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PURSUIT ROTOR TRACKING PERFORMANCE IN CONJUNCTION WITH EXTENDED FLIGHT OPERATIONS IN A HELICOPTER SIMULATOR

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20. ABSTRACT:

Six US Army Initial Entry Rotary Wing School graduates participated as subjects in a week-long study to examine the effects of extended simulated helicopter operations on pursuit tracking skills. Using a photoelectric rotary pursuit device, three fixed patterns (a square, a circle, and a triangle) were presented to each subject three times daily for 5 days. An analysis of the results revealed a significant difference in subject performance between patterns. It also revealed a statistically significant difference in performance over days on one of the patterns--the triangle. The thread woven through these results seemed to be one of relative complexity. It suggested that the effects of sustained operations interfered with the aviator's ability to fully integrate his mental and psychomotor skills in order to meet the requirements of a more complex task.

ACKNOWLEDGMENTS

The authors wish to gratefully acknowledge the efforts of the people who helped in preparing this report: of course, to the subjects without whom no study gets done; to Richard N. Armstrong and Ronald R. Cisco who, as associate investigators, helped in the overall conduct of the larger experiment; to Dr. Heber D. Jones, who painstakingly prepared all of the computer programs used for the analyses and graphics; and finally, to Carolyn H. Troisi and Jean E. Roebuck, whose typing helped to convert the seemingly shapeless bulk of handwriting into the finished document.

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INTRODUCTION

Modern technology and logistics give military forces the capability to conduct warfare almost continuously for extended periods of time. Improvements in helicopter reliability, the sophistication of all-weather avionics and electronics, and the adoption of night vision enhancement devices allow the Army aviator to be included among those forces. In fact, US Army doctrine suggests that future combat scenarios may require a sustained military aviation effort for periods up to 72 hours or more during surge operations. Projected aircrew ratios indicate that it is probable that Army aviators will be required to fly almost continuously for up to 6 hours at a time. In view of the principal role tracking plays in aviation, the question is: What effect can sustained operations be expected to have on the aviator's ability to track?

Tracking in aviation is basically of two kinds--compensatory and pursuit. Examples of compensatory tracking include most instrument flying and much of visual flying, such as traffic patterns and hovering. The intent is to reduce to a minimum the error between some object (the aircraft) and a fixed line (or point, in the case of a hover) representing an ideal course. Examples of pursuit tracking include formation flying and air-to-air gunnery where the purpose is to match, in some way, two independently moving objects.

To answer questions about both types of tracking, the authors took advantage of a laboratory study designed to measure psychological (including psychomotor), physiological, and biochemical aspects of aviator performance, stress, and "fatigue" in a week-long flight schedule in a helicopter simulator (Krueger, Armstrong, and Cisco, 1980). In that investigation, three 2-man crews performed 14 hours of precision instrument flying in a simulator each day for 5 successive days. Missions included repetitions of routine 2-hour standardized day and night flight profiles that were occasionally interrupted by simulated flight emergency situations. When not flying, pilots were engaged in various scheduled laboratory activities.

The study on pursuit tracking reported here was integrated into the larger investigation as one of the laboratory tests. It sought to examine the effects of sustained operations on a pilot's ability to manually track a moving target over a series of geometrically shaped patterns on the premise that his performance would change in some systematic way as a function of the length of time he spent in flight operations.

MATERIALS AND METHOD

MATERIALS

The following equipment was used in this investigation.

Photoelectric Rotary Pursuit

A photoelectric rotary pursuit tracking device with hand-held stylus (containing a photoelectric cell in the tip) and three masks (for triangular, square, or circular tracks) was used as the basic apparatus (Figure 1). The 14-inch square glass masks were blackened except for a 3/4-inch-wide outline of the respective track. Beneath the glass was a variable-speed rotor table in which was imbedded a 3/4-inch-wide white plastic diffuser radial (Figure 2). A circular fluorescent tube was installed below that. The result was a moving spot of light about 3/4-inch square which served as a target. The motion characteristics (velocity, acceleration, and direction) of the target were thus under the control of the experimenter.

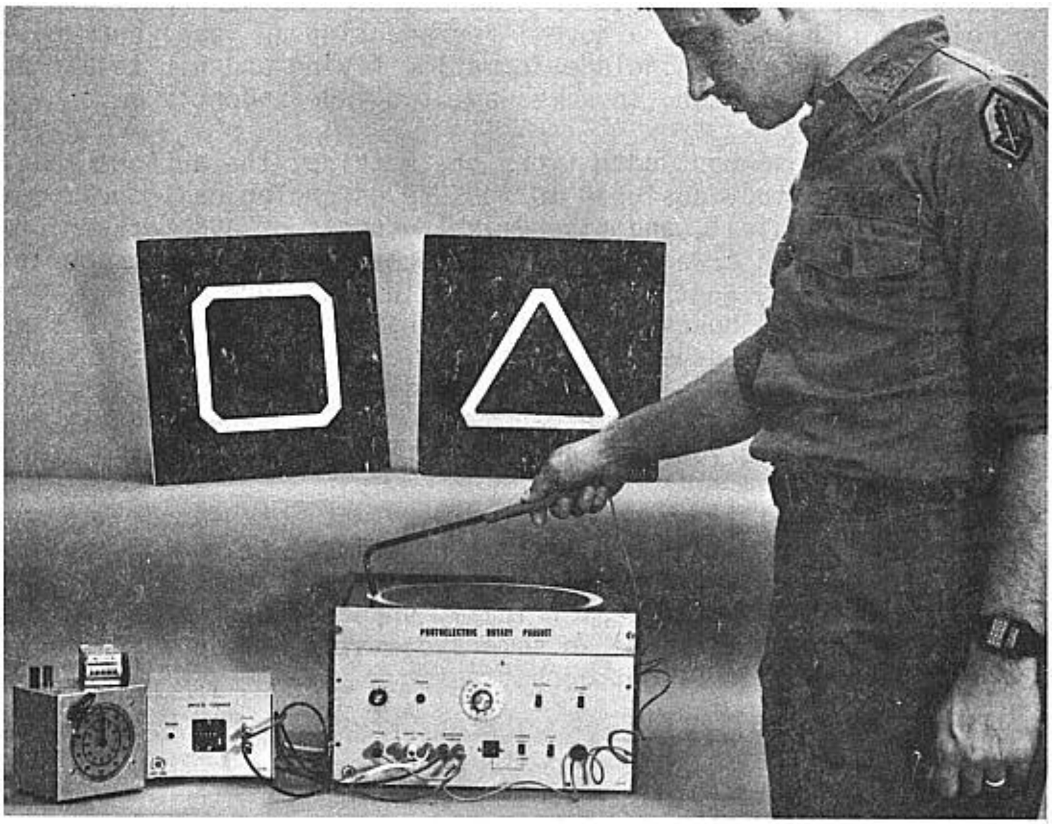

FIGURE 1. Basic Apparatus for Pursuit Rotor Tracking Task

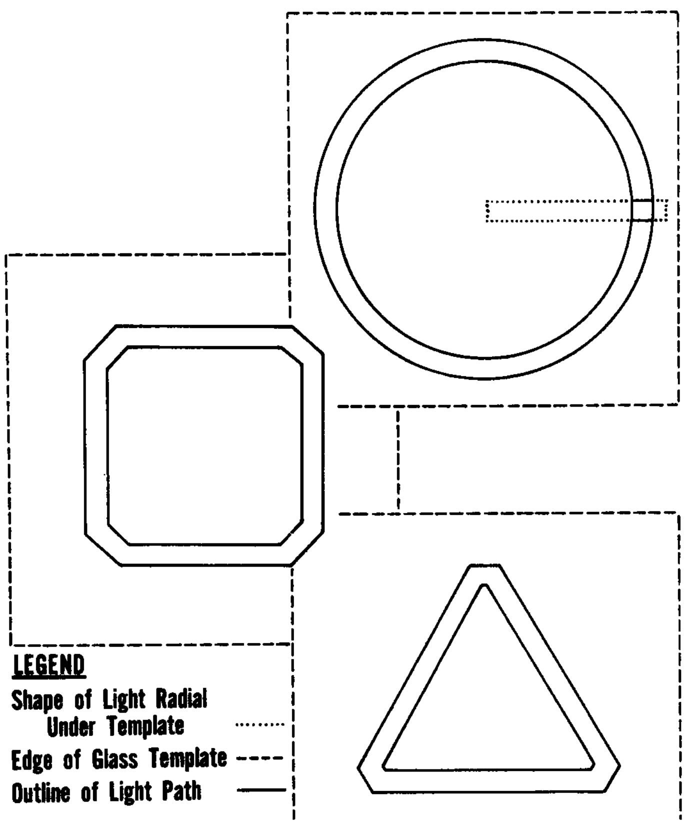

FIGURE 2. Patterns of Tracking Displays Presented to Subjects.

Timer

An electric timer measured cumulative elapsed time to the nearest 1/100th second.

Counters

A simple electric event counter and an impulse counter were used to tally specific events.

METHOD

This examination of a pursuit rotor tracking task, although designed as an independent study, is better understood in the context of the larger experiment of which it was an integral part. The subject's state of being as he came to the pursuit rotor task was directly affected by his participation in the larger experiment. Figure 3 shows the overall experimental plan with the scheme of pursuit rotor tracking trials. The table, p. 11, outlines the daily flying, testing, and sleeping schedule (Krueger, Armstrong, and Cisco, 1980).

Each pair of subjects trained for the overall experiment for 3 days. The training was followed by approximately 45 hours of unsupervised free time and a supervised rest day during which physiological baseline measurements were taken. There were then 5 test days followed by a day of supervised rest in the laboratory and a day and a half of unsupervised rest. Lastly, there was a "recovery" day of flight and laboratory testing. At least one complete set of tracking trials was presented on each of the training, testing, and recovery days.

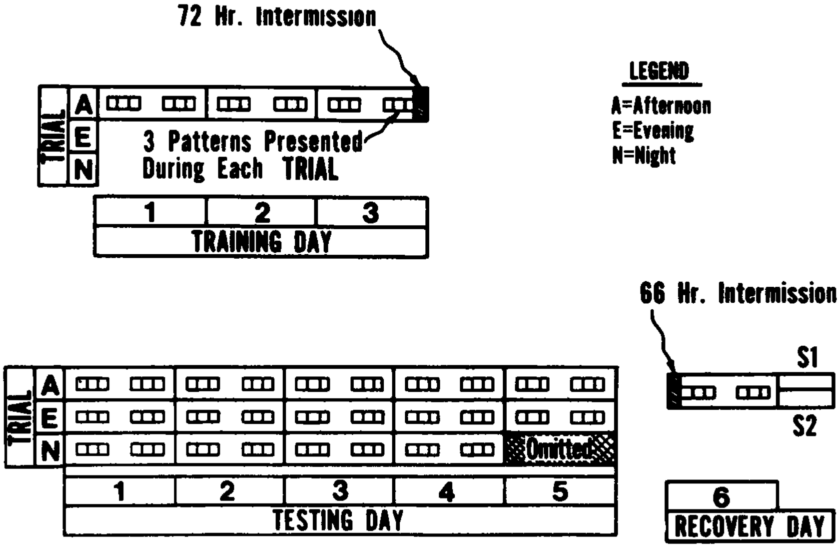

FIGURE 3. Experimental Plan Showing Scheme of Pursuit Rotor Tracking Trials.

On each training day, trials were presented just before lunch (A for Afternoon in Figure 3). On the testing days, trials were presented in the early afternoon, just before lunch (A); in the evening, just before supper (E); and shortly after midnight, just before bedtime (N). The late trials were omitted on Test Day 5 because the flight portions of the overall experiment were terminated after supper on that day. The tracking task was presented again just before lunch on the recovery day.

Six volunteer pilots, ages 21 to 28, were recruited for the extended flight investigation from three Initial Entry Rotary Wing (IERW) flight classes as they finished their 9 months of flight training at Fort Rucker, Alabama; and, although they participated in the larger study in pairs, each subject performed the pursuit rotor task individually. Order of participation within pairs was arbitrarily alternated between trials to reduce order effects. Each of the subjects was instructed in the operation of the apparatus (Appendix A) and the conduct of the trials before the first training period. Questions were answered freely, and specific instructions were repeated if warranted; e.g., subject requesting clarification or exhibiting inappropriate behavior, such as leaning against the table. All trials were carried on in a quiet, well-lighted room with no onlookers, save the experimenter. Subjects used their preferred hand to hold the stylus and then used the same hand throughout the trials.

DAILY FLYING, TESTING, AND SLEEPING SCHEDULE

Time (Daily)	Subject Activities	Simulator & Cardiovascular Data	Navigation (Memory) Task	Eye Movement Data	Subjective Performance Rating	Isoprene & Urine	Oral Tem-pera-ture	Visual Search	PURSUIT ROTOR TRACKING	Mood Scale	Flight Surgeon Evaluation
0045-0445	Sleep										
0445-0515	Wake Up Period					X	X				
0515-0550	Breakfast & Testing									X	X
0550-0755	Flight	X	X								
0755-0810	Hot Refuel Break				X	X	X				
0810-1010	Flight	X	X								
1010-1020	Hot Refuel Break				X	X					
1020-1220	Flight	X	X								
1220-1310	Testing				X	X	X	X	X	X	
1310-1340	Lunch										
1340-1540	Flight	X	X								
1540-1555	Hot Refuel Break				X	X					
1555-1650	Flight	X		X							
1650-1705	Break				X						
1705-1800	Flight	X		X							
1800-1840	Testing				X	X	X		X	X	
1840-1930	Supper & Flt. Surg.										X
1930-2130	Flight	X	X								
2130-2145	Hot Refuel Break				X	X	X				
2145-2345	Flight	X	X								
2345-0040	Testing				X	X		X	X	X	

The rotor speed was adjusted to 45 revolutions per minute (rpm) and trials covered 90 revolutions as registered on the impulse counter. Thus, each trial was about 120 seconds duration. The rotor velocity was checked between sets of trials for constancy. The geometric patterns functioned to change the complexity of the tracking task by controlling the direction, velocity, and acceleration of the target. Each time the subject found the target with the tip of the stylus, the event counter registered a "hit" and the timer started running. As long as the photocell remained over the target, the clock continued to run. Losing the target stopped the clock and set the event counter to register another "hit" whenever that occurred. The cumulative time on target and the number of hits constituted the recorded data. At the end of each trial, the experimenter stopped all inputs and the subjects rested while data were recorded (Appendix B) and the pattern was changed (approximately 1 minute). All three patterns were presented during each set of trials. The order of that presentation was randomized without replacement between pairs (or groups) of subjects, but each pilot of a given pair (or group) received the same order.

DATA ANALYSIS

The experiment was designed to measure two variables--time on target and number of hits on each of the three geometrically shaped tracks. Measurements were repeated on each pilot within the groups over three sets of trials per day for 5 days of testing. As a result of the omission of the night trials on the fifth day of testing, the plan became an asymmetric repeated measures design with four factors--groups of subjects (G), days (D), trials (T) within days, and geometric patterns (P).

During the preparation phase of the study, it was observed that subjects were responding differently to the different patterns. A brief review of the motion mechanics involved suggested at least one reason. Figure 4 shows a set of velocity curves for a full cycle of each tracking pattern. The circle pattern presents a target which moves at a constant velocity; and the direction, although constantly changing, does so at a uniform rate. Thus, the velocity curve for the circle is a straight line (across the top of the figure). Each of the other two patterns, however, present a target whose velocity is constantly changing, and whose direction of movement shifts periodically--the square more frequently than the triangle, but the triangle more abruptly than the square. Accordingly, one would expect the circular track to be much easier to follow than either of the other two. It was decided, therefore, to examine performance on the three patterns both collectively and separately.

The first statistical hypothesis to be tested held that the mean performance was the same for all patterns: i.e., H_{0_P}: $m_T = m_S = m_C$, where m was the population mean, T represented the triangular track and S and C represented the square and circular ones, respectively. The second hypothesis held that the groups were also equal in terms of their performance on the variables; i.e., H_{0_G}: $m_{G1} = m_{G2} = m_{G3}$.

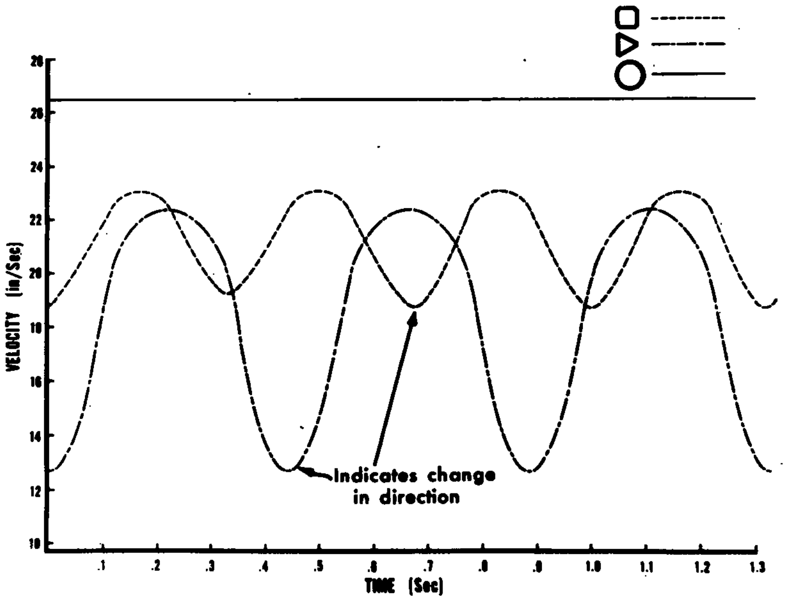

FIGURE 4. Velocity Curves for Patterns Used in Pursuit Rotor Tracking Task.

In keeping with the asymmetric design, the choice of analyses--for patterns and for each pattern separately--consisted of (1) analyzing the data for 4 test days with three sets of trials within each day (ignoring the data of the 5th day) - 4x3 analysis; (2) analyzing the data for 5 days with two sets of trials (first and second) within each day (ignoring the data of the third set of trials) - 5x2 analysis; and (3) analyzing all of the data via the General Linear Hypothesis Method* described by Searle (1971) - 5x3 analysis. Ultimately, the latter approach was used to construct the analysis of variance tables in Appendix C and then as a basis for the results reported here.

RESULTS

PATTERNS AND GROUPS

For purposes of the first analysis (involving patterns and groups), a statistical significance level of $p < .01$ was selected to increase the probability that any difference found would represent real differences in behavior between groups of subjects as a function of geometric patterns (Miller 1966). This level tended to reduce the risk of chance significance in the numerous

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*The computations for this method were obtained through the General Linear Hypothesis program (#2) from the BMD package of statistical programs, more specifically, BMD10V (Dixon 1973).

statistical tests performed during the analysis. The chance that smaller differences, even though real, would go undetected, was considered not of practical significance. (Analysis of variance tables may be found in Appendix C1.)

None of the interactions involving patterns and groups (P and G in the tables of Appendix C1) were found to be statistically significant at the .01 level. With respect to the interactions involving pattern only, all were statistically significant except the one involving days and trials (PxDxT) for the variable "time on target" ($p = .053$). Even so, the evidence was overwhelmingly in favor of separation; therefore, patterns were separated for further analysis.

With respect to the interactions involving the group factors alone, none were statistically significant. It was decided, therefore, to collapse the groups for subsequent analysis. Figure 5 illustrates the group by pattern interaction for each of the two measured variables.

SUBJECTS

The mean performance of the six subjects on the two variables measured over the 14 sets of trials is illustrated in Figure 6. Between subject variability was about as expected. That is to say that one subject was consistently able to "lock on" for high time on target, while another was just about as consistent in his inability to track well. Much of the variance for the variable "time on target" stemmed from only one subject, while performance on the variable "number of hits" showed a more even distribution.

DAYS AND TRIALS

For the second analysis (groups collapsed and patterns separated), a statistical significance level of $p < .01$ was thought to be too demanding. It tended to increase the likelihood that a real difference, if present, might go unnoticed. The result of such an error here would have the potential effect of suggesting there were no differences in performance when, in fact, there were. To reduce the risk of such an outcome, the point of statistical significance, for this analysis only, was set at $p < .05$.

There were no statistically significant interactions involving days and trials (DxT) for either variable on any of the three patterns (or tracks) (Figure 7 and Appendix C2). The analysis of variance failed to show a statistically significant difference between trials on either measure for the square or circular tracks. On the triangular pattern, however, the difference between trials for the variable "number of hits" was statistically significant. Trial effects are displayed graphically in Figure 8. The day effect revealed by the analysis of variance was statistically significant for both variables on the triangle only. Figure 9 graphically displays the effect of days.

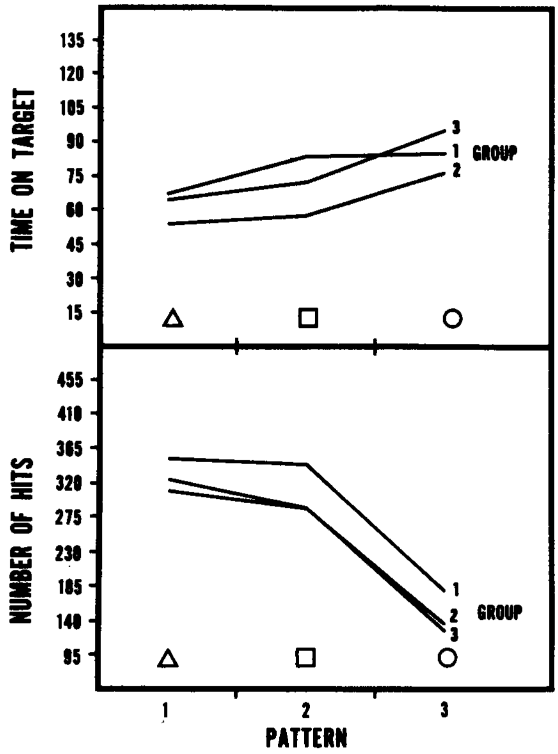

FIGURE 5. Group by Pattern Relationship for Each Variable.

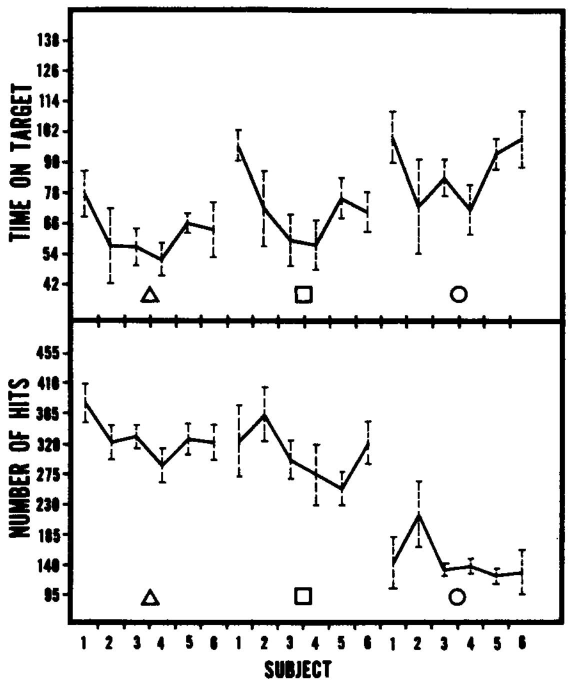

FIGURE 6. Mean and Standard Deviation of Subject Performance Over All Trials for Each Pattern.

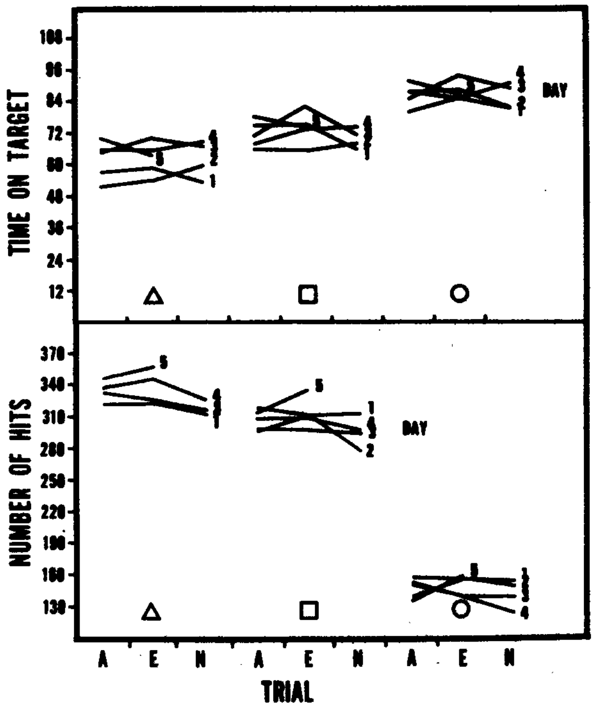

FIGURE 7. Mean Day by Trial Interaction for Each Pattern.

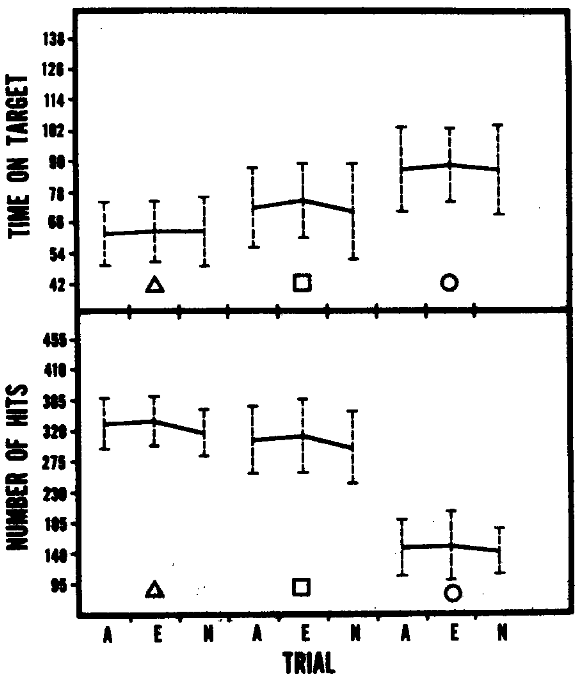

FIGURE 8. Mean Trial Effects for Each Pattern.

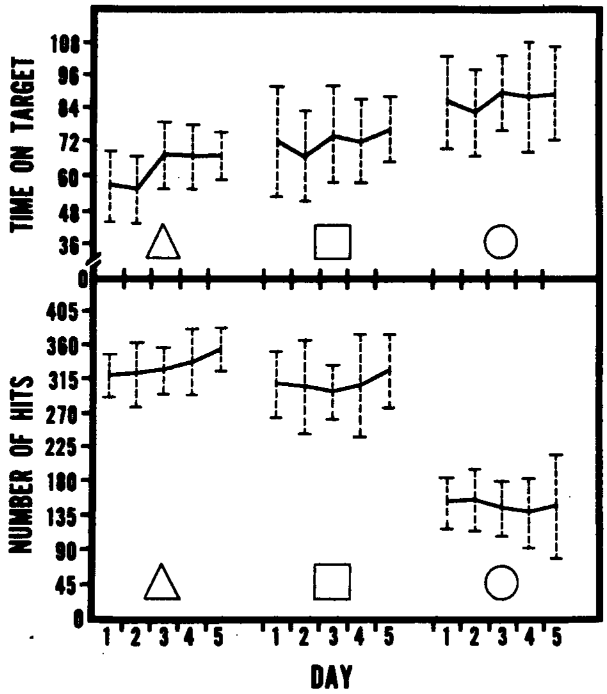

FIGURE 9. Mean Day Effect for Each Pattern.

DISCUSSION

Both graphic plots and numeric analyses confirmed the initial observations that tracking the different patterns did, indeed, seem to call for different skills and/or different levels of similar skills. The circle was relatively easy to track. The triangle, on the other hand, was considerably more difficult. Performance on the square pattern, in terms of the mean number of hits, tended to be more like the triangle than the circle. In terms of mean time on target, however, performance tended to fall more evenly between that seen on the other two patterns.

The statistically significant difference observed in trials with the triangle track appeared to be the result of a decrease in the number of hits measured at night (see Trial 3, Figure 8). It was not accompanied by a commensurate change--up or down--in the total time on target (Figure 8). That suggested a nocturnal effect in which the subjects seemed to "settle down." That is, they got the same total amount of time on target with fewer hits; but only on the triangle, and only at night.

Considering the effect over days, a picture began to develop with the simultaneous plot of both variables across all 5 days separated by pattern (Figure 9). Additionally, dividing the time on target by the number of hits produced a third informative measure, "time per hit." In the case of the circular pattern, tracking was characterized by an essentially uniform performance on all three variables. Subjects did not seem to improve their time on target as a function of repeated trials on the task. Neither did they improve on the number of hits significantly. That tended to strengthen even more the observation that the circular track was relatively easy to follow. The square track, too, showed a relatively uniform time per hit, but the character of the factors which produced the uniformity were different. Both factors were increasing in value. The increasing time on target could have been reflecting a practice effect, but the increasing number of hits could not. An increase in that measure after so much practice suggested the presence of some sort of interference.

Performance on the triangular track was found to be quite different from that seen on the other two tracks. Both measured variables were relatively uniform at the outset. Around the third day, the data appeared to be like that for the square; i.e., relatively uniform time per hit associated with an increase in both variables. Then the time on target leveled off, but the number of hits continued to rise--even suggesting a non-linear increase through the fifth day. As with the square track, increased proficiency could explain the increased time on target over days, but not the increased number of hits. An increase in the number of hits tended to suggest a decay function. And in the case of the triangles, the onset occurred sooner.

The thread that weaves through the results seems to be one of relative complexity. Referring back to Figure 4, the circular track presented no change to speak of. Once into the "groove," as it were, it was not very difficult to stay there. Any effect of the extended flight regimen seemed to have no statistically measurable influence--at least within the prescribed time and task frame. In terms of velocity, acceleration, and changes in direction, the square and triangular tracks presented the subjects with a considerably different set of circumstances. Negotiating those tracks called for more fine muscle dexterity and psychomotor and mental control. And at first, the aviators seemed to exert a conscientious effort to follow the track precisely. Somewhere during the process, however, they seemed to change their respective strategies to, literally, cut corners. Most of them appeared to have superimposed a circle over the square.

Such a change in strategy fits a statement from Gilmer (1971) that: "Laboratory experiments confirm the common experience that the loss of sleep, like other effects of fatigue does not appreciably change a person's capacity to work, but it does reduce his drive to perform efficiently." The change in strategy could also explain the slightly reduced time on target and the greatly increased number of hits on the square as compared to the circle. It could not explain, however, why the mean number of hits continued to increase. Nor does it explain why the mean number of hits in the triangle was higher than that for the square. Fewer corners would seem to predict fewer hits.

A partial explanation may lie in the observed relationship between pattern complexity and the incidence of decreased time per hit as a result of the increased number of hits. One of the consequences of sleep deficit cited by Johnson and Naitoh (1974) held that: "The more complex the task with respect to a sequence of mental operations and/or the execution of complex muscular activities, the more likely it is to be sensitive to sleep loss." In this case, it is suggested that the effects of sustained operations interfered with the aviator's ability to fully integrate his mental and psychomotor skills in order to meet the requirements of the more complex task.

CONCLUSION

Extended simulator flight operations do have an effect on pursuit rotor tracking behavior; however, performance depends upon the complexity of the tracking task. Simple tracking tasks (perhaps including more complex, but well-learned ones) seem to be more resistant to the effects of extended flight, while the more complex (perhaps here to include the less complex, but not yet well-learned ones) are affected sooner.

Observations also suggest that at some point well into a period of extended operations pilots may alter their strategy in such a way as to "overlay" a simpler behavior pattern on a more complex task, presumably, without considering the consequences (if any) of doing so. The possibility of such a behavioral phenomenon, however, requires further research.

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APPENDIX A

INSTRUCTIONS FOR SUBJECT PERFORMING PURSUIT ROTOR TRACKING TASK

The object of this task is simply to keep the tip of the wand over the moving spot of light as much as possible. For best results, keep the tip about 1/2 - 3/4 inches above the glass. In any case, try to avoid touching the glass. While you are tracking, stand firmly on both feet and do not lean on the table. You may hold the stylus in either hand while you put the free hand behind your back, in your pocket or hook it over your belt.

Keep the stylus in the corner nearest your preferred stylus hand until I say, "START." Return to that positon when I say, "STOP." There will be a 1-2 minute rest period between trials while I change templates, record data, and reset the apparatus.

Be aware that there may be other people working on equipment in nearby rooms. Your score on this task will be better if you can ignore all these noises and concentrate on the tracking.

APPENDIX B

PURSUIT ROTOR DATA

PURSUIT ROTOR DATA

Group	Subject Within Group	Subject Within Study	Day	Period (Trial)	Pattern	Time on Target	No. of Hits
1	1	1	1	1	1	69.88	333
1	1	1	1	1	2	107.50	213
1	1	1	1	1	3	105.78	120
1	1	1	1	2	1	80.98	318
1	1	1	1	2	2	98.70	330
1	1	1	1	2	3	113.54	98
1	1	1	1	3	1	66.20	379
1	1	1	1	3	2	96.17	399
1	1	1	1	3	3	112.19	185
1	1	1	2	1	1	62.45	402
1	1	1	2	1	2	91.41	359
1	1	1	2	1	3	96.35	204
1	1	1	2	2	1	65.12	390
1	1	1	2	2	2	86.93	389
1	1	1	2	2	3	79.16	202
1	1	1	2	3	1	84.69	380
1	1	1	2	3	2	95.42	317
1	1	1	2	3	3	98.42	147
1	1	1	3	1	1	83.21	395
1	1	1	3	1	2	100.19	276
1	1	1	3	1	3	81.63	182
1	1	1	3	2	1	88.72	366
1	1	1	3	2	2	103.43	281
1	1	1	3	2	3	105.24	112
1	1	1	3	3	1	89.22	360
1	1	1	3	3	2	102.26	273
1	1	1	3	3	3	105.99	98
1	1	1	4	1	1	75.49	412
1	1	1	4	1	2	86.92	387
1	1	1	4	1	3	101.78	141
1	1	1	4	2	1	83.88	403
1	1	1	4	2	2	99.21	296
1	1	1	4	2	3	107.54	103
1	1	1	4	3	1	82.66	390
1	1	1	4	3	2	100.13	322
1	1	1	4	3	3	101.14	118
1	1	1	5	1	1	83.60	379
1	1	1	5	1	2	95.40	357
1	1	1	5	1	3	98.43	130
1	1	1	5	2	1	72.10	422
1	1	1	5	2	2	92.30	341
1	1	1	5	2	3	93.34	164
1	2	2	1	1	1	65.17	325

PURSUIT ROTOR DATA
(Continued)

Group	Subject Within Group	Subject Within Study	Day	Period (Trial)	Pattern	Time on Target	No. of Hits
1	2	2	1	1	2	89.96	344
1	2	2	1	1	3	108.11	106
1	2	2	1	2	1	47.54	362
1	2	2	1	2	2	91.98	323
1	2	2	1	2	3	72.86	241
1	2	2	1	3	1	34.41	298
1	2	2	1	3	2	45.46	345
1	2	2	1	3	3	51.16	161
1	2	2	2	1	1	31.62	288
1	2	2	2	1	2	49.16	388
1	2	2	2	1	3	41.60	216
1	2	2	2	2	1	45.02	335
1	2	2	2	2	2	63.96	406
1	2	2	2	2	3	72.37	215
1	2	2	2	3	1	53.71	341
1	2	2	2	2	2	75.92	374
1	2	2	2	3	3	64.34	225
1	2	2	3	1	1	58.81	339
1	2	2	3	1	2	65.13	381
1	2	2	3	1	3	81.77	205
1	2	2	3	2	1	82.63	278
1	2	2	3	2	2	92.50	303
1	2	2	3	2	3	92.25	219
1	2	2	3	3	1	71.96	287
1	2	2	3	3	2	80.18	285
1	2	2	3	3	3	96.88	210
1	2	2	4	1	1	55.17	326
1	2	2	4	1	2	64.00	365
1	2	2	4	1	3	60.81	269
1	2	2	4	2	1	64.95	331
1	2	2	4	2	2	66.27	429
1	2	2	4	2	3	54.25	205
1	2	2	4	3	1	75.30	329
1	2	2	4	3	2	84.42	372
1	2	2	4	3	3	85.00	194
1	2	2	5	1	1	63.14	351
1	2	2	5	1	2	72.25	389
1	2	2	5	1	3	68.31	220
1	2	2	5	2	1	50.02	322
1	2	2	5	2	2	64.09	393
1	2	2	5	2	3	66.18	324
2	1	3	1	1	1	48.80	345
2	1	3	1	1	2	57.00	323

PURSUIT ROTOR DATA
(Continued)

Group	Subject Within Group	Subject Within Study	Day	Period (Trial)	Pattern	Time on Target	No. of Hits
2	1	3	1	1	3	77.19	146
2	1	3	1	2	1	47.23	313
2	1	3	1	2	2	71.34	328
2	1	3	1	2	3	85.47	137
2	1	3	1	3	1	43.15	299
2	1	3	1	3	2	48.07	277
2	1	3	1	3	3	72.78	138
2	1	3	2	1	1	54.23	330
2	1	3	2	1	2	56.53	309
2	1	3	2	1	3	76.43	132
2	1	3	2	2	1	55.41	343
2	1	3	2	2	2	53.61	291
2	1	3	2	2	3	93.55	121
2	1	3	2	3	1	52.32	304
2	1	3	2	3	2	50.36	255
2	1	3	2	3	3	80.95	130
2	1	3	3	1	1	53.47	331
2	1	3	3	1	2	50.15	281
2	1	3	3	1	3	86.80	125
2	1	3	3	2	1	66.96	340
2	1	3	3	2	2	69.42	336
2	1	3	3	2	3	91.85	115
2	1	3	3	3	1	56.89	320
2	1	3	3	3	2	43.83	248
2	1	3	3	3	3	70.66	139
2	1	3	4	1	1	59.81	343
2	1	3	4	1	2	51.88	263
2	1	3	4	1	3	87.89	135
2	1	3	4	2	1	65.93	342
2	1	3	4	2	2	65.28	304
2	1	3	4	2	3	87.49	141
2	1	3	4	3	1	61.18	345
2	1	3	4	3	2	68.42	310
2	1	3	4	3	3	91.20	118
2	1	3	5	1	1	65.34	321
2	1	3	5	1	2	70.51	323
2	1	3	5	1	3	87.84	138
2	1	3	5	2	1	62.61	357
2	1	3	5	2	2	74.29	302
2	1	3	5	2	3	85.81	139
2	2	4	1	1	1	43.81	281
2	2	4	1	1	2	60.22	288
2	2	4	1	1	3	69.43	147

PURSUIT ROTOR DATA
(Continued)

Group	Subject Within Group	Subject Within Study	Day	Period (Trial)	Pattern	Time on Target	No. of Hits
2	2	4	1	2	1	47.00	282
2	2	4	1	2	2	47.45	261
2	2	4	1	2	3	81.02	140
2	2	4	1	3	1	57.14	277
2	2	4	1	3	2	53.78	279
2	2	4	1	3	3	83.48	149
2	2	4	2	1	1	44.20	256
2	2	4	2	1	2	64.52	336
2	2	4	2	1	3	77.86	153
2	2	4	2	2	1	49.79	282
2	2	4	2	2	2	52.98	251
2	2	4	2	2	3	88.41	138
2	2	4	2	3	1	45.71	279
2	2	4	2	3	2	38.39	209
2	2	4	2	3	3	58.20	132
2	2	4	3	1	1	55.30	289
2	2	4	3	1	2	66.93	313
2	2	4	3	1	3	65.47	141
2	2	4	3	2	1	51.63	312
2	2	4	3	2	2	63.94	289
2	2	4	3	2	3	76.61	146
2	2	4	3	3	1	51.69	304
2	2	4	3	3	2	63.13	326
2	2	4	3	3	3	68.86	130
2	2	4	4	1	1	51.08	275
2	2	4	4	1	2	56.38	265
2	2	4	4	1	3	67.99	143
2	2	4	4	2	1	47.55	267
2	2	4	4	2	2	57.14	236
2	2	4	4	2	3	62.09	131
2	2	4	4	3	1	51.42	255
2	2	4	4	3	2	44.35	190
2	2	4	4	3	3	55.18	110
2	2	4	5	1	1	62.29	340
2	2	4	5	1	2	58.07	257
2	2	4	5	1	3	78.64	144
2	2	4	5	2	1	65.92	333
2	2	4	5	2	2	76.39	340
2	2	4	5	2	3	67.59	125
3	1	5	1	1	1	62.67	336
3	1	5	1	1	2	65.78	271
3	1	5	1	1	3	84.67	144
3	1	5	1	2	1	69.58	336

PURSUIT ROTOR DATA
(Continued)

Group	Subject Within Group	Subject Within Study	Day	Period (Trial)	Pattern	Time on Target	No. of Hits
3	1	5	1	2	2	81.09	273
3	1	5	1	2	3	88.54	137
3	1	5	1	3	1	70.68	326
3	1	5	1	3	2	82.12	273
3	1	5	1	3	3	84.73	137
3	1	5	2	1	1	70.55	357
3	1	5	2	1	2	78.93	256
3	1	5	2	1	3	95.80	129
3	1	5	2	2	1	59.47	300
3	1	5	2	2	2	69.88	222
3	2	5	2	2	3	91.49	111
3	1	5	2	3	1	62.71	287
3	1	5	2	3	2	80.23	234
3	1	5	2	3	3	91.20	117
3	1	5	3	1	1	66.56	307
3	1	5	3	1	2	76.27	250
3	1	5	3	1	3	89.16	132
3	1	5	3	2	1	65.20	332
3	1	5	3	2	2	89.69	235
3	1	5	3	2	3	96.33	113
3	1	5	3	3	1	67.31	319
3	1	5	3	3	2	64.03	308
3	1	5	3	3	3	89.17	124
3	1	5	4	1	1	69.96	308
3	1	5	4	1	2	75.29	243
3	1	5	4	1	3	97.43	126
3	1	5	4	2	1	63.07	359
3	1	5	4	2	2	69.02	221
3	1	5	4	2	3	91.71	124
3	1	5	4	3	1	69.58	312
3	1	5	4	3	2	72.79	234
3	1	5	4	3	3	104.62	108
3	1	5	5	1	1	67.62	336
3	1	5	5	1	2	88.53	261
3	1	5	5	1	3	100.68	112
3	1	5	5	2	1	61.16	363
3	1	5	5	2	2	69.45	275
3	1	5	5	2	3	99.65	108
3	2	6	1	1	1	52.66	312
3	2	6	1	1	2	69.13	341
3	2	6	1	1	3	79.72	177
3	2	6	1	2	1	60.37	323
3	2	6	1	2	2	61.70	350

PURSUIT ROTOR DATA
(Continued)

Group	Subject Within Group	Subject Within Study	Day	Period (Trial)	Pattern	Time on Target	No. of Hits
3	2	6	1	2	3	68.57	183
3	2	6	1	3	1	49.11	295
3	2	6	1	3	2	68.90	306
3	2	6	1	3	3	85.97	156
3	2	6	2	1	1	46.72	280
3	2	6	2	1	2	54.03	266
3	2	6	2	1	3	92.68	113
3	2	6	2	2	1	50.43	293
3	2	6	2	2	2	66.86	312
3	2	6	2	2	3	85.79	150
3	2	6	2	3	1	60.20	304
3	2	6	2	3	2	68.17	279
3	2	6	2	3	3	68.15	334
3	2	6	3	1	2	65.50	291
3	2	6	3	1	3	103.87	117
3	2	6	3	2	1	65.58	327
3	2	6	3	2	2	73.98	340
3	2	6	3	2	3	101.14	135
3	2	6	3	3	1	66.07	306
3	2	6	3	3	2	73.03	322
3	2	6	3	3	3	104.20	136
3	2	6	4	1	1	82.88	356
3	2	6	4	1	2	73.34	326
3	2	6	4	1	3	109.75	100
3	2	6	4	2	1	67.99	371
3	2	6	4	2	2	83.64	363
3	2	6	4	2	3	106.30	129
3	2	6	4	3	1	72.74	323
3	2	6	4	3	2	75.36	358
3	2	6	4	3	3	108.38	91
3	2	6	5	1	1	76.70	349
3	2	6	5	1	2	84.06	294
3	2	6	5	1	3	116.15	70
3	2	6	5	2	1	70.80	345
3	2	6	5	2	2	69.19	357
3	2	6	5	2	3	109.24	92

APPENDIX C

COMPOSITE ANALYSIS OF VARIANCE TABLES

APPENDIX C-1

ANALYSIS OF VARIANCE FOR

PATTERN (P) X GROUP (G) X DAY (D) X TRIAL (T)

ANALYSIS OF VARIANCE TABLE
PURSUIT ROTOR TRACKING TASK
Subjects (Grouped)
Time on Target (All Patterns)

Source	df	SS	MS	F	p
G	2	1.313	.657	1.472	.35856
S/G	3	1.338	.446	---	---
D	4	.332	.083	3.495	.04106
DG	8	.373	.047	1.963	.14099
DS/G	12	.285	.024	---	---
T	2	.022	.011	3.667	.09111
TG	4	.047	.012	3.917	.06730
TS/G	6	.018	.003	---	---
DT	8	.193	.024	.907	.53197
DTG	16	.442	.028	1.038	.46603
DTS/G	18	.479	.027	---	---
P	2	2.567	1.284	71.972	.00006
PG	4	.386	.097	5.411	.03424
PS/G	6	.107	.018	---	---
PD	8	.165	.021	4.500	.00193
PDG	16	.141	.009	1.923	.07162
PDS/G	24	.110	.005	---	---
PT	4	.052	.013	6.500	.00506
PTG	8	.020	.003	1.250	.35094
PTS/G	12	.024	.002	---	---
PDT	16	.185	.012	1.909	.05338
PDTG	32	.168	.005	.867	.65719
PDTS/G	36	.218	.006	---	---

ANALYSIS OF VARIANCE TABLE
PURSUIT ROTOR TRACKING TASK
Subjects (Grouped)
Number of Hits (All patterns)

Source	df	SS	MS	F	p
G	2	12.328	6.164	7.121	.07258
S/G	3	2.597	.866	---	---
D	4	.887	.222	2.056	.15012
DG	8	3.462	.433	4.013	.01545
DS/G	12	1.294	.108	---	---
T	2	.843	.422	3.719	.08901
TG	4	.331	.083	.730	.60322
TS/G	6	.680	.113	---	---
DT	8	.684	.086	.744	.65343
DTG	16	4.085	.255	2.221	.05267
DTS/G	18	2.069	.115	---	---
P	2	165.178	82.589	52.649	.00016
PG	4	.948	.237	.151	.95568
PS/G	6	9.412	1.569	---	---
PD	8	2.784	.348	3.923	.00434
PDG	16	1.743	.109	1.228	.31646
PDS/G	24	2.129	.089	---	---
PT	4	2.623	.656	8.104	.00209
PTG	8	.521	.065	.805	.61080
PTS/G	12	.971	.081	---	---
PDT	16	16.808	1.051	8.107	.00000 (1.0E-7)
PDTG	32	1.822	.057	.439	.98987
PDTS/G	36	4.665	.130	---	---

APPENDIX C-2

ANALYSIS OF VARIANCE

DAY (D) X TRIAL (T)

ANALYSIS OF VARIANCE TABLE
PURSUIT ROTOR TRACKING TASK

Subjects (Ungrouped)
Time on Target (Triangle)

Source	df	SS	MS	F	p
S	5	.551	.110	---	---
D	4	.252	.063	7.123	.00098
DS	20	.178	.009	---	---
T	2	.007	.004	.987	.40626
TS	10	.036	.004	---	---
DT	7	.086	.012	1.788	.12094
DTS	35	.241	.007	---	---

Subjects (Ungrouped)
Number of Hits (Triangle)

Source	df	SS	MS	F	p
S	5	5.852	1.170	---	---
D	4	1.080	.270	3.538	.02440
DS	20	1.526	.076	---	---
T	2	.857	.429	18.554	.00043
TS	10	.231	.023	---	---
DT	7	.616	.088	1.289	.28433
DTS	35	2.390	.068	---	---

ANALYSIS OF VARIANCE TABLE
PURSUIT ROTOR TRACKING TASK

Subjects (Ungrouped)
Time on Target (Square)

Source	df	SS	MS	F	p
S	5	1.310	.262	---	---
D	4	.090	.022	3.137	.03726
DS	20	.143	.007	---	---
T	2	.041	.021	3.948	.94932
TS	10	.052	.005	---	---
DT	7	.105	.015	1.115	.37581
DTS	35	.472	.013	---	---

Subjects (Ungrouped)
Number of Hits (Square)

Source	df	SS	MS	F	p
S	5	10.687	2.137	---	---
D	4	.600	.150	.724	.58579
DS	20	4.144	.207	---	---
T	2	.728	.364	1.848	.20751
TS	10	1.969	.197	---	---
DT	7	1.011	.144	.780	.60830
DTS	35	6.478	.185	---	---

ANALYSIS OF VARIANCE TABLE
PURSUIT ROTOR TRACKING TASK

Subjects (Ungrouped)
Time on Target (Circle)

Source	df	SS	MS	F	p
S	5	1.144	.229	---	---
D	4	.062	.015	.739	.57641
DS	20	.417	.021	---	---
T	2	.010	.005	.501	.62036
TS	10	.100	.010	---	---
DT	7	.070	.010	.507	.82289
DTS	35	.689	.020	---	---

Subjects (Ungrouped)
Number of Hits (Circle)

Source	df	SS	MS	F	p
S	5	8.942	1.788	---	---
D	4	.286	.071	.453	.76908
DS	20	3.150	.158	---	---
T	2	.044	.022	.082	.92188
TS	10	2.652	.265	---	---
DT	7	.476	.068	.389	.90247
DTS	35	6.117	.175	---	---