase. Because of the large number of degrees of freedom, and the apparent preciseness of the experiment which resulted in a very small error term, all interactions were highly significant. Examination of the graphs of these interactions, however, revealed no startling differences in performance from day to day. The significance of the main block effect (B) indicated that there was some overall improvement in performance as a result of practice. This same conclusion was drawn regarding the significant interactions of the block effect with each independent variable, that is, increases in performance occurred differentially among various levels of each factor. This was a logical finding since the various levels of each main effect must have differed at some point or points during the acquisition phase in order to be significant overall and at the terminal point.

The three second-order interactions and single third-order interaction were illustrations of the extreme sensitivity of the analysis due to the small error term. Examination of the graphs of these effects (not shown) indicated that the curves of the two-way interactions across blocks differed slightly when compared to the third variable. For example, in the BxMxP effect the BxP curves for M_1 were similar to those of M_2 except for the compensatory-fixed pattern. Apparently this was sufficient to result in a significance term even though the MxP interaction itself was not significant, either when averaged over blocks or at the terminal point (see Tables 2 and 3). Examination of the raw data revealed that three of eight subjects in the Compensatory-Fixed-R_2 condition were "poor" starters, that is, their scores were abnormally high, and this succeeded in raising the average performance for that cell to a value higher than the I3X or Random groups. By the end of training, however, these subjects had improved so that their scores matched those of the remainder of the group (see Fig. 1). This also occurred to a lesser degree with the Compensatory-Fixed-R_3 condition to the extent that the mean value after the first ten trials was higher than that of the I3X cell. By the end of training the deviant scores also had dropped to a level comparable to the rest of the group. Apparently some subjects at the more difficult levels of a compensatory task have considerable difficulty in grasping the concept of compensating for the cursor's movements, but, given sufficient training, they can attain an adequate level of performance.

Retention

To test for significant effects which may have occurred over the 5-6 week retention period, an analysis of variance using the same three main effects (mode, rate, and predictability) was computed. The last block of five trials of the acquisition data and the first block of five trials of the retention phase were the two repeated measures in the design. During the retention phase a total of 26 subjects were lost due to incorrect calibration of the equipment (21) or failure to return (5). These losses were spread over nine of the eighteen retention groups, thereby creating an unequal n situation.

In addition, the three complete groups at the Compensatory-R_3 task (24 subjects) had to be discarded because a faulty timer had decreased trial length and thereby decreased the error scores for those groups. An examination of these scores indicated that their relationship to each other was constant over the retention interval--indicating a decrease in magnitude but no change in the experimental relationship. A trial analysis of variance (including the "bad" data) on all groups across the retention interval showed no overall block effect, that is, no gains or losses occurred over the retention interval. Considering the type of shift, the nature of the overall results, and initial analysis data, it was decided that these three data points could be estimated effectively. Since no correction factor based on the system error was readily available, the values were estimated statistically.

Compensation for unequal subjects within cells was done using an unweighted means analysis (Winer, 1962; Snedecor, 1956). This analysis involves using group means as single observations within cells, and then multiplying these values by the harmonic mean which was the sum of the reciprocals of the number of subjects within each group. Since a single mean per cell was used, it was then feasible to estimate the means for the three missing cells using the iterative method explained in Snedecor (p. 312).

Table 4 summarizes the analysis. The independent variables were again highly significant ($p < .001$) suggesting that the effects obtained in the acquisition phase were still in evidence over the retention interval. The interaction of mode with rate (MxR) was also highly significant, indicating that the difference in performance on the two modes increased with an increase in target velocity.

The PxR relationship found in acquisition failed to appear at the retention interval. That this absence may be attributed to the effects of estimating the means for the three missing Compensatory-R_3 groups may be seen from an examination of Fig. 4. The greatest degree of interaction

Table 4

Harmonic Means Analysis for Retention Interval Using Block 20 of Acquisition and Block 1 of Retention as Repeated Measures

Source of Variation	df	SS	MS	F
Between Ss	143	710.812		
M (mode)	1	87.632	87.632	67.879*
P (predictability)	2	23.583	11.792	9.134*
R (rate)	2	402.735	201.368	155.978*
MxP	2	1.748	---	---
MxR	2	24.377	12.188	9.441*
PxR	4	7.122	1.780	1.379n.s.
MxPxR	4	0.927	---	---
Ss/gps. (error betw.)	126	162.688	1.291	---
Within Ss	95	116.813		
B (blocks)	1	0.945	---	---
BxM	1	0.041	---	---
BxP	2	1.120	---	---
BxR	2	0.395	---	---
BxMxP	2	0.564	---	---
BxMxR	2	0.170	---	---
BxPxR	4	0.977	---	---
BxMxPxR	4	1.271	---	---
BxSs/gps. (error w/in.)	77	111.330	1.446	---
Total	238	827.625		

* Significant at .001 level

$\bar{n}_h=4.589$

occurred at R_3 where both the Random and I3X patterns differed significantly from the Fixed pattern. The estimation procedure for the missing values at this point treated them as independent variables, and the values obtained did not contain "interaction effects." Therefore, in order for the PxR term to have manifested significance, it would have had to depend on half of the observations at the R_3 point, along with the observations at the R_2 point where differences were not as large. These differences apparently were not great enough to show a significant effect in this analysis.

Neither the block effect (B) nor any of the interactions of the main effects with blocks were significant, thus indicating no changes in performance (gains or losses) over the retention interval.

DISCUSSION

Acquisition

Results indicated that performance on both the pursuit and compensatory displays deteriorated as the rate of target movement increased. This was expected, for as Senders (1959) observed, "For virtually all signals, for practically any tracking system, and irrespective of the criterion chosen, system performance gets worse as frequency or velocity increases." (p. 7)

As an explanation of this general deterioration in performance, Noble, et al. (1955), in studying frequency response in a pursuit task, stated that, although the subject could probably:

> discriminate and/or produce the required amplitudes of movement, ... his inability at these [high] frequencies to perceive the temporal relations between stimulus and response patterns and to control the temporal organization of his own motor behavior...

was the probable cause of this loss of preficiency. Examination of Figs. 1 and 2 suggested that this may indeed have been true here. As rate increased, error scores for both displays increased, but, in general, scores on the more predictable patterns were lower than those on the less predictable patterns for a particular rate. This suggested that amplitudes (Noble, et al., used simple sinusoids) as well as more difficult repeatable sequences were discriminable, but that temporal errors (phase differences between target and cursor) may have been the cause of the increased error scores.

The fact that the effects of faster response rates may be offset by patterning the input is shown in Fig. 2 for the pursuit display. The subjects were able to learn the Fixed-R_3 pattern well enough so that there was no difference at the end of training between it and both the Random and I3X patterns of the slower R_2. Furthermore, there was no difference between the Fixed-R_2 pattern and the Random and I3X patterns for R_1, although the R_2 score did not fall below either of the R_1 scores. It appeared that Senders' (1953) conclusion that performance differences between these two displays is a function of the availability of information regarding direction, amplitude, rate, and acceleration of the target applies directly to the informational characteristics of the input as well as to the amount of pursuit component in a task.

As expected, the first prediction was verified, that is, performance on the pursuit mode became increasingly superior to that on the compensatory mode as the rate increased. Examination of the MxR interaction (Fig. 3) revealed that no significant difference existed between modes at R_1, but as target velocity increased, separation between the two modes also increased so that a difference existed at both of the higher rates. This finding was in general accord with studies (see Brigg's 1962 review) comparing performance as rate increased on both tracking conditions.

Prediction 2 was also verified: for any given rate, performance on both modes improved as the degree of stimulus predictability increased.

The results on the pursuit mode were similar to those obtained on the earlier unpublished pursuit tracking study mentioned in the Introduction. Since the input patterns were equated for number of cycles and total distance traveled by the target, differential performance indicates that the subjects who were presented the predictable patterns apparently were able to use this information to anticipate future responses.

The third prediction was that the subjects trained on the pursuit mode would better utilize predictability information and track better than their counterparts on the compensatory task, since the information would have greater <u>availability</u> under pursuit than under compensatory conditions. The findings suggested this but did not verify it since there was no significant MxP interaction term in either analysis. It was assumed that subjects on the Pursuit-I3X patterns would be able to discriminate the repeatable portions of the pattern, and thereby perform better than subjects with the Random pattern, while subjects on the Compensatory-I3X tasks would not be able to utilize the input redundancies because of the type of display. Error scores for subjects on the Pursuit-I3X patterns at R_1 and R_2 were different at the 0.10 probability level from those for the Random patterns, suggesting a tendency for this to occur. However, similar comparisons for the Compensatory display showed almost no difference in error between I3X and Random conditions.

Evidence for the fourth prediction that performance would degrade in both modes as stimulus predictability decreased and rate increased is presented in Fig. 4. At the slowest rate of movement, no differences existed, but, as rate increased, a significant difference occurred between the Fixed and Random patterns for both modes. At R_3 further separation occurred so that the I3X pattern was also different from the Fixed.

These results suggested that at R_1 the rate of target movement was slow enough to enable the subject to respond adequately to all levels of predictability. At faster rates of target movement performance on the Fixed pattern was significantly better than on the less predictable patterns indicating that the subjects' responses were facilitated by the redundancies in this pattern. It was expected that differential performance would be evident between the I3X and Random patterns but this was not apparent.

The fifth prediction assumed that the subjects on the pursuit task would show greater improvement on the Fixed and I3X patterns than would those tracking in the compensatory mode. Subjects on both modes were able to use the complete repeatability of the Fixed pattern, but neither group could distinguish the I3X from the Random pattern. As indicated in the discussion of the third prediction, the data did suggest that the fixed portions of the I3X pattern apparently facilitated performance because there was a difference between the Random and I3X patterns at the .10 level of the pursuit task. On the compensatory task there was no difference between the I3X and Random patterns, suggesting that the relatively minute amount of information presented to the subject was inadequate in that he was unable to use the repeatable portions of the I3X pattern.

It should be mentioned that the data may also support the counter-argument that subjects on both modes were able to perceive differences in predictability, but that the perceptual limitations of the compensatory task did not permit them to become very apparent. That is, terminal scores of the conditions in both modes lie mainly in the order of their predictability (Fixed-I3X-Random). Though there were significant differences only between the Fixed and I3X or Fixed and Random sequences, this general ranking would suggest that learning may have occurred on both modes for the Fixed and I3X patterns, but that the confounding of the subject's responses with the input on the compensatory display masked this conclusion. Depending on the amount of learning that occurred on each tracking mode, the differences between pursuit and compensatory would then be both learning and performance differences. The limiting case would be if compensatory trackers learned as much as pursuit trackers. The differences would then be totally performance differences and not learning differences. This suggestion would support that of Briggs and Rockway (1966) that these measures are performance and not learning.

Retention

Results of the retention analysis (Table 4) clearly showed no losses in performance over the 5.2 week average retention interval. The sumsof-squares from acquisition phase to retention phase (Blocks) was less than unity, as were all of the possible interactions. The F-values of the main effects summed across this interval were at the same significance level ($p < .001$) as they were during acquisition (Tables 2 and 3). Differences of performance between modes as a function of rate of target movement was similarly significant. As previously stated in the Results section, no conclusions may be drawn regarding the interaction of predictability with rate for this phase because of the estimated values for the Compensatory-R_3 tasks.

The conclusion that there were no losses in performance over the retention interval as measured by the integrated error data was in general agreement with the findings of Naylor and Briggs (1961). The results were contrary to the earlier triangular-wave study where performance on the predictable patterns showed losses over a one-month retention interval. Part of this difference may be due to differential practice. In the first study the acquisition phase consisted of 55 trials over a three-day interval, and for the present study subjects received 100 trials over a five-day period. Examination of performance curves for both experiments revealed that subjects on the fixed conditions for the prior study were still improving their performance at the end of the 55 trials, while the performance of subjects in the present study had reached a stable level by the end of 100 trials. Subjects in the first study apparently did not receive sufficient practice to completely learn and retain the pattern, while subjects in the present study appeared to have learned and even overlearned the pattern. This interpretation is supported by Naylor and Briggs' (1961) review in which tasks learned to an adequate level suffered little or no losses during retention.

The agreement of these findings with those in the review article does not necessarily imply contradiction to the findings of Trumbo, Noble, Cross, and Ulrich (1965), who found substantial losses over retention intervals "for those tasks in which greatest gains were realized during training." By examining individual trials of subjects over the total learning and retention period, the authors concluded that a loss in temporal accuracy was the most critical factor for skill retention losses in a task employing a step-function input. For a triangular-wave task the temporal accuracy may also deteriorate during the retention interval, but this would not be evident from the integrated error data. Since the error in both tasks is proportional to the distance and time the cursor is away from the target, very little error would build up due to timing inaccuracies in a constant rate task because the distance between the two increases more slowly than it would on a step-function task. It follows then, that, in terms of performance as measured by integrated error scores, spatial accuracy (i.e., learning the spatial positions), and rate-matching skills may be much more important for a constant rate task than for a discrete task.

Summary

The effects of task predictability and task rate on pursuit and compensatory tracking tasks were studied using a continuous-wave, constant-rate input function with nine reversal points displayed on a CRT.

A 2x3x3 factorial design was used with comparisons between two tracking modes (pursuit and compensatory), three levels of predictability (Fixed, I3X, and Random), and three rates of target velocity (1, 2, and 3 cm./sec.).

It was assumed from a review of previous research that the effects of task predictability would be affected by the type of tracking task and target velocity. Five predictions were drawn from the research:

1. Differences in performance levels between pursuit and compensatory tracking would become greater as a function of an increase in rate. This would be indicated by a mode by rate (MxR) interaction in the analysis of variance computed on the data.
2. Performance on both modes would improve as the degree of stimulus predictability increased.
3. The pursuit mode would allow higher performance levels on the predictable and semi-predictable patterns than would the compensatory mode. In other words, it was predicted that distinctly different performance scores would be attained as a

function of pattern predictability on the pursuit mode, whereas the compensatory trackers would be able to distinguish only the completely predictable pattern.

4. Performance would degrade in both modes as stimulus predictability decreased and rate increased.
5. As rate is increased, the effects of increasing predictability would be greater for the pursuit mode than for the compensatory. This would be indicated by an MxPxR interaction.

Results indicated that:

1. Performance on the pursuit mode became superior to that of the compensatory mode as a function of an increase in rate.
2. Performance as a whole was facilitated by an increase in stimulus predictability.
3. There was a tendency for subjects on the pursuit mode to discriminate between the I3X and Random patterns, but no such tendency was observed on the compensatory mode.
4. An interaction between stimulus rate and task predictability was observed in that, as rate increased, performance on the semi-predictable (I3X) pattern degraded.
5. The deterioration in performance due to the above interaction appeared to be greater in the compensatory mode.
6. No significant retention effects were found for either tracking display.

The overall results tended to support Sender's (1953) hypothesis that tracking proficiency (as measured by performance scores) is determined by the availability of information as to direction, rate, amplitude, and acceleration. It has been suggested by this study that availability of information applies to recurring or redundant patterns of the input stimulus as well as to the amount of pursuit component present in a task as demonstrated by Senders. The results also independently tend to support the conclusion that the superiority of the pursuit mode may be due to performance differences and that learning effects may be approximately equal.

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APPENDICES

APPENDIX A

Construction of the Fixed, I3X, and Random Patterns

All sequences begin and end at the center of the CRT. Units are in centimeters with the maximum range of target travel ± 4 centimeters. R and L denote movement to the right and left as seen by an observer facing the CRT. Data for the 1 cm./sec. rate (R_1) is shown. R_2 and R_3 were constructed in similar fashion with the necessary increase in cyclic rate due to the increase in rate of movement. The I3X pattern is three trials long to prevent "random" portions of the pattern from occurring too frequently. Underlined figures are the random values. The random pattern was also three trials long to increase "randomness."

Fixed	I3X			Random		
	#1	#2	#3	#1	#2	#3
4R	4R	4R	4R	1R	4R	2L
8L	8L	8L	8L	3L	8L	6R
6R	6R	6R	6R	1R	3R	8L
5L	4L	6L	1L	2L	2L	4R
7R	1R	6R	1R	7R	6R	1L
3L	3L	5L	2L	2L	6L	5R
1R	6R	7R	4R	1R	3R	7L
2L	1L	3L	1L	5L	1L	4R
4R	1R	1R	1R	3R	3R	1L
8L	2L	2L	3L	1L	4L	5R
6R	4R	4R	1R	3R	4R	8L
5L	7L	7L	4L	6L	2L	4R
7R	7R	7R	1R	4R	1R	2L
3L	3L	3L	3L	2L	5L	5R
1R	1R	1R	6R	5R	8R	1L
2L	6L	2L	2L	7L	8L	2R
	6R		4R	4R	4R	6L
	2L		8L	5L		2R
			6R	6R		
			2L	3L		
				1R		

APPENDIX B

Instructions

Pursuit

The task in which you will be participating this week is called a tracking task. The upper line on the scope (E points to the target line) is called the target. When we begin you will see this line move back and forth at a constant rate of speed, reversing itself at different points along the horizontal axis. The lower line is called the follower or cursor (E points to the cursor). The position of this line is determined by the position of your arm control. Try moving the arm control back and forth to see how it works. Your task in this experiment is to keep the follower as nearly superimposed on the target as possible while the target is moving back and forth across the screen. It will look like this when you have the follower positioned properly (E superimposes the cursor on the target).

The primary way in which your performance will be evaluated is in terms of your error score. Error in this case is the amount by which the position of the target and the follower differ. For example, if the position of the follower is here with respect to the target (E positions the follower so that it is not superimposed on the target) this difference (E points out difference between the target and the cursor) represents the error and this error accumulates all during the time the follower is not superimposed on the target. If there is a large difference between the target and the follower, the error score will build up very rapidly. If there is only a small difference, the error score will build up more slowly. But remember, any time the two lines are not perfectly superimposed, there is always some error building up. At the end of a trial, which lasts about one minute, we record this score. So that you may have an idea of how well you are performing, we will tell you the score you made on every other trial. This will be done by announcing it over the intercom. This will be a number and will be meaningless at first. As you become more proficient, however, your scores will become smaller and smaller.

There are a couple of strategies that can be used to keep your error score as small as possible. One of these is anticipation. As you have more and more experience with the task, you may find that all or part of the sequence of movements repeat themselves during a trial. That is, the distance that the target travels and the positions on the scope where it reverses direction may become familiar so that you may anticipate the directional change. By anticipating this change you eliminate your reaction time which can add a great deal to your error score. The second strategy is, once you superimpose the follower onto the target, move the arm control at a constant rate and you will stay locked onto the target untilit changes direction .

Remember, the sequence of movements or pattern may repeat itself constantly in a completely fixed manner, or only parts of the pattern may repeat, or perhaps no part will repeat. Whatever type of pattern you do have, you will have it for the rest of the week. We do not tell you which of these patterns you will have--we want you to try to determine if there are recognizable parts in the sequence so that you can bring your score down by the strategies mentioned.

Each day you will have twenty one-minute trials with a fifteen-second rest period between each trial. During this rest period we will tell you your score every other time--remember the lower the score the better you are doing. Two seconds before the rest period is over a buzzer will sound and the next trial will begin. Do you have any questions?

Compensatory

The task in which you will be participating this week is what is called a tracking task. The upper line on the scope (E points to the target line) is called the target. This is a reference point and will remain stationary. The bottom line is called the follower or cursor (E points to the cursor). This line is controlled jointly by me in the control room by use of a programmed tape, and by you through manipulation of your arm control. Try moving the arm control back and forth to see how it works. Your task in this experiment will be to counteract the movement that we give to the cursor by moving the arm control in the opposite direction so that it is brought back to the center and superimposed onto the reference target. Your task then is to maintain the follower exactly in the center of the scope, touching the reference line. A perfect job of tracking would be such that the cursor never deviates from the target. Naturally you will find this impossible to do because changes in direction of movement cannot be seen and only when the cursor suddenly deviates from the target will you know that you must change the direction of movement of your arm control.

An everyday example of this is trying to maintain a car at a constant rate of speed, say, 50 mph. The top line or target might be the 50 mph mark on the speedometer, and the lower line might be the speedometer needle. As you climb a hill, the tendency would be for the car to slow down and the needle would then fall to the left. To maintain the desired speed you would step on the gas (in this case the arm control is the gas control) to increase speed by moving the control to the right. As you top the hill and start down, you must decrease the gas (move the control to the left) because the increased speed would cause the needle to move past the 50 mph mark to the right. This is approximately the same thing you will be doing on this task--compensating for changes from a desired needle setting by manipulating your arm control.

The primary way in which your performance will be evaluated is in terms of your error score. Error in this case is the amount by which the position of the target and the follower differ. For example, if the position of the follower is here with respect to the target (E positions the follower so that it is not superimposed on the target) this difference (E points out difference between the target and the cursor) represents the error and this error accumulates all during the time the follower is not superimposed on the target. If there is a large difference between the target and the follower, the error score will build up very rapidly. If there is only a small difference, the error score will build up more slowly. But remember, any time that the two lines are not perfectly superimposed, there is always some error building up. At the end of a trial, which lasts about one minute, we record this score. So that you may have an idea of how well you are performing, we will tell you the score you made on every other trial. This will be done by announcing it over the intercom. This will be a number and will be meaningless at first. As you become more proficient, however, your scores will become smaller and smaller.

There are a couple of strategies that can be used to keep your error score as small as possible. One of these is anticipation. As you have more and more experience with the task, you may find that all or part of the sequence of movements that you must make with the arm control repeat themselves during a trial. That is, the distance that you move the control before a deviation from the target tells you to change direction may become familiar such that a sequence of these movements can be learned. Or perhaps only some of the movements may remain the same while others change. By anticipating these changes and not waiting for the sudden deviation of the cursor from the center mark, you can eliminate your reaction time which will contribute a great deal to lowering your error score. The second strategy is, once you superimpose the follower on the target, move the arm control at a constant rate, and you will stay locked onto the target until a direction change occurs.

Remember, the sequence of movements or pattern may repeat itself constantly in a completely fixed manner, or only parts of the pattern may repeat, or perhaps no part will repeat. Whatever type of pattern you do have, you will have it for the rest of the week. We do not tell you which of these patterns you will have--we want you to try to determine if there are recognizable parts in the sequence so that you can bring your score down by the strategies mentioned.

Each day you will have twenty one-minute trials with a fifteen-second rest period between each trial. During this rest period we will tell you your score every other time--remember the lower the score the better you are doing. Two seconds before the rest period is over a buzzer will sound and the next trial will begin. Do you have any questions?

PERFORMANCE IN PURSUIT AND COMPENSATORY TRACKING TASKS AS A FUNCTION OF RATE AND PREDICTABILITY

by

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B. A., New Mexico State University, 1964

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The effects of task predictability and task rate on pursuit and compensatory tracking tasks were studied using a continuous-wave, constant-rate input function with nine reversal points displayed on a CRT. A 2x3x3 factorial design was used with comparisons between two tracking modes (pursuit and compensatory), three levels of predictability (Fixed, I3X, and Random), and three rates of target velocity (1, 2, and 3 cm./sec.).

Predictions were: 1) Performance on the pursuit mode would be superior to the compensatory mode as rate increased. 2) Performance on both modes would improve as the degree of stimulus predictability increased. 3) Performance on the pursuit mode would be superior to that of the compensatory mode as predictability increased. 4) Performance would deteriorate on both modes as predictability decreased and rate increased. 5) As rate is increased, the effects of increasing predictability would be greater for the pursuit mode than for the compensatory mode.

Results suggested that: 1) Performance on the pursuit display was superior to the compensatory display as rate increased. 2) Performance as a whole was facilitated by an increase in stimulus predictability. 3) Pursuit subjects tended to discriminate partially predictable inputs, whereas those subjects on the compensatory display could not. 4) With an increase in rate, the ability to discriminate the partially predictable patterns deteriorated. 5) The compensatory trackers appeared to have

more difficulty in tracking the I3X pattern than did the pursuit trackers. 6) No significant retention effects were found for either display.

The general findings tended to support the theory that tracking proficiency is determined by the availability of information presented to the subject. The results also tended to support the assumption that superiority of pursuit trackers is a performance measure and not a learning measure.