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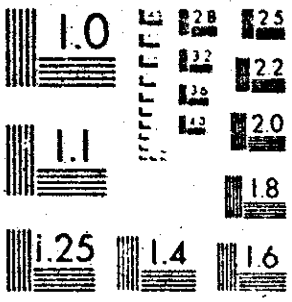

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THE EFFECTS OF PHYSICAL FATIGUE AND ALTITUDE ON PHYSIOLOGICAL, BIOCHEMICAL, AND PERFORMANCE RESPONSES

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16. Abstract Twelve healthy young men were evaluated in each of four experimental conditions involving the possible combinations of two exercise conditions given prior to performance testing (1 h of heavy exercise vs. no exercise) and two altitude conditions (ground level vs. 12,500 ft) which were administered during performance testing. Performance was measured during a 2¼-h test session with the Multiple Task Performance Battery (MTPB) which involved time-shared performance in monitoring of warning lights and meters, mental arithmetic, problem solving, and tracking. Heart rate was statistically higher after exercise than after no exercise and statistically higher at 12,500 ft than at ground level. Norepinephrine excretion rate was higher during exercise experiments than during no-exercise experiments. There was no altitude effect for this measurement. The overall composite score of MTPB performance was significantly lower at 12,500 ft than at ground level. The adverse effect of higher altitude was greatest in the tracking task. The 1-h period of vigorous physical exercise had no statistically significant main effect on overall MTPB scores. Residual effects of exercise resulting in increased arousal may account for the tendency for performance to be slightly higher in several individual tasks of the MTPB following exercise, and significantly higher in the case of problem solving. The interaction of altitude with exercise was also significant in the case of tracking performance. The most important aspect of the interaction was that tracking performance was significantly better at 12,500 ft following exercise. This finding is possibly due to the increase in cardiovascular circulation induced by prior exercise. Possible protection from mild hypoxia by prior exercise and exercise "breaks" should be examined in future research.

17. Key Words
Aviation environment, Simulation, Hypoxia, Physical fatigue, Complex performance, Physiology, Biochemistry, Physical exercise

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THE EFFECTS OF PHYSICAL FATIGUE AND ALTITUDE ON PHYSIOLOGICAL, BIOCHEMICAL, AND PERFORMANCE RESPONSES

Although the word is difficult to define, "fatigue" is almost universally conceptualized as an undesirable state produced by effort--either the physical or mental effort of doing work or the effort of maintaining vigilance when there is no physical work to be done. Fatigue is an undesirable state because fatigued individuals tend to commit errors; fatigue can adversely affect not only the accuracy but also the timeliness of performance.

Since Lindbergh's 1927 transatlantic flight, fatigue has been recognized as a potential threat to flight safety (22). To mitigate this threat, the Federal Aviation Administration (FAA) in 1964 imposed specific limitations on "duty aloft" times on the crews of air carriers (10). This regulation limits annual, monthly, weekly, and daily flight times and specifies minimum numbers of off-duty hours for a variety of flying schedules.

Thus far, the special problem of fatigue due to circadian desynchronosis has not been the subject of regulation, but the possible risks from this type of fatigue have not escaped the notice of Congress (23). A workshop on the subject was convened by the National Aeronautics and Space Administration (NASA) in the summer of 1980 (23). The consensus of the participants was that disruption of normal circadian rhythms could be associated with increasing fatigue and that desynchronosis could result from a variety of circumstances, including time-zone crossings and the switching of employees into unusual work shifts. Participants also concluded that, at present, pilot fatigue can be assessed only in subjective terms and that sleepiness and lowered arousal cannot easily be distinguished from the fatigue that ensues from prolonged and/or intense work demands. In any case, they agreed that performance is the best measure of the deleterious effects of fatigue, and "error reduction," regardless of the cause of the errors, "would probably lead to statistically increased air safety."

With an increased recognition of fatigue as a cause of aviation accidents have come increased efforts to assess the prevalence of fatigue in aviation operations. In November 1978, the National Safety Data Branch of the FAA's Flight Standards National Field Office began to include fatigue as a factor which may have contributed to an accident or incident; from that time to August 1981 there were 37 accident or incident reports that mentioned fatigue as a factor. Involved in these 37 instances were 6 airline transport pilots, 19 commercial pilots (including four flight instuctors), and 12 private pilots. Extrapolation of the data indicates that an accident or incident involving fatigue may be expected to occur about once per month.

Other data bases permit higher estimates of the current rate of fatigue-related flying problems. The NASA Aviation Safety Reporting System (ASRS) provides pilots with a channel for giving unofficial reports of incidents occurring in flight. A recent NASA report (19), which was restricted to incidents involving air transport flights, cited 425 occurrences of fatigue-related decrements in flight crew performance. Although a precise time span for the study was not given, a conservative estimate of 4 years (ASRS became operational in April 1976) indicates that fatigue-ascribed problems may occur at a rate of about nine per month in air transport flights alone.

A variety of factors may contribute to the development of fatigue. Such factors include physical exertion, hypoxia, monotony, medical conditions such as anemia and cardiovascular problems, aging, enforced bed rest, and some factors related to desynchronosis. As an initial step toward our goal of understanding this poorly defined and complex phenomenon we have investigated effects of prior physical exertion on some physiological and biochemical responses and on complex performance during mild hypoxia.

The detrimental effects of hypoxia on performance have been summarized by McFarland (20), Tune (27), and Ernsting and Sharp (8). In general, the altitude at which tasks are first affected by hypoxia varies inversely with task complexity, and well-learned tasks are less sensitive to the effects of hypoxia than are novel tasks. Absolute visual sensitivity and tasks involving discrimination of visual signal intensity are especially sensitive to hypoxia and may show decrements at 5,000-6,000 ft (8). Performance in simple reaction time tasks is unaffected at altitudes below 16,000 ft while choice reaction time and complex psychomotor tasks can be affected at 10,000-12,000 ft (3,18). Glideslope tracking by pilots during simulated flight was adversely affected at 12,300 ft while localizer tracking and control of airspeed, heading, and vertical speed were affected at 15,000 ft (25). A cognitive task involving mathematical computations was affected at 12,000 ft (1) while memory tasks were affected at 10,000 ft (21). Since continuous flight in unpressurized aircraft is permitted at altitudes up to 12,500 ft without supplemental oxygen, adverse effects on flying performance due to hypoxia effects are possible and civilian and military education programs for pilots alert them to this possibility. There is need for additional research on the effects of factors which may adversely interact with hypoxia. Physical exertion is one such factor.

The effects of prior physical exertion on subsequent performance at altitude have not been studied previously. Studies of the effects of prior exertion on performance at ground level have found both positive and negative effects. These studies have examined the effects of both "local exercise" on responses from the same limb being exercised and "general exercise" involving larger body areas, usually the lower body. Simple reaction times were found to increase with amount of local exercise (13,16,26). More complex psychomotor tasks including tracking have shown enhancement of performance at moderate levels of local exercise and decrements occurring at higher levels (7,28).

General exercise also has produced varying effects on performance. Performance in a simple "tapping" psychomotor task was consistently enhanced by exercise, even with exercise to exhaustion (7). No effect of general exercise was found in performance of an easy tracking task (11,12), but performance was decreased in more complex psychomotor tasks such as ball throwing (5) and pistol shooting (9). Davey (6) found an "inverted-U" shaped relationship between general exercise and performance in an auditory recognition task. Schmidtke (25) found a similar relationship of exercise to performance of a clock-monitoring task.

Studies of prior physical exertion have typically reported effects on performance for relatively short periods following exercise, typically no more than a few minutes. Only one study has examined longer time periods: Bonnet (2) studied performance during a 6.5-h march and for 6 h afterward. Performance deficits occurred during exercise in both psychomotor and cognitive performance after 5 h of marching. Recovery was apparent following the end of the march, but some decrements were still evident 6 h after marching. No beneficial effects were noted.

Theoretical interpretations of effects of physical exertion on performance typically involve the mechanisms of physiological activation and associated psychological arousal, and physical fatigue. The latter factor has been used to explain detrimental effects of exercise. Activation level and associated psychological arousal have been used to account for both decrements and increments in performance. Performance has been thought to have an "inverted-U" shaped relationship to activation level (6). This implies that there is some optimal level of arousal for performance. Several studies discussed above have observed such a function in the case of dose-effect curves for exercise. The above findings concerning exercise effects suggest that both beneficial and adverse consequences of physical exertion prior to flight are possible depending on the kind and amount of exercise and the type of task in which performance is measured.

The present preliminary research examined some effects of prior strenuous physical exertion during subsequent mild hypoxia, studying: (i) their possible interaction in performance, (ii) their effects on performance of flight-related tasks in a complex time-sharing task, and (iii) their effects over a 2¼-h period following exercise.

METHODS

Twelve healthy young men served as experimental subjects. All were fully informed of the experiment and met the selection criteria; each was qualified by a physician for the FAA Class III medical certificate, and none achieved a pulse rate greater than 150 beats per minute (bpm) or a systolic blood pressure greater than 200 mm Hg after the first 10 min of the exercise test to be used in the experiment.

Each subject was given five 3-h training sessions on the Civil Aeromedical Institute's (CAMI) Multiple Task Performance Battery (MTPB). After training, subjects underwent four 4-h experimental sessions held with at least 2 days of rest between successive test sessions. The four test sessions involved the four possible combinations of two exercise treatments administered before performance testing (exercise vs. no exercise), and two altitude treatments administered during performance testing (12,500 ft (3,810 m) vs. ground level) as described in Table I. A 30-min "break" period always occurred

TABLE I. Experiment Schedule

		Experiment Time	
Condition	0.00 - 1.00 h	1.00 - 1.50 h	1.50 - 3.75 h
1	Exercise	Break	Hypoxia Performance Test at 12,500 ft
2	Exercise	Break	No Hypoxia Performance Test at Ground Level
3	No Exercise	Break	Hypoxia Performance Test at 12,500 ft
4	No Exercise	Break	No Hypoxia Performance Test at Ground Level

between exercise (or rest) periods and performance testing since some interval would normally be expected between heavy physical exertion and flight.

The exercise condition consisted, in full, of four 10-min trials during which the subject pedaled a bicycle ergometer at loads of 30 watts (W) for 2 min, 60 W for 4 min, and 100 W for the last 4 min of the trial. Five-min rest periods followed each trial, so that the total exercise test period was 1-h long. In the no-exercise control condition subjects sat upright in an armchair without performing work. A 30-min "break" period followed the exercise or no-exercise treatment. A hand-steadiness test and a fatigue checklist were administered at that time.

Exposure to the altitude condition was simulated by an oxygen/nitrogen breathing mixture equivalent to 12,500 ft (3,810 m) altitude. In the control condition each subject breathed an oxygen/nitrogen mixture equivalent to Ground level.

The four experimental conditions, comprising the four possible combinations of the two exercise and the two altitude conditions, were presented in a different order to each subject so that over all subjects, each condition followed each other condition an equal number of times.

Multiple Task Performance Battery.

The CAMI MTPB was used to measure time-shared performance in up to six component tasks simultaneously. The MTPB system is computerized; task presentation and data collection are automatic. The test panel displays and response controls are depicted in Fig. 1. The system has been described in

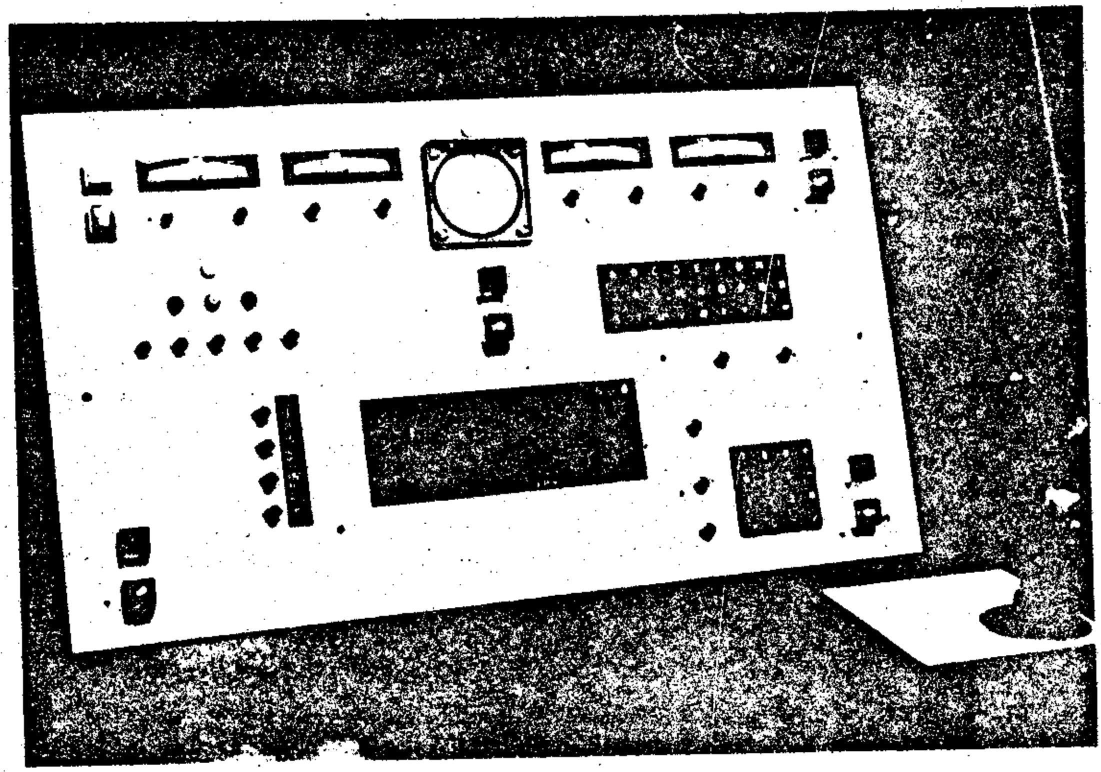

Figure 1. Console of the Multiple Task Performance Battery.

detail (4). A brief description follows:

Tasks 1 and 2: Monitoring of Red and Green Warning Lights.

This is a choice/reaction time task involving the monitoring of five green lights (normally on) and five red lights (normally off). The 10 lights are arranged in pairs of green and red. One pair is located in each corner of the test panel and a fifth is located in the center of the panel. The light lenses also serve as the pushbutton/switch. The subject was instructed to push the light/switch whenever the light changed state. The measure of performance on these tasks is mean response latency recorded separately for red and green lights.

Task 3: Monitoring of Meters.

This task involves monitoring four meters whose pointers move at random around the midpoint of the meter scale. The subject responds to a shift in the mean position of the pointer by pressing one of two buttons under the meter to report a left or right shift. The four meters are arranged across the top of the test panel. The performance measure is mean response latency.

Task 4: Mental Arithmetic.

The subject is required mentally to add two numbers and subtract a third number from the sum of the first two. All numbers are of two digits. Answers are recorded by a 10-key response panel. The arithmetic task display is located in the lower center of the test panel with the keyboard to the right of the display. Performance measures are the mean response latency and percent correct answers.

Task 5: Two-Dimensional Compensatory Tracking (TRK).

The tracking task display is an oscilloscope screen mounted in the top center of the subject's panel. The target on the screen is a dot of light about 1 mm in diameter. A varying amplitude disturbance is imparted to the target in each dimension; the subject attempts to counteract the disturbance, keeping the dot at the screen's center, by moving a control stick with his/her right hand. Performance is measured in arbitrary units (volts) by analog circuitry in terms of mean vector absolute error and mean vector root mean square (RMS) error.

Task 6: Problem Solving (PS).

Each test panel is equipped with five response buttons, a "task active" light, and three "feedback" lights, all located at the left center of the test panel. The problem is to discover the correct sequence in which to press the five response buttons. Each button appears only once in a given sequence. Subjects are instructed to use a trial-and-error procedure and a left-to-right search pattern. An amber feedback light is illuminated every time a button is pressed to show that the response is acknowledged by the system. Pressing a button in incorrect order causes a red light to turn on and stay on until the next correct response is made. Pushing all five buttons in correct order causes a blue light to turn on. When a problem is solved, a lapse of 15 sec occurs, following which the same problem is presented a second time. The subject is expected to reenter the previous solution from memory on the second, or confirmation, presentation. After another 15 sec a new problem is presented Performance measures for this task are: (i) mean response latencies for the first solution and the confirmation stages; and (ii) the mean number of errors per problem made during the confirmation phase.

MTPB Procedure. A basic 42-min schedule of the six MTPB tasks was used. This 42-min period was divided into three 14-min intervals. Tasks 1, 2, and 3 were given throughout the schedule. In the first 14-min interval, Task 4 was also active. In the second interval of each period, Tasks 5 and 6 were also active. In the third interval, Tasks 4, 5, and 6 were also active. These three interval schedules were named the low, medium, and high workload conditions, respectively, and were always presented in the same order in each period.

The five practice sessions were each of four 42-min periods. The experimental test sessions contained three 42-min periods.

Performance was assessed in terms of raw and composite scores for each task. Composite scores summarized all measures of performance for the particular task. An overall composite score (all tasks) was also obtained. Individual composite scores were calculated as follows: for each measure of performance on a task, the scores for an individual subject were converted to standard scores with a mean of 500 and a standard deviation of 100. The task composite score for each subject and experimental treatment was the mean of standard scores on each performance measurement. The sign of scores was changed, when necessary, so that higher standard scores always indicated better performance and lower scores, poorer performance. An overall composite score was also calculated for each subject and treatment by averaging the composite scores for different tasks so that each task made an equal contribution to the variance. Analyses of task and overall composite scores were made because they: (i) simplify the evaluation of a large amount of data; (ii) have been found to be more sensitive to the effects of experimental conditions than the individual measurements of performance; and (iii) have higher reliability than raw score data on individual performance measures (4,13).

On experiment days, subjects reported to the laboratory at 1200. Each subject emptied his bladder as completely as possible without collection of urine. The time was recorded and urine was subsequently collected at the end of each experiment. The volume was recorded and a portion of the sample was frozen for later analysis of catecholamines (10). The subjects were then fitted with adhesive chest electrodes which were connected to an electromagnetic tape recorder for continuous heart rate (HR) recording and for monitoring during the exercise portions of the experiments. A sphygmomanometer cuff was placed on the right arm of each subject for the monitoring of blood pressure during exercise. Thirty min after the exercise/no exercise period subjects donned oxygen masks and the performance testing was begun.

RESULTS

All data were treated by analysis of variance techniques (29).

Heart Rate. The HR data are presented in Fig. 2. During the exercise/no exercise portion of the experiments there was a highly significant effect for exercise ($p < .001$), with HR almost 40 percent higher during exercise than during rest. During the performance testing phase HR was significantly higher ($p < .05$) for those who had exercised than when they had not. There was also a significant altitude effect ($p < .01$), with HR higher during the 12,500 ft exposure than during the ground level exposure.

Urinary Excretion Rate of Catecholamines. There were no significant findings for the urinary excretion rate of epinephrine (E) (Fig. 3). There was no altitude effect for the urinary excretion rate of norepinephrine (NE). The NE values were significantly higher ($p < .05$) during exercise experiments than during the no-exercise experiments (Fig. 4)

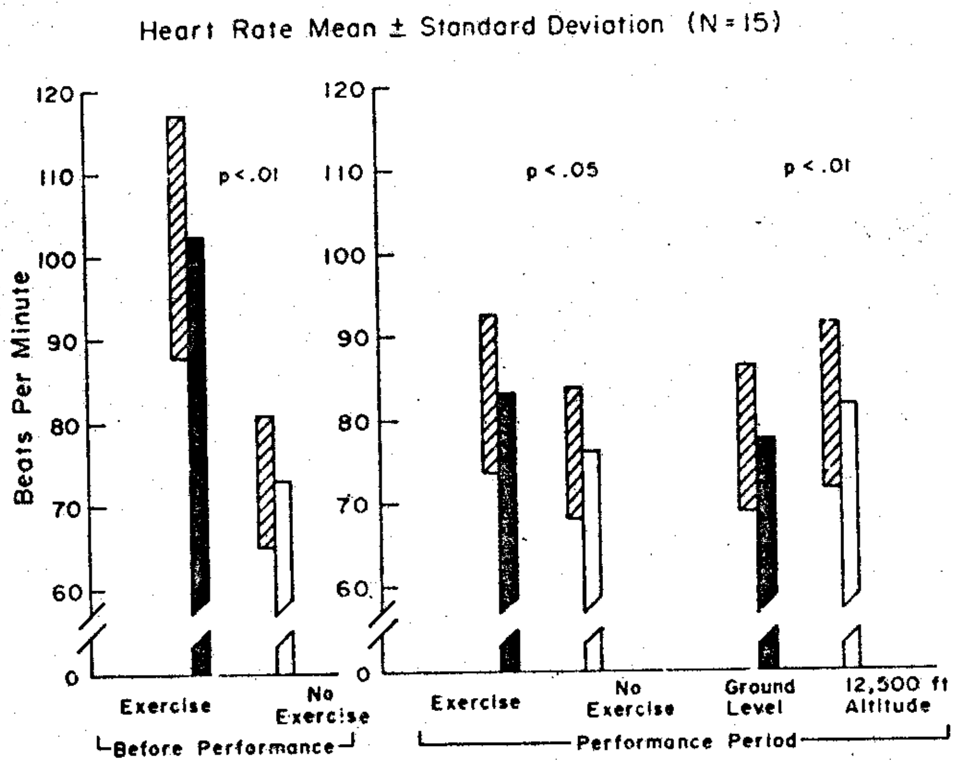

Figure 2. Bargraph of Heart Rate as a Function of Experimental Condition Before and During Complex Performance.

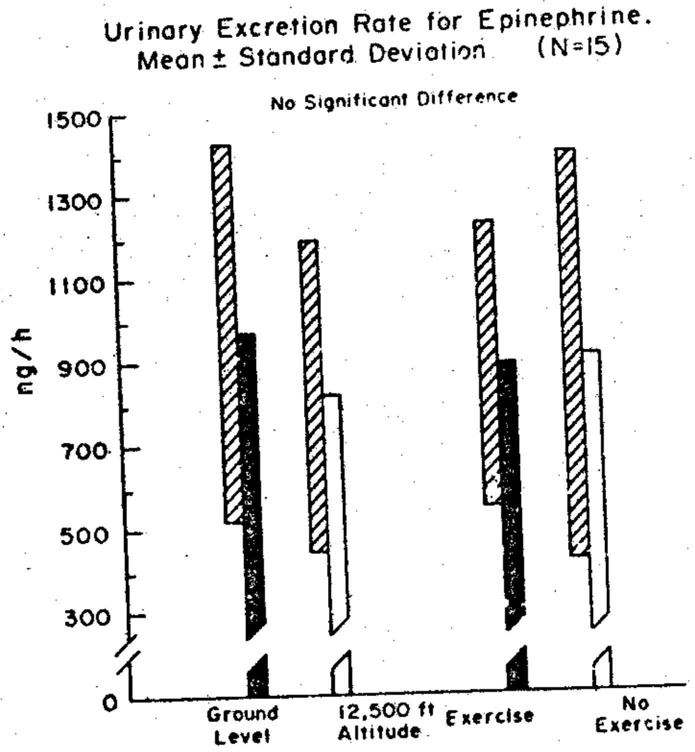

Figure 3. Bargraph of Urinary Excretion Rate for Epinephrine as a Function of Altitude or Exercise Condition.

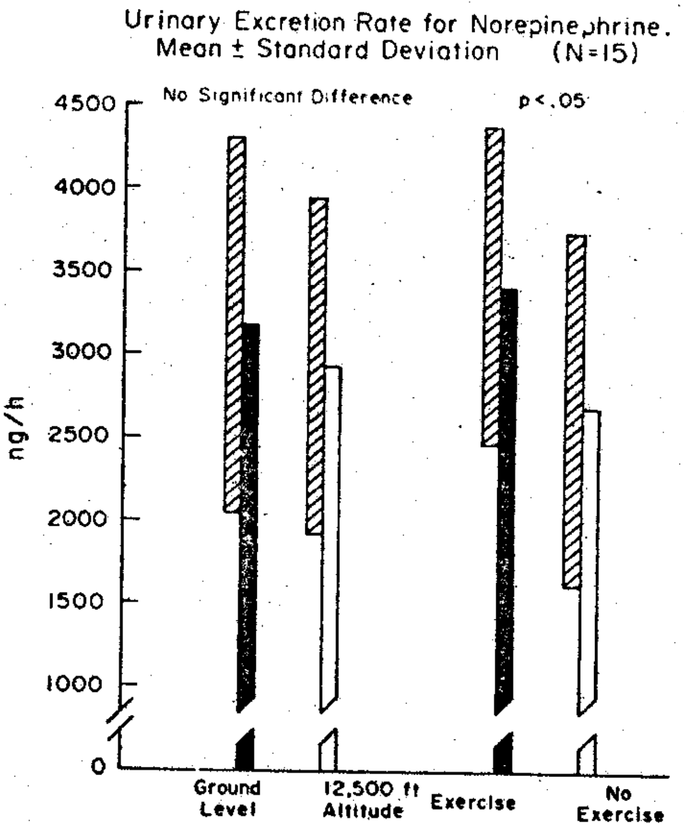

Figure 4. Bargraph of Urinary Excretion Rate for Norepinephrine as a Function of Altitude or Exercise Condition.

Fatigue Checklist. There were no significant effects of exercise or altitude on the subjective feeling of fatigue. Variability, however, was great (Fig. 5).

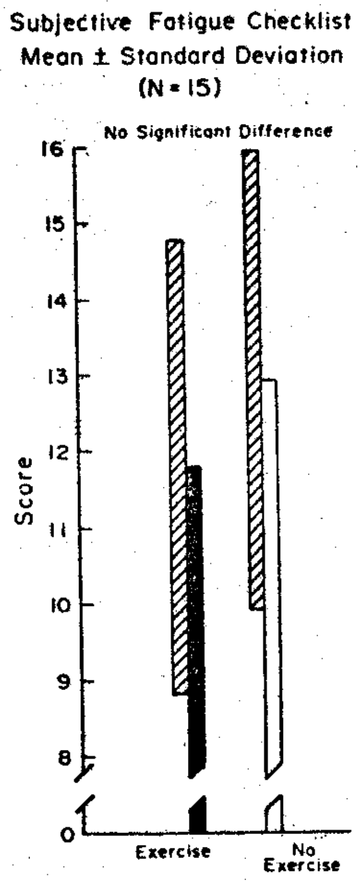

Figure 5. Bargraph of Subjective Fatigue Checklist Scores as a Function of Exercise Condition.

<u>Hand Steadiness</u>. The only significant finding for the Hand-Steadiness Test was for subject variability ($\underline{p} < .01$). The scores ranged from 0 to 218 counts during the 10-min test period (Fig. 6).

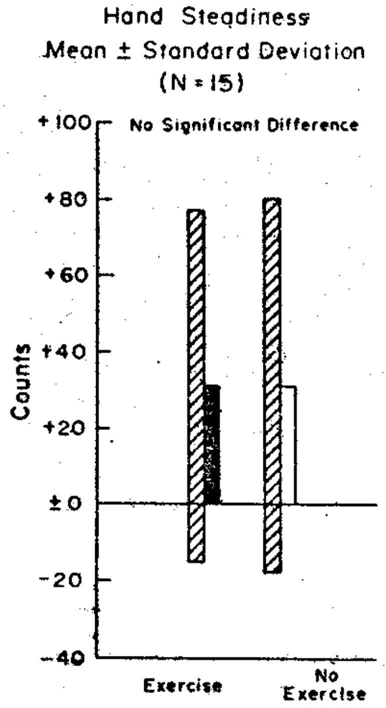

Figure 6. Bargraph of Hand Steadiness Scores as a Function of Exercise Condition.

<u>Complex Performance</u>.

<u>Composite Score Data</u>. The overall composite score data (means and standard deviations) are shown for the main effects of exercise, altitude, and periods, in Table II. Since all tasks did not occur at all workloads, these data are averaged over workload conditions. Overall performance was significantly lower ($\underline{p} < .05$) at 12,500 ft than at ground level but exercise had no significant effect. Overall performance declined in the second period of a session, with recovery occurring in period three to nearly the level of the first period of the session. However, the effect of periods was not statistically significant.

TABLE II. Standard Scores for Individual Monitoring Tasks, Composite Scores fur Active Tasks, and Overall Composite Scores of Exercise, Altitude, Period, and Workload

		Exercise		Altitude		Period			Workload		
		Exercise	No Exercise	Ground Level	12,500 ft	1	2	3	Low	Medium	High
Green Lights	Mean	507	493	507	493	499	493	508	514	504	481**
	S.D.	90.0	106.0	96.6	100.1	96.1	100.1	98.2	86.4	90.1	114.0
Red Lights	Mean	496	504	508	492	516	499	485	495	508	497
	S.D.	97.3	99.7	92.7	103.5	86.0	101.4	105.0	96.3	91.9	106.5
Meters	Mean	501	499	508	492	510	484	506*	551	508	441**
	S.D.	96.4	98.8	92.4	103.9	92.0	110.0	90.7	61.7	87.3	107.6
Arithmetic	Mean	503	497	500	500	497	484	519**	534	---	466**
	S.D.	66.7	80.8	70.4	77.8	64.2	81.0	72.1	59.8	---	71.4
Problem Solving	Mean	511	489*	503	497	498	496	506	---	536	464**
	S.D.	74.7	83.7	80.4	79.5	80.2	84.0	75.3	---	63.7	78.2
Tracking	Mean	499	501	518	482**	514	490	496	---	548	452**
	S.D.	90.0	95.4	94.7	87.3	105.0	81.2	88.6	---	83.5	75.6
Overall	Mean	503	497	507	493*	506	491	503	---	---	---
	S.D.	36.5	39.5	36.8	38.1	36.5	37.9	38.3	---	---	---

* $p < .05$
** $p < .01$

Composite scores (means and standard deviations) for each task are also shown in Table II for the main effects of exercise, altitude, period, and workload. These data show that the effect of altitude on overall scores was due primarily to a statistically significant decline in performance in the tracking task and nominally lower performance at altitude in all other tasks except arithmetic.

The main effect of exercise was statistically significant ($p < .05$) only in the case of the problem-solving task. The exercise treatment in that case had the effect of enhancing performance.

Increasing task workload typically had the effect of decreasing performance significantly ($p < .01$) in all tasks except the monitoring of red lights. In the latter case, the effect of workload was not statistically significant. Performance was similar at the low and high workload levels and lower in those conditions than in the medium workload condition.

Table III shows the significant interaction of exercise with altitude on tracking, the only task in which this significant interaction was found. The 20-unit superiority of tracking performance in the no-exercise condition over the exercise condition at ground level was completely reversed at altitude, even though performance was generally lower at altitude in both exercise conditions.

TABLE III. Composite Tracking Scores as a Function of Altitude and Exercise

	Altitude		
	Ground Level	12,500 ft	Mean
Exercise	507	492	499.218
No Exercise	528	473	500.782
Mean	518	482	

The only other interaction in composite score data that was statistically significant ($p < .01$) was the interaction of workload with period in the monitoring of green lights as shown in Table IV.

TABLE IV. Standard Scores for Monitoring of Green Lights as a Function of Workload and Period

		Period		
		1	2	3
Workload	Low	520	515	508
	Medium	520	498	495
	High	458	466	520

Raw Score Data. Raw score means and standard deviations for individual performance measures in each task are shown in Table V as a function of the main effects of exercise, altitude, workload, and period. These data show that the significant effect of exercise on problem-solving performance was due to a statistically significant beneficial effect on response times during both solution and confirmation stages of a problem and on errors during confirmation measures. Performance was also nominally better following exercise in all other measures in other tasks except for response times in monitoring of green lights and meters and in arithmetic percent correct.

The decrease in performance at altitude was significant in both measures of tracking performance and in mean response latency in the arithmetic task. Nominal performance decreases at altitude also occurred, with one exception, in all other measures of performance in other tasks.

Increasing workload consistently caused a decrease in performance in all tasks but monitoring of red lights. Measures on all tasks except red lights-monitoring and problem-solving response times typically showed a decline in performance in period two with recovery in period three. In monitoring of green lights and meters, in arithmetic response time, and in tracking RMS errors, performance in the final period was even better than in the first period. In red-lights monitoring, response times showed a continued increase over periods, whereas response times continued to improve (decrease) over the three periods in both solutions and confirmations of the problem-solving task. The effect of test period was significant only in response latency raw scores for arithmetic.

Several interactions were significant in the raw score data. These are shown in Table VI. The interaction of exercise and altitude was significant in the case of arithmetic response latency and tracking absolute error. The workload and test period had a significant interaction in the case of green-lights response latency and tracking RMS error. The only other interaction of significance involved the interaction of exercise with workload for arithmetic percentage correct. No significant second order interactions occurred.

Subjective Rating Scales. Subjects made subjective ratings before and after each performance testing session regarding attentiveness, tiredness, tenseness, boredom, and irritation. The main effects of exercise, altitude, and time of measurement on subjective ratings are shown in Table VII. The main effect of time of measurement (before vs. after the performance testing session) was significant in the case of all scales except attentiveness. After sessions subjects were significantly more tired, more tense, more bored, and more irritated. The only significant interaction was the second order interaction of exercise, altitude, and time of measurement with tiredness, as shown in Table VIII. This shows that the increase in tiredness after the performance sessions occurred only at ground level when exercise was given and only at 12,500 ft when the no-exercise condition was given.

TABLE V. The Main Effects of Exercise, Altitude, Period, and Workload in Raw Data for the Individual Performance Measures (Raw Scores) in all Tasks

		Exercise		Altitude	
		Exercise	No Exercise	Ground Level	12,500 ft
Green Lights					
Mean Response	Mean	3026	3259	2992	3294
Latency (ms)	S.D.	1762	1973	1739	1988
Red Lights					
Mean Response	Mean	1813	1763	1722	1855
Latency (ms)	S.D.	1192	1119	1018	1277
Meters					
Mean Response	Mean	13474	13204	13276	13402
Latency (ms)	S.D.	10957	9022	11640	8123
Problem Solving **Solution**					
Mean Time/	Mean	719	753*	730	743
Response (ms)	S.D.	166	225	203	194
Confirmation					
Errors Per	Mean	.484	.669**	.573	.579
Confirmation	S.D.	.558	.671	.644	.603
Mean Time/	Mean	751	788*	770	768
Response (ms)	S.D.	224	234	228	232
Arithmetic					
Mean Response	Mean	8.117	8.294	8.062	8.349**
Latency (sec)	S.D.	1.431	1.390	1.378	1.435
Percent	Mean	95.6	95.6	95.3	95.9
Correct	S.D.	4.2	5.0	4.6	4.6
Tracking					
Absolute	Mean	791.9	802.9	775.4	819.4**
Error (Vector)	S.D.	232.1	204.7	209.7	225.6
RMS Error	Mean	108.6	109.2	106.0	111.9**
(Vector)	S.D.	22.7	22.0	21.4	23.0

* p <.05
**p <.01

TABLE V. The Main Effects of Exercise, Altitude, Period, and Workload in Raw Data for the Individual Performance Measures (Raw Scores) in all Tasks Continued

		Period			Workload		
		1	2	3	Low	Medium	High
Green Lights							
Mean Response	Mean	3167	3257	3004	2882	3057	3489**
Latency (ms)	S.D.	1830	2038	1733	1658	1635	2218
Red Lights							
Mean Response	Mean	1629	1849	1886	1814	1753	1797
Latency (ms)	S.D.	911	1217	1289	1214	1166	1085
Meters							
Mean Response	Mean	13010	14361	12646	10670	12806	16541**
Latency (ms)	S.D.	11300	10981	7233	7701	8292	12511
Problem Solving							
Solution							
Mean Time/	Mean	749	745	715	---	686	787*
Response (ms)	S.D.	214	211	165	---	159	220
Confirmation							
Errors Per	Mean	.528	.609	.596	---	.433	.720**
Confirmation	S.D.	.549	.633	.680	---	.432	.742
Mean Time/	Mean	781	772	754	---	692	846*
Response (ms)	S.D.	246	235	208	---	197	236
Arithmetic							
Mean Response	Mean	8.250	8.567	7.799**	7.412	-----	8.999**
Latency (sec)	S.D.	1.324	1.441	1.367	1.015	-----	1.307
Percent	Mean	95.6	95.5	95.7	95.7	----	95.5
Correct	S.D.	4.2	4.8	4.8	4.9	----	4.3
Tracking							
Absolute	Mean	779.8	813.8	798.7	-----	728.0	866.9**
Error (Vector)	S.D.	227.0	218.4	209.7	-----	213.5	201.5
RMS Error	Mean	106.8	109.8	101.2	-----	102.6	115.2**
(Vector)	S.D.	23.7	21.8	21.5	-----	21.7	21.2

* p < .05
**p < .01

Table VI. Significant Interactions in Raw Score Data

Arithmetic - % Correct

	Workload	
	Low	High
Exercise	95.26	96.03
No Exercise	96.18	94.94

Arithmetic - RT (sec)

	Altitude	
	Ground Level	12,500 ft
Exercise	7.866	8.367
No Exercise	8.258	8.331

Tracking - Abs Error (arbitrary units)

	Altitude	
	Ground Level	12,500 ft
Exercise	785	798
No Exercise	765	841

Green Lights - RT (sec)

		Period		
		1	2	3
	Low	2.808	2.810	3.029
Workload	Med	2.871	3.087	3.213
	Hi	3.822	3.875	2.771

Tracking - RMS Error (arbitrary units)

		Period		
		1	2	3
Workload	Med	97.599	104.023	106.218
	Hi	115.904	115.500	114.210

TABLE VII. The Main Effects of Exercise, Altitude, and Time of Measurement on Subjective Rating Scale Responses

RATING SCALE		Exercise Exercise	Exercise No Exercise	Altitude Ground Level	Altitude 12,500 ft	Time of Measurement Before	Time of Measurement After
Attentiveness	Mean	5.06	4.96	4.88	5.15	5.17	4.85
	S.D.	1.31	1.17	1.18	1.29	1.14	1.32
Tiredness	Mean	5.54	5.33	5.63	5.25	5.17	5.71*
	S.D.	1.70	1.74	1.52	1.88	1.61	1.78
Tenseness	Mean	4.38	4.17	4.25	4.29	3.63	4.92**
	S.D.	1.62	1.67	1.61	1.68	1.15	1.18
Boredom	Mean	4.29	4.54	4.35	4.48	4.06	4.77*
	S.D.	2.00	2.19	2.02	2.18	1.89	2.23
Irritation	Mean	2.58	2.46	2.40	2.65	1.60	3.44*
	S.D.	1.83	1.81	1.73	1.91	.95	2.02

TABLE VIII. The Significant 2nd Order Interaction of Exercise, Altitude, and Time in Tiredness Ratings

	Before Ground Level	Before 12,500 ft	After Ground Level	After 12,500 ft
Exercise	5.42	5.17	6.42	5.17
No Exercise	5.33	4.75	5.33	5.92

DISCUSSION

The intent of the protocol was to induce a degree of physical fatigue prior to a standard performance test period. However, the level of fatigue produced by the standard exercise routine appeared to be quite variable and possibly was related to the level of physical fitness of the subjects. The exercise level was sufficient to cause a statistically significant rise in the urinary excretion rate of NE when the exercise condition was compared to the no-exercise condition. Although several subjects complained of the exercise being "difficult" and of their legs being "tired," they did not register a significant increase in subjective fatigue for exercise over no exercise. The high variability on the fatigue checklist following exercise is reflective of the range of physical conditioning of the 12 subjects. The maximum HR attained, usually during the last 10 min of exercise, ranged from 117 to 172 bpm and served as another indication of the varied levels of fitness among the subjects.

The 30 min between the end of exercise and the beginning of the performance testing was apparently not adequate for full recovery from the effects of exercise. This was demonstrated by the fact that the average HR during the MTPB period was statistically higher after exercise than after no exercise.

The only physiological index indicating an effect of altitude was HR. In both exercise conditions HR was slightly, but significantly, higher in the altitude condition. Epinephrine excretion rate was nominally higher at ground level, on the average, whereas norepinephrine excretion rate was nominally higher at 12,500 ft.

It was found that a 1-h period of vigorous physical exercise which ended 1/2 h prior to performance testing had little effect on subsequent complex performance. Analogous bouts of exercise may normally occur in work or recreation prior to flight. The 1/2-h rest period between exercise and testing was found to be sufficient to prevent adverse effects on the overall index of MTPB performance at both ground level and the 12,500 ft altitude. Corollary physiological measurements during this experiment indicate, however, that recovery from exercise was not complete at the start of performance testing. Those residual effects of exercise, perhaps resulting in increased arousal, may account for the tendency of MTPB performance to be slightly higher in general and significantly higher in the case of the problem-solving task. The physiological data, however, are not entirely consistent with that hypothesis. Some support is suggested by the higher NE excretion rate and higher HR after exercise. Mean E and NE excretion rates were nominally higher in the ground level condition, consistent with the higher overall level of performance at ground level as compared to 12,500 ft, but HR was slightly lower at ground level.

One important finding was that there was no adverse effect of prior exercise at altitude. The level of exercise was high, though of short (1-h) duration, and apparently sufficient recovery occurred to prevent adverse effects.

The present study adds to the body of literature on the effects of altitude (hypoxia) on performance by demonstrating a significant decrement in complex (time-shared) performance at the simulated altitude of 12,500 ft. That altitude is the highest at which pilots may fly continuously without supplemental oxygen in unpressurized aircraft. Particularly important was the large and statistically significant decrement that occurred at 12,500 ft in tracking, a skill of well-known importance to pilots. At the 12,500 ft altitude, performance in the first 42-min period of testing was similar in both exercise and no-exercise conditions. Tracking performance dropped off markedly, however, in the no-exercise condition during subsequent periods of the test session. Performance was maintained at a much higher level following exercise as can be seen in Table II in the case of tracking. This finding suggests that the increase in the rate of cardiovascular circulation induced by the prior exercise may result in protection from hypoxia effects over an extended period of performance (2½ h in this case). Future research on the effects of exercise and altitude should examine this possibility.

The present demonstration of sensitivity of MTPB performance to mild hypoxia at the 12,500-ft general aviation altitude adds to the value of the MTPB for study of the effects of various physiological, pharmacological, and environmental factors which are thought to interact with hypoxia in the aviation environment.

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