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TRACKING PERFORMANCE ON COMBINED
COMPENSATORY AND PURSUIT TASKS

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**TRACKING PERFORMANCE ON COMBINED
COMPENSATORY AND PURSUIT TASKS**

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FOREWORD

This report was prepared by the Psychology Branch of the Aero Medical Laboratory, Research Division, Wright Air Development Center, under a project identified by Research and Development Order No. 694-17, "Design and Arrangement of Aircraft Controls", with John W. Senders acting as Project Engineer.

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ABSTRACT

A comparison has been made between compensatory and pursuit tracking for a one dimensional visual tracking task, and the functional relationship between tracking accuracy and the nature of the tracking task has been determined for various combinations of pursuit and compensatory tracking. The results indicate that important, as well as statistically significant, differences exist between compensatory and pursuit tracking, and that accuracy of tracking increases markedly as a function of the amount of pursuit component which exists in the task. However, a tracking task which has a pursuit component of 50 per cent or greater is not significantly different, in terms of time-on-target score, from a 100 per cent pursuit task.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:

for *Henry S. Murrell, H Co/USAF*
ROBERT H. BLOUNT
Colonel, USAF (MC)
Chief, Aero Medical Laboratory
Research Division

SECTION I

INTRODUCTION

The term "tracking" describes a wide variety of tasks. Virtually every human task involving adjustment and control functions, coupled with a source of information about the results of the adjustment, can be included in a discussion of tracking. It has been customary to classify tracking tasks as one of two kinds, compensatory tracking and pursuit tracking, which may be defined as follows:

A compensatory tracking task is one in which an operator is presented with a display consisting of an indicator and a zero reference point and is required to maintain the indicator on the reference point by compensating for the movements of the indicator imposed upon it by outside influences. A motorist, trying to maintain a constant speed by keeping his speedometer needle always on 50, or a radar operator maintaining a target pip on the center of the screen, are both engaged in compensatory tracking. A perfect performance in a compensatory tracking task would result in a situation of no movement, since the target, or zero reference point, would never move, and if tracking were perfect the follower or pip or needle would never move off the reference point.

A pursuit tracking task is one in which an operator is presented with a display consisting of two indicators, called, for convenience, the target and the follower. The target is caused to move by outside influences and the operator controls the follower in such a way as to keep it superimposed on the target. A gunner, following a moving airplane with the sights of a flexible gun on a fixed platform, is engaged in pursuit tracking. Perfect pursuit tracking would result in continuous movement, since the target moves and the follower would reproduce this movement perfectly.

Although it has been customary to classify all tracking tasks into these two categories, such classification is not always easy or satisfactory. On radar presentations if both the target and the cursor move then the task is pursuit tracking, if only the target (or the cursor) moves then the task is compensatory. There are, however, tasks of visual and radar gunnery where there are aspects both of pursuit and compensatory tracking. Further, much tracking is done from platforms which are not steady in that they are subject to vibration, or to continuous movement relative to the ground or some other fixed background. Although studies have been performed on the effects of vibration on tracking (as in a tank), the emphasis has been on control motions, friction, jolting, and the relations between and among them instead of on the total tracking task, including both a perceptual and a motor component (1, 2). However, as Hick (2) points out, "... the effects of an unsteady platform on misalignment or on the perception of misalignment, may be more severe than its effects on the manipulation of the control."

Instead of dichotomizing tracking tasks, it seems reasonable to think of a continuum, on which the two limiting cases are pure pursuit tracking and pure compensatory tracking, but with many steps between. A task can then be described as including a component of each kind, and the relative amount of each component can be specified. The ends of this continuum have already been investigated: Poulton has shown that visual pursuit tracking is more accurate than compensatory

tracking by a factor of two to one (3). The functional relationship between some measure of performance and the per cent of the pursuit component in the task has not been investigated, and it is the purpose of this experiment to investigate this relationship. Under the conditions to be described the compensatory component was introduced directly into the display, rather than by moving the operator's platform as in some operational cases and generalizing from the results of this study to operational situations should therefore be done cautiously.

SECTION II

APPARATUS AND PROCEDURE

Apparatus. A dual beam cathode ray oscilloscope, using a P-2 phosphor (blue against the gray of the tube face) served as a display device. The problem was generated by a cam rotating at one revolution per minute. The cam profile was composed of the sum of two sinusoids. The problem signal was derived from a low torque potentiometer driven by a rack and pinion, the rack being provided with a miniature ball bearing at the point of contact with the cam.

The output of this assembly was divided into two parts by a proportioning network, permitting varying proportions of the problem signal to be fed into the two channels of the oscilloscope. In series with one channel was a subject controlled voltage and a circle generator. The other channel led directly to the oscilloscope amplifier. This arrangement provided a circle under the control of both the subject and the problem generator and a spot that could be moved by the problem generator. The gains of the two amplifiers were adjusted to give equal displacements of the two indicators at all positions of the proportioning control. The subject was provided with a $3 \frac{1}{4}$ " fluted knob in a plane parallel to that of the tube face. Rotation of the knob enabled the subject to bring the circle over the spot by compensating for the voltage difference between the two input channels. One hundred and sixty degrees of knob movement (eighty degrees on each side of center) provided control over the whole range of the display. In the pursuit setting, the circle moved .07 degrees of visual angle for each degree of control movement. Time-on-target scoring was accomplished by amplifying the voltage difference between the two channels to a level which would operate a relay which in turn controlled the scoring clock. The scoring area was a function of the gain of the scoring amplifier and could be controlled precisely. Circle size was adjusted by a separate control to correspond to the size of the scoring area. A block diagram of the apparatus is shown in Figure 1.

The display and the subject's control were mounted in an experimental room apart from the remainder of the apparatus. The subject's control was placed below and to the right of the display screen (or to the left for the one left-handed subject). The experimental room was painted flat black, and sufficient glareless illumination was provided to make the whole arrangement visible to the subject. The problem generator and the scoring device were mounted in a separate chamber where the experimenter could operate the device and record results, and where the relay clicks would be inaudible to the subject. Figure 2 shows the display apparatus and the experimental layout.

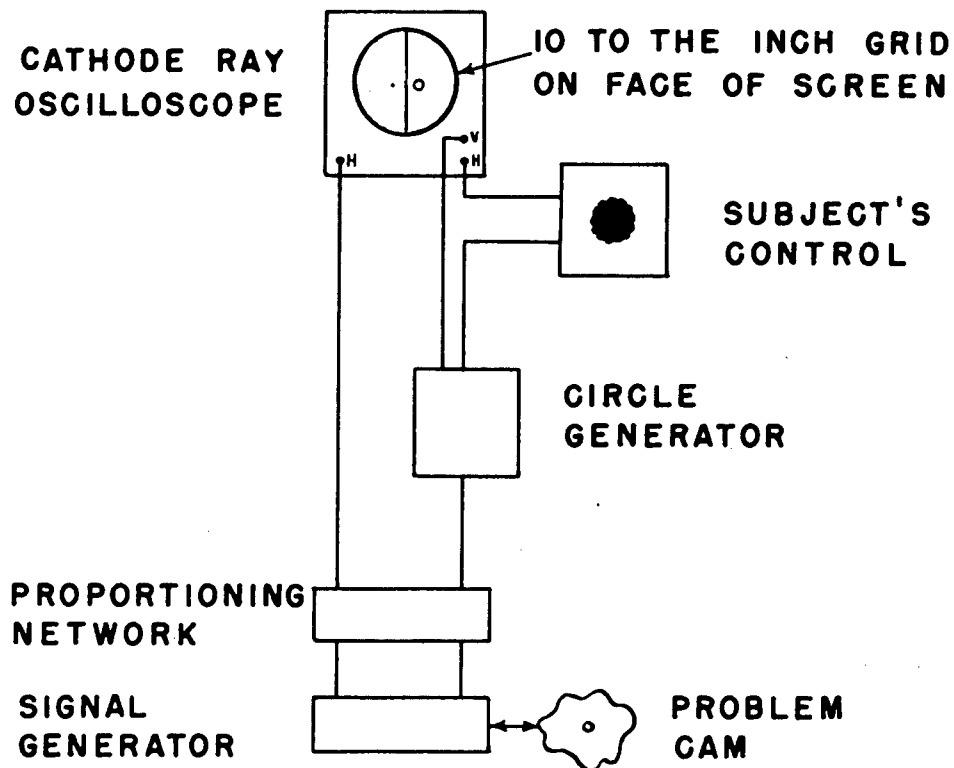


FIGURE 1: BLOCK DIAGRAM OF APPARATUS

Procedure: The subject sat before the display so as to place the screen at eye level. The screen was approximately 14 inches from the subject's eyes. To the right (left for the left-handed subject) was an arm rest and the subject's control knob. Subjects wore headphones to shield out any audible clues coming from the scoring apparatus.

The apparatus was allowed to warm up for four hours prior to the actual testing of the subjects. The warm-up period eliminated virtually all drift from the amplifiers during experimentation. Immediately before running a subject, the scoring area was checked for width and centering.

Five college students, two men and three women all with normal, uncorrected vision and with no prior experience in radar or oscilloscope operation, were used as subjects. When the subjects were comfortably seated, with the headphones on, the following instructions were given:

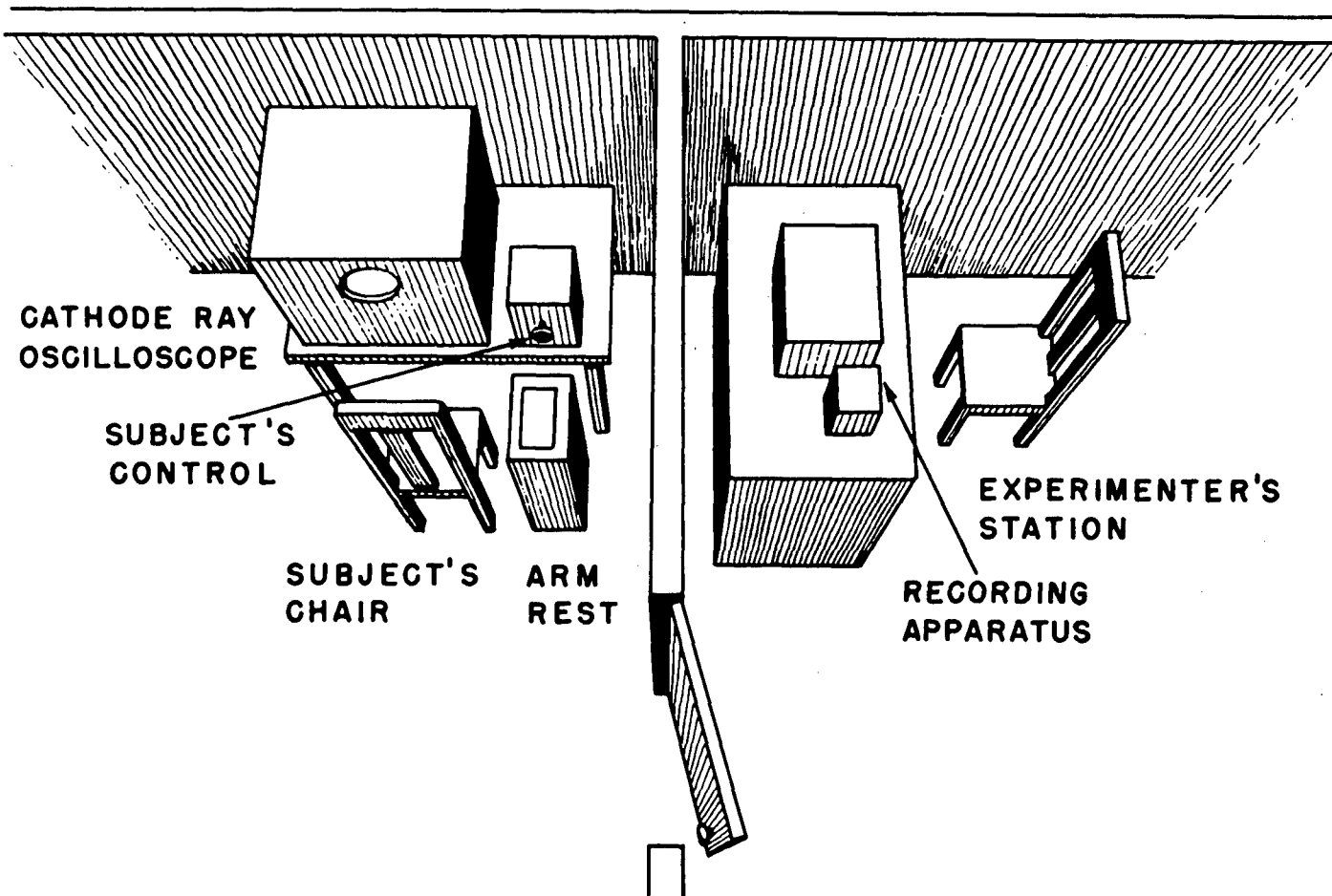


FIGURE 2: EXPERIMENTAL LAYOUT

"Each trial will be one minute long. Your task is to keep the circle over the dot by moving this knob (pointing to the control knob) appropriately. There will be five one minute trials and then a two minute rest. After each trial place the circle over the dot if it is not already there. Your task will be the same for each trial although the nature of the trial may vary." The subject was then given an opportunity to operate the control knob for 30 seconds and observe the behavior of the circle, with the apparatus set in the pursuit condition, before beginning the actual trials.

The subject was allowed a two minute rest between successive sets of five trials and a five minute rest between the third and the fourth sets. During these rest periods, the experimenter checked the centering and corrected any drift that might have occurred.

Five conditions or task variations were tested;

1. 0% pursuit. (100% compensatory): The circle moved and the subject tried to return it promptly and correctly to the (stationary) spot, which provided the zero reference point.
2. 25% pursuit. (100% compensatory): The ratio of spot movement to circle movement was 1:3. That is, if the spot moved one degree to the left, the circle moved three degrees to the right.
3. 50% pursuit. The ratio of spot movement to circle movement was 1:1. If the spot moved two degrees to the left, the circle moved two degrees to the right.
4. 75% pursuit. The ratio of spot to circle movement was 3:1. If the spot moved three degrees to the left, the circle moved one degree to the right.
5. 100% pursuit. Only the spot moved, the circle remaining stationary unless moved by the subject.

These conditions were achieved by dividing the cam output between the target spot and the follower. In all conditions the control motion required to maintain the circle over the spot was identical, both in direction and in amount. Figure 3 shows in schematic fashion the display changes and the required control movement for a given slope of the cam profile.

The order of presentation of the various conditions was such as to balance out the effects of interaction between and among them.

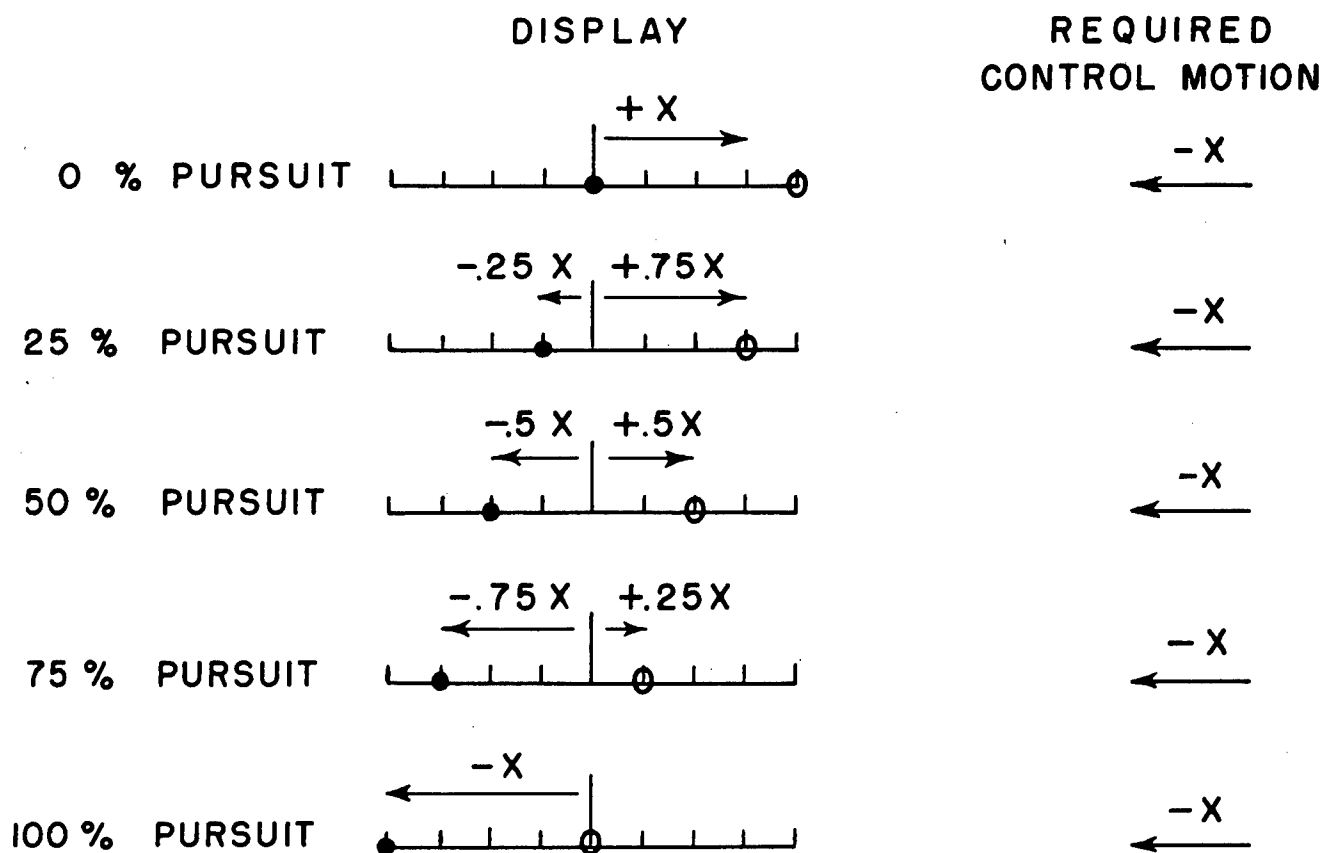


FIGURE 3: CONTROL MOTION AND DISPLAY VARIATIONS FOR A CONSTANT INPUT UNDER VARIOUS CONDITIONS.

RESULTS

Each of five inexperienced subjects performed twenty-five sets of five trials each, five sets on each of the five conditions tested (a total of 125 sets for each subject, or 625 sets in all). Table I presents the average time-on-target scores for each subject, under each condition, on each of the five practice days. (Each figure is the average of the five trials on a given day). This table also presents the mean for each subject for each condition, and the mean for all subjects for each condition (all days).

TABLE I

Average Time on Target in Seconds Per One Minute Trial

Subject	Day	Task				
		Compensatory	.25 Pur.	.50 Pur.	.75 Pur.	Pursuit
JA 1	1	19.61	22.24	29.75	27.79	28.50
	2	23.48	23.45	27.34	29.95	27.53
	3	24.25	27.26	30.10	29.76	35.72
	4	30.61	36.42	37.95	41.19	41.66
	5	32.13	32.60	34.17	38.76	34.92
	MEAN	26.02	28.39	31.86	33.49	33.67
JA 2	1	22.29	28.50	31.28	30.88	29.29
	2	26.05	29.37	31.69	35.20	34.84
	3	28.06	29.21	37.39	39.01	36.76
	4	29.19	29.30	36.06	37.46	34.47
	5	33.92	31.72	37.11	38.22	39.15
	MEAN	27.90	29.62	34.71	35.95	34.90
PC	1	22.58	25.95	27.34	29.23	28.26
	2	33.66	35.70	38.55	39.21	39.09
	3	37.57	40.81	38.80	44.43	42.47
	4	35.42	40.61	41.39	43.91	42.64
	5	33.73	40.98	41.94	44.52	42.88
	MEAN	32.59	36.81	37.60	40.26	39.07
DN	1	21.44	25.03	31.07	31.88	30.97
	2	32.17	35.77	39.30	41.93	40.57
	3	35.36	37.61	41.98	41.11	41.90
	4	37.12	43.38	45.72	47.17	47.22
	5	36.67	40.57	42.37	45.79	46.10
	MEAN	32.55	36.47	40.09	41.58	41.35
RM	1	20.62	25.71	29.63	30.91	30.49
	2	26.49	31.82	34.93	34.15	35.67
	3	31.89	35.71	37.45	40.62	41.12
	4	28.12	32.58	37.80	36.18	40.48
	5	29.67	34.40	40.29	43.41	41.60
	MEAN	27.36	32.04	36.02	37.05	37.97
GROUP MEAN		29.28	32.67	36.06	37.67	37.39

TABLE II
ANALYSIS OF VARIANCE

Source	Sum of Squares	D.f.	Variance Estimate	F	P
Conditions	1288.20	4	322.05	145.07	.001
Subjects	1028.20	4	257.05	8.94	.01
Days	2134.75	4	533.69	18.56	.001
C x S	57.97	16	3.62	1.63	NS
C x D	28.08	16	1.76		NS
S x D	460.25	16	28.75	12.95	.001
C x S x D	141.97	64	2.22		
Total	5139.42	124			

An examination of this table shows that for all five subjects, time-on-target score increased as the task shifted from compensatory to pursuit tracking, and, although no curves have been fitted to the data, the function is a negatively accelerated one with relatively little difference between 75% pursuit and 100% pursuit.

The data were analyzed by the analysis of variance technique. The results, as summarized in Table II, show that individual differences, differences between days, and differences between experimental conditions were all highly significant, P being less than .001. The interaction between subjects and days was also significant, indicating that different individuals learn at different rates. T-tests were then performed between each condition and every other condition, and the results are summarized in Table III.

TABLE III

Values of "t" for the Various
Differences Between Conditions

	25% Pur.	50% Pur.	75% Pur.	100% Pur.
0% Pur. (Comp.)	6.28***	***	***	***
25% Pur.		6.28***	***	***
50% Pur.			2.98***	2.46*
75% Pur.				.52 NS
*** P < .001 ** P < .003 * .01 < P < .02				

This table shows that performance changes significantly when the amount of the pursuit component in a tracking task is increased from zero or from a small amount to 75%, but does not continue to change as the amount of the pursuit component is increased from 75% to 100%.

Figures 4, 5, and 6 present graphically the data of Table I. Figure 4 shows the relation between time-on-target and the per cent of the pursuit component in the task. In this figure the leveling off of the curves between 50 and 100% should be noted. Figure 5 is a learning curve showing the relation between time-on-target and the number of days practice; it should be noted that the shape of the curve is essentially the same for all experimental conditions although of course the absolute level is different. These curves, too, show a leveling by the fifth day, indicating that learning was reaching a maximum. Figure 6 is again a score-vs.-task function, this time with the scores for all subjects combined for each of the five successive days. Here, too, the shape of the function is essentially the same for all days, although the absolute scores show improvement for successive days.

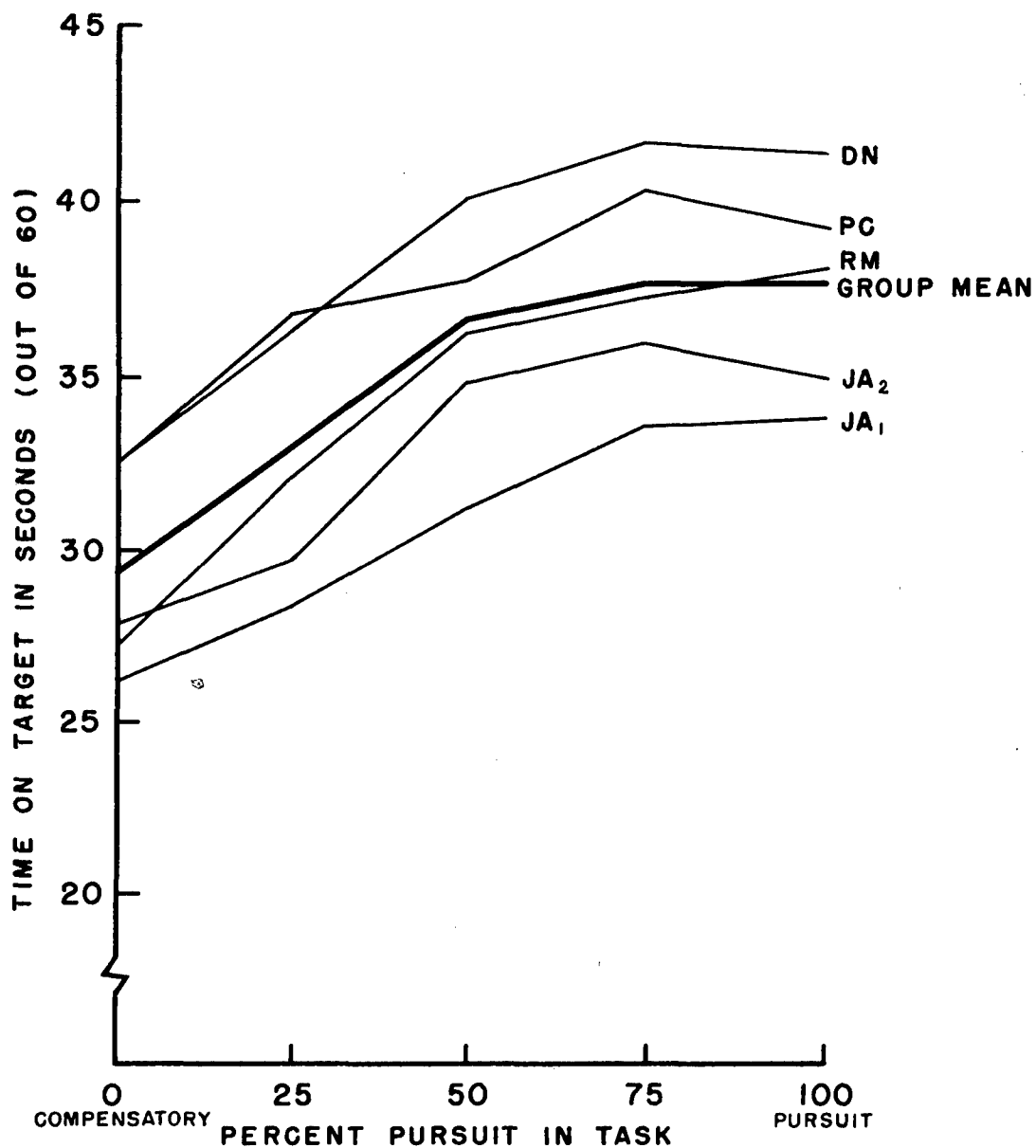


FIGURE 4: COMBINED TIME-ON-TARGET SCORES FOR EACH SUBJECT AND FOR THE GROUP.

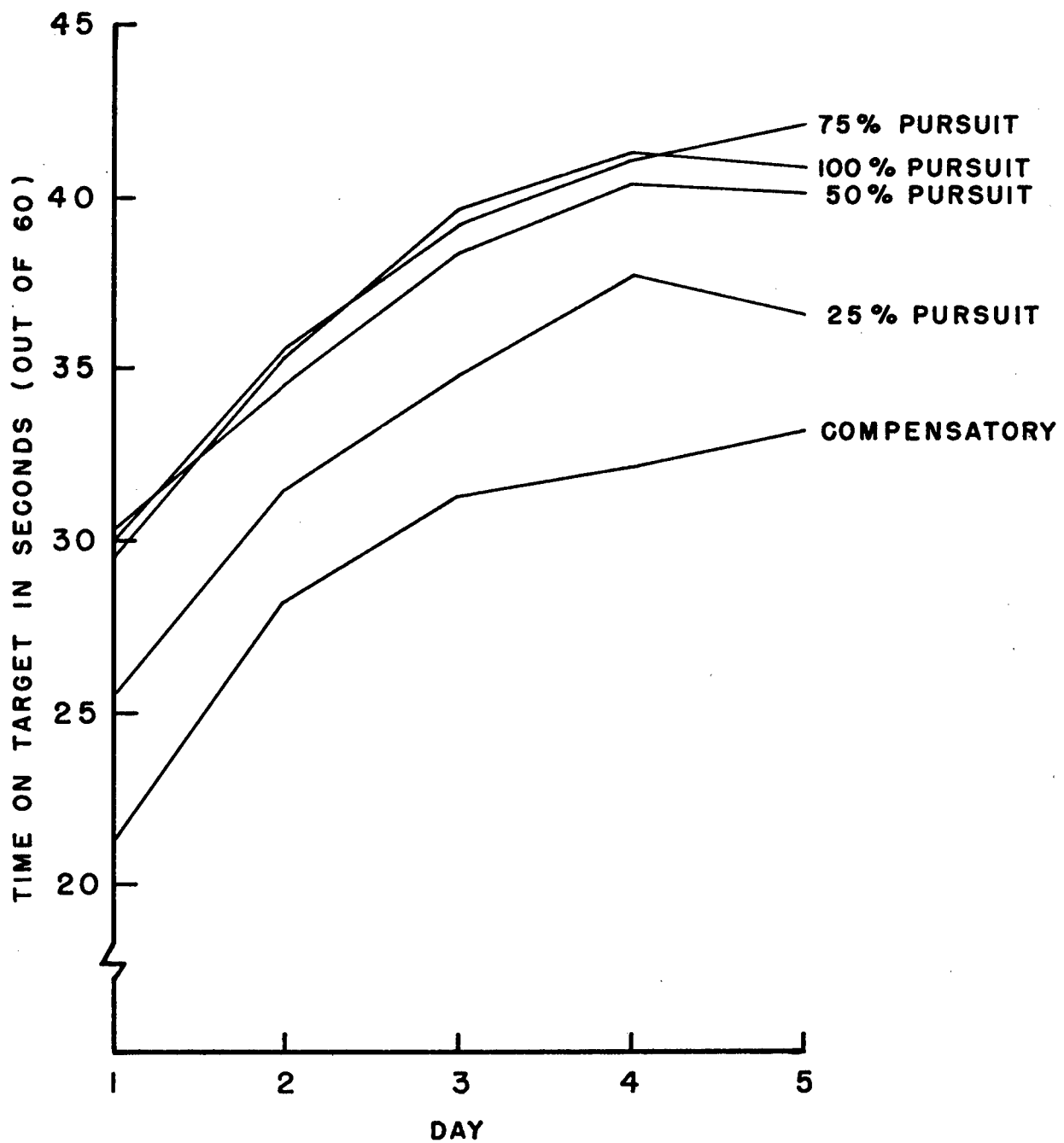


FIGURE 5: LEARNING CURVES OF EACH OF THE 5 TASKS.
GROUP MEANS

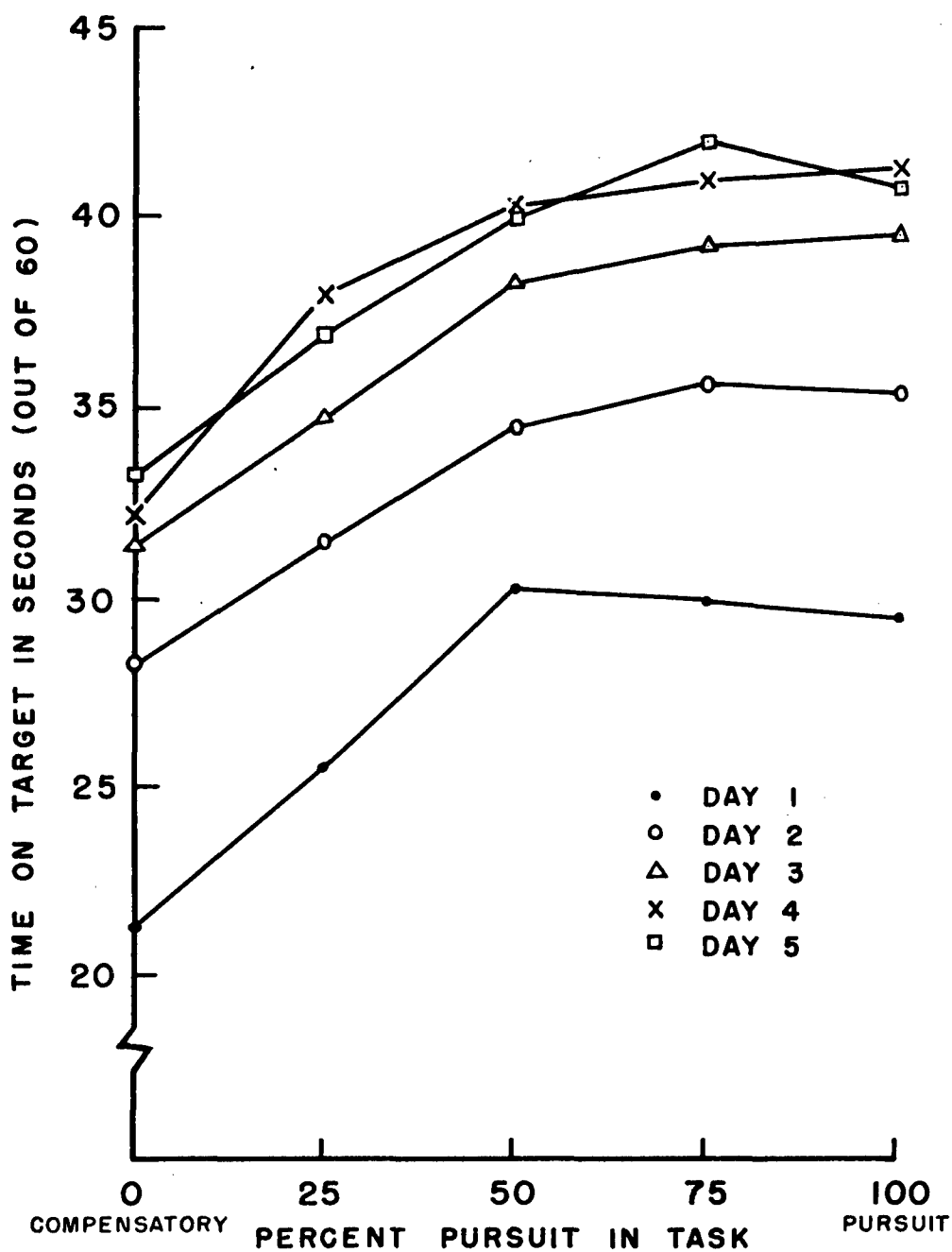


FIGURE 6: SCORE VS. TASK FUNCTION FOR FIVE SUCCESSIVE DAYS - ALL SUBJECTS COMBINED.

DISCUSSION

The results are clear. Tracking performance improves continuously and significantly as the per cent of the pursuit component in a tracking task is increased from zero to 75, and thereafter shows little or no improvement. The superiority of pursuit tracking over compensatory tracking confirms Poulton's results, (3), but the nature of the functional relationship could not have been predicted from his study.

The differences found between different kinds of tracking could not have been due to the motor functions involved, since these were identical for all conditions. Therefore, they must have been due to differences in the nature of the visual display. So considered, the differences are not surprising. In pursuit tracking, three sorts of information are continuously available to the subject, whether he performs well or poorly: position, rate, and acceleration. In compensatory tracking, these sorts of information are available only if he tracks poorly or not at all. The better he performs, the less information is available to him, until, if he ever achieved perfect tracking, he would have no information at all available. (From the visual display, that is; since the kinesthetic feedback is the same for both conditions, it is not considered here.) Under the experimental conditions described here, then, perfect compensatory tracking could be achieved only by a subject who had learned the cam and reacted to proprioceptive clues alone. Furthermore, rate and acceleration information would not be available to subjects engaged in compensatory tracking, since these are affected and changed by his control motions.

The intermediate conditions, although introducing interference into the subject's control over the follower, apparently present enough information about target rate and acceleration to permit high tracking efficiency. At the same time the range of the motions of the two indicators is reduced and this might serve to facilitate tracking performance. The scores obtained at the intermediate points were well above those for compensatory tracking. Such a finding might have important implications for the design of cathode ray tube presentations of sighting information.

Conclusions: Pursuit tracking of the sort reported here is more accurate than compensatory tracking by a large factor. In part, at least, this increased accuracy may be due to the fact that the operator, in pursuit tracking, can predict the future motion of the target even when his alignment is perfect. The experimental results indicate that he can track as well even if he must compensate for movements of his own follower pip (such as would be caused by movements of his platform) as long as the compensatory component of the total tracking task does not exceed the pursuit component.

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