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THE EFFECTS OF AGE, SLEEP DEPRIVATION, AND ALTITUDE ON COMPLEX PERFORMANCE

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16. Abstract

Little research has been concerned with the combined effects on performance of age, sleep deprivation, and altitude. This study examined their potential interaction with laboratory tasks measuring aviation-related psychological functions. Healthy men in two age groups, 30-39 yr (N=16) and 60-69 yr (N=14), were evaluated for complex (time-shared) performance in the four possible combinations of two altitudes (ground level vs. 3,810 m (12,500 ft)) and two sleep conditions (sleep permitted vs. sleep deprived). Following training, performance was evaluated during 3-h test sessions in the morning and afternoon of each of 4 test days. Complex performance, measured by the Multiple Task Performance Battery (MTPB), included: monitoring of warning lights and meters, mental arithmetic, problem solving, target identification, and tracking. Workload was varied within each hour by varying the tasks performed simultaneously. Performance was significantly lower in the older subjects, but age did not interact significantly with sleep deprivation or altitude. There was, however, a significant interaction of sleep deprivation and altitude. When subjects were rested, altitude had no effect. When subjects were sleep deprived, performance was significantly lower in general, and the greatest decrement in performance occurred at altitude. Increasing workload enhanced the interaction of sleep deprivation and altitude. The performance of older subjects tended to be more affected by increases in workload, but decrements induced by sleep deprivation and altitude did not appear to interact with age. These findings provide empirical evidence in support of warnings in the aeromedical literature concerning greater effects of sleep deprivation as altitude increases within the general aviation range.

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THE EFFECTS OF AGE, SLEEP DEPRIVATION, AND ALTITUDE ON COMPLEX PERFORMANCE

INTRODUCTION

Two aviation stressors, sleep deprivation and altitude, have been studied individually regarding their frequently adverse relation to performance, but little research has been concerned with their combined effects or the interaction of those effects with age in spite of concerns expressed by some writers for such potentially adverse synergistic effects (Institute of Medicine, 1981; Johnson, 1982; Webb and Levy, 1982).

A small study by Lottig (1938) over 45 years ago suggested a possible adverse interaction of sleep deprivation and altitude, but the issue appears not to have been addressed in research since that time. In Lottig's study, three out of six subjects manifested an average decrease of 250 ft (76.2 m) in the altitude at which symptoms of altitude sickness first appeared when sleep was reduced from 8 to 4 hours, and there was corresponding evidence of mental impairment in a handwriting task and in subjective observations of speech, mood, and thought processes. The effects observed by Lottig appeared only at altitudes greater than 5,000 m (16,404 ft); however, the normal range of general aviation altitude is limited to 3,810 m (12,500 ft) for continuous operations without supplemental oxygen in unpressurized aircraft. The possibility should be examined that more sensitive flight-related tasks would reveal an interaction of altitude with sleep deprivation at lower altitudes within the range of the present-day general aviation environment.

McFarland (1941) and Mertens, Higgins, and McKenzie (1983) have studied the interaction of age and altitude. Both studies examined subjects within the age range of approximately 20 to 70 years. Although both studies found that performance decreased with age, the effects of altitude did not differ among age groups. The age-related performance decrements found by Mertens et al., which were not affected by a 3,810-m general aviation altitude, occurred only in higher workload conditions, suggesting that the workload factor should be systematically varied in research on the interaction of stressors with age.

Two studies have found an interaction of age with sleep deprivation. Webb and Levy (1982) evaluated the performance of 10 young subjects, 20-22 yr, and 10 older subjects, 40-49 yr, in a number of psychological tasks during the second night of sleep deprivation (approximately 41-45 h of sleep deprivation). Although the rested performance of the older subjects was initially higher, the decrements in performance were larger in the older subjects for several tasks. Brezinova, Hart, and Vojtechovsky (1969) studied the effects of prolonged sleep deprivation on alertness as measured by electroencephalographic responses in a group of middle-aged alcoholics (average age = 40 yr) and a group of younger alcoholics (average age = 22 yr). They concluded: "In the first phases of sleep deprivation, after the first and second nights of the vigil, signs of a relatively smaller decrease in vigilance in older subjects were found... During prolonged sleep deprivation, after the fourth and fifth nights without sleep, signs of better tolerance were seen in younger subjects..." There is apparent disagreement between the findings of Webb and Levy and the findings of Brezinova et al. regarding the effects of sleep deprivation as a function of age during the first 48 h of sleep deprivation. Clearly, additional research on the age/sleep deprivation interaction is needed.

It is the purpose of the present study to reexamine the effects and interactions of the aviation stressors age, sleep deprivation, and altitude. The second order interaction of age, sleep deprivation, and altitude has not been previously evaluated experimentally. These possible interactions were evaluated in the present preliminary experiment with (i) two age groups, 30-39 yr vs. 60-69 yr, (ii) two sleep deprivation conditions, a normal night's sleep vs. loss of one night's sleep, and (iii) two altitude conditions, ground level vs. 3,810 m. The Civil Aeromedical Institute's Multiple Task Performance Battery (MTPB) was used to measure the effects of stressors on complex (time-shared) performance of several flight-related tasks under varying workload conditions.

METHOD

Subjects. Thirty men, 16 in a 30- to 39-yr age group and 14 in a 60- to 69-yr age group, served as subjects. Physiological condition and intellectual ability of subjects in both age groups were controlled by requiring that subjects pass the equivalent of a Class III airman physical examination, exhibit pulmonary function in the normal range, and have an intelligence quotient in the normal range or above.

MTPB. The MTPB is well known in the performance literature through the work of Alluisi, Chiles, Adams, Morgan, and others (Alluisi, 1967; Chiles, Alluisi, and Adams, 1968; Morgan, and Alluisi, 1972; Chiles and Alluisi, 1979). The Civil Aeromedical Institute's version of the MTPB was developed by Chiles (Jennings, Chiles, and West, 1972). Five subjects can be run independently at the same time with this system. The MTPB tasks have high content validity and high face validity for aviation and are presented in various combinations to produce a synthetic work situation involving variation of workload and time sharing of work in assorted tasks. One of the consoles at which subjects work is shown in Figure 1. The MTPB tasks are described as follows:

Monitoring of Warning Lights. Two tasks involved monitoring of red and green warning lights. These are choice reaction-time tasks involving monitoring of five green lights (normally on) and five red lights (normally off). The subjects were instructed to push the light/switch whenever a light changed state. Response times were recorded separately for red and green lights.

Monitoring of Meters. This task involved monitoring four meters arrayed across the top of the console. The pointers of these meters constantly moved at random about the center position. The subjects were instructed to respond to a shift in mean position of the pointer to the left or right of center by pushing a button under the meter on the side of the deflection. Response times were scored.

Mental Arithmetic. The subject was required to add two two-digit numbers and subtract a third number from the sum of the first two without using paper and pencil. Answers were recorded with a 10-key pad. Response time and accuracy were assessed.

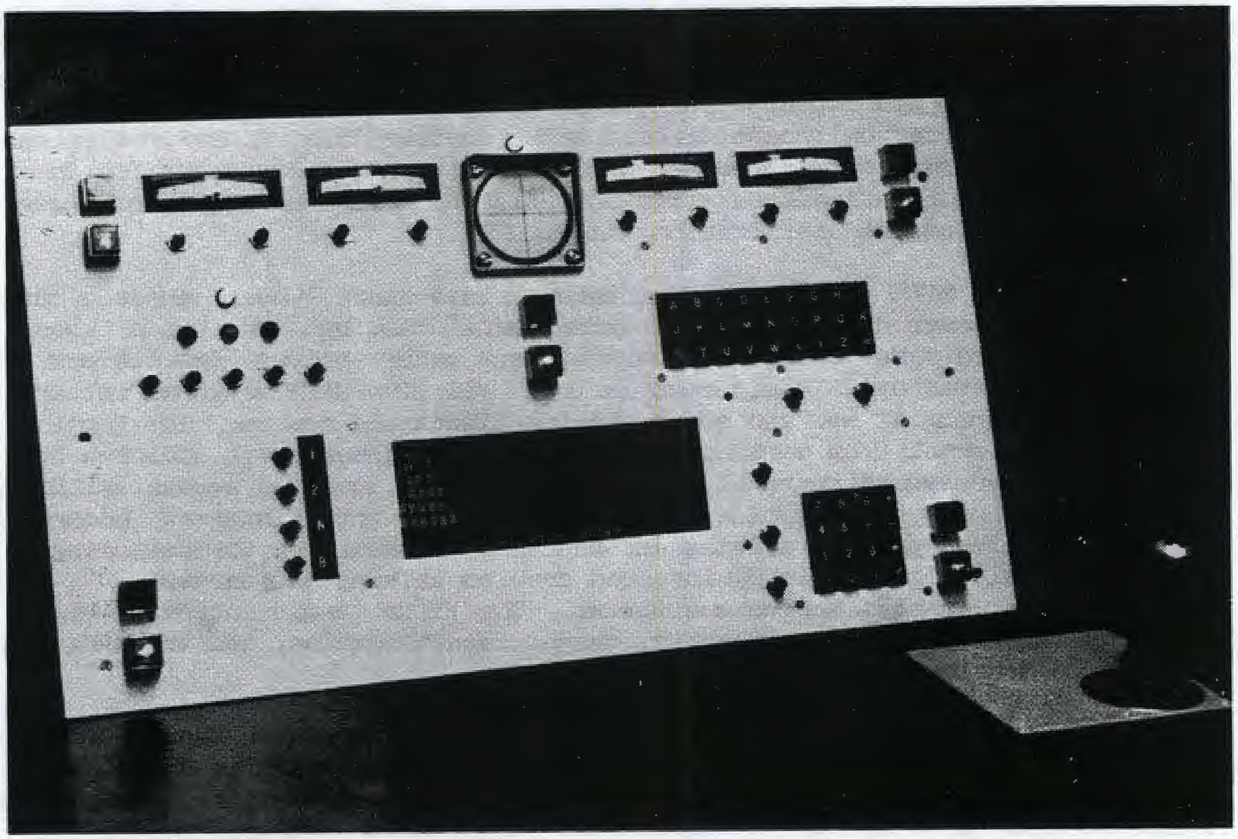

Figure 1. Multiple Task Performance Battery console.

Target Identification. A standard histogram pattern was displayed on a six- by six-cell matrix for 5 s by successive presentations of two comparison patterns for 3 s each. The subject then decided if one, neither, or both of the comparison patterns matched the standard pattern. The answer was given by pressing the appropriate response button. Response latency and accuracy were recorded.

Tracking. The display for the two-dimensional compensatory tracking task was an oscilloscope screen. A varying amplitude disturbance was imparted to the green dot target in each dimension; the subject attempted to counteract the disturbance to keep the dot at screen's center by moving a control stick. Performance is measured in arbitrary units by analog circuity in terms of mean vector absolute error and mean vector root mean square error.

Problem Solving. For the problem-solving task, each test panel was 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 for the subject was to discover the correct sequence in which to press the five response buttons. Each button appeared only once in a given sequence. The subject was instructed to use a trial-and-error procedure with a left-to-right search procedure. Pressing a button in incorrect order caused a red light to turn on and stay on until the next correct response was made. Pushing all five buttons in correct order caused a blue light to turn on. When a problem was solved, a lapse of 15 s occurred, following which the same problem was presented a second time. The subject was expected to reenter the previous solution from memory on the second, confirmation presentation. After another 15 s, a new problem was presented. Performance measures were: (i) mean response latencies for the first solution and confirmation stage and (ii) the mean number of errors per problem made during the confirmation stage.

MTPB Workloads. MTPB tasks were administered in a basic 1-hour schedule that was constant throughout training and experimental testing. The basic 1-hour schedule involved five 10-min intervals of work under various combinations of MTPB tasks followed by a 10-min rest period. All five MTPB workload intervals involved monitoring of red and green warning lights and meters. The first 10-min MTPB interval (low workload) always included tracking in addition to monitoring. The second interval (moderate workload) involved mental arithmetic and problem solving, in addition to monitoring. The third interval (moderate workload) involved problem solving and tracking, in addition to monitoring. The fourth interval (high workload) involved problem solving and target identification, in addition to monitoring. The fifth 10-min interval (high workload) included mental arithmetic, target identification, and tracking, in addition to monitoring.

Performance was assessed in terms of 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, as well as a composite score for the three monitoring tasks (red lights, green lights, meters) and a composite score for the four "active" tasks (mental arithmetic, target identification, tracking, problem solving), which involved greater demand on cognitive resources. Task composite scores were calculated as follows: For each measure of performance on a task, the raw scores for all subjects 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 for that task. The sign of scores was changed, when necessary, so that higher standard scores always indicated better performance, and lower scores, poorer performance. Overall, monitoring and active composite scores were computed by averaging the appropriate task composite scores for each subject and treatment so that each task made an equal contribution to the variance. Analyses of the 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 individual measurements of performance, and (iii) have higher reliability than raw-score data on individual performance measures (Jennings, Chiles, and West, 1972).

Procedure. Following 21 h of training on the MTPB, subjects participated in four experimental test sessions spread over a 2-week period with at least 2 days between each two tests. Subjects were run in groups of five, with at least two members of each age group in each group of five. The four test conditions included the four possible combinations of the two altitude and two sleep conditions. The altitude conditions, 3,810 m or ground level (approximately 396 m), were administered during all performance measurement sessions. Altitude simulation was accomplished by gas mixtures administered through face masks worn by subjects. The mixture used to simulate the 3,810-m altitude contained 13.5 percent oxygen and 86.5 percent nitrogen. Compressed air was used for the ground level condition.

The two sleep conditions involved normal unregulated sleep at home prior to performance testing vs. sleep deprivation involving loss of one night's sleep immediately prior to performance testing. In the sleep deprivation condition, subjects reported to the laboratory at 2030 in the evening and remained there until performance testing was completed the following day. Subjects were closely supervised by two experimenters to prevent dozing. Caffeine and food intake were controlled during the sleep deprivation period and during performance sessions. During the sleep deprivation period, subjects were permitted to play cards, ping-pong, computer games, and video games; watch television; or read, but no vigorous exercise was permitted. In the normal sleep condition, subjects slept at home, ate a prescribed light breakfast, and reported to the laboratory at 0800 of the performance test day.

In all four experimental conditions, the morning MTPB performance session began at 0900 and involved three repetitions of the basic 1-hour work schedule, ending at 1200. After a lunch break, the afternoon session began at 1300 and involved a schedule similar to the morning session. During every morning and afternoon experimental test session, subjects breathed the appropriate gas mixture for the entire 3-hour duration. Questionnaires concerning amount of sleep and breakfast intake and mood rating scales were administered before the morning performance session. Mood rating scales were also administered after both morning and afternoon sessions. Subjects rated mood, on nine-point scales, regarding levels of attentiveness, tiredness, tenseness, boredom, and irritation (Thackray, Bailey, and Touchstone, 1977).

RESULTS

All data were treated by analysis of variance techniques.

Complex Performance. The main effects of age, sleep deprivation, altitude, and workload are shown in Table I. Data are shown for performance of individual tasks, an overall composite summarizing scores in all tasks, and composites summarizing performance separately for the monitoring tasks (green lights, red lights, and meters) and the active tasks (mental arithmetic, target identification, problem solving, and tracking). Since all active tasks did not occur at all workloads, overall composite scores and composite scores for active tasks were averaged over workload intervals. Overall performance was consistently lower in the 60- to 69-yr group than in the 30- to 39-yr group in all tasks, and significantly so in the overall composite scores ($p < .01$); monitoring composite scores ($p < .05$); and two individual tasks, the monitoring of red lights ($p < .001$) and the monitoring of green lights ($p < .05$).

Sleep deprivation consistently decreased performance. The effect of sleep deprivation was highly significant in all individual tasks and all composite scores.

TABLE I. The Main Effects of Age, Sleep Deprivation, and Altitude in Composite Scores and Individual Task Scores

Score		Age		Sleep		Altitude		Workload Interval				
		30's	60's	Yes	No	Gnd	Alt	1	2	3	4	5
Overall Composite	Mean	513	484*	519	480**	502	497*	-	-	-	-	-
	S.D.	53	39	33	55	46	52	-	-	-	-	-
Monitoring Composite	Mean	519	477**	517	482**	501	498	528	497	504	482	486**
	S.D.	63	71	54	80	67	73	52	65	64	80	76
Active Tasks Composite	Mean	508	490	520	479**	503	496**	-	-	-	-	-
	S.D.	60	41	38	58	50	56	-	-	-	-	-
Arithmetic	Mean	509	489	512	487**	504	495**	-	544	-	-	455**
	S.D.	84	76	74	87	77	85	-	55	-	-	79
Target Ident.	Mean	499	500	533	467**	506	493**	-	-	-	495	504
	S.D.	103	84	44	118	84	104	-	-	-	99	90
Problem Solving	Mean	513	485	517	482**	500	499	-	500	531	467	- **
	S.D.	87	69	65	89	81	80	-	75	66	86	-
Tracking	Mean	512	486	519	480**	502	497	573	-	462	-	463**
	S.D.	100	82	100	81	94	92	95	-	65	-	68
Green Lights	Mean	534	461*	519	480**	503	496	533	500	500	483	482**
	S.D.	80	106	93	102	100	99	86	102	96	102	102
Red Lights	Mean	511	486**	511	488**	498	502	524	487	508	486	493**
	S.D.	95	103	90	107	105	94	81	105	87	107	101
Meters	Mean	513	484	520	480**	504	495*	527	505	506	477	484**
	S.D.	85	112	54	127	88	109	54	89	89	121	121

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

The effect of altitude was significant in the meters ($p < .05$), mental arithmetic ($p < .01$), and target identification tasks ($p < .01$) as well as in the overall ($p < .05$) and active tasks composite scores ($p < .01$). As will be shown below, this effect of altitude was due to an interaction of sleep deprivation and altitude.

The main effects of session and hourly period within a session were small and, therefore, are not shown in Table I. Performance tended to be slightly lower in afternoon sessions, but the main effect of sessions was significant only in the scores for the meters task ($p < .05$) and tracking ($p < .05$), not in composite measures.

Performance in successive 1-h periods of experimental sessions tended to be highest in period 1 and lowest in period 3, but that effect of periods was significant only in the case of the meters ($p < .05$) and tracking tasks ($p < .001$), as in the case of the effects of sessions.

The main effect of workload was statistically significant in all tasks except target identification. The effect of workload was significant at the $p < .001$ level in the composite scores for monitoring as well as several individual tasks, including red-light and green-light monitoring, mental arithmetic, problem solving, and tracking. The workload effect was significant at the $p < .01$ level in the meters tasks. The three monitoring tasks tend to be given lower priority by subjects than other MTPB tasks that require more active participation. The monitoring tasks, therefore, generally have secondary status and provide an index of residual attention that is inversely related to workload. The pattern of main effects in monitoring performance indicates that task demands (workload) were highest (and monitoring performance lowest) in workload 4 with workloads 5, 2, 3, and 1 following in that order. That order is in general accord with the number of tasks presented in each interval, with the exception of workload intervals 4 and 5. The combination of problem solving and target identification with monitoring apparently created higher workload than did the combination of arithmetic, problem solving, and tracking with monitoring, even though one less task was involved.

Interactions. Cell means and standard deviations for the interaction of age, sleep deprivation, and altitude are shown for individual tasks and composite scores in Table II.

Data are averaged over workload, session, and period in these tables. The second order interaction of age, sleep deprivation, and altitude was not significant in any case, nor was the first order interaction of age with sleep deprivation. There was a significant interaction of age with altitude, but only in the case of the problem-solving task ($p < .05$), not in any other task or in any composite score.

In contrast, the interaction of sleep deprivation with altitude was significant in overall ($p < .004$), monitoring ($p < .004$), and active-task ($p < .05$) composite scores, as well as in three individual tasks including monitoring of red lights ($p < .05$) and meters ($p < .05$) and in target identification ($p < .05$). This interaction is illustrated for overall composite scores in Figure 2.

TABLE II. Composite and Individual Task Scores as a Function of Age,

Score		30-39 yr				60-69 yr			
		Sleep		No Sleep		Sleep		No Sleep	
		Gnd	Alt	Gnd	Alt	Gnd	Alt	Gnd	Alt
Overall Composite**	Mean	533	535	500	483	499	502	472	463
	S.D.	30	29	58	66	30	27	39	44
Monitoring Composite**	Mean	531	541	511	494	494	494	463	455
	S.D.	33	25	55	66	39	38	52	57
Active Tasks Composite**	Mean	534	531	493	474	503	508	478	469
	S.D.	37	40	64	71	33	30	41	46
Arithmetic	Mean	529	522	500	486	495	498	489	474
	S.D.	36	64	73	70	45	41	44	60
Target Ident.*	Mean	536	537	477	447	527	529	484	460
	S.D.	37	31	107	139	47	33	77	104
Problem Solving	Mean	534	533	500	482	494	502	468	475
	S.D.	57	62	77	88	44	34	70	49
Tracking	Mean	539	531	494	483	498	504	472	468
	S.D.	69	76	68	61	43	53	41	40
Green Lights	Mean	559	554	520	501	476	477	444	445
	S.D.	34	37	48	61	72	64	76	71
Red Lights*	Mean	506	533	510	495	498	504	473	470
	S.D.	80	45	56	65	44	48	72	59
Meters*	Mean	529	535	502	487	509	502	473	452
	S.D.	35	17	83	104	39	44	90	119

Significance of the sleep deprivation by altitude interaction:
* $p < .05$
** $p < .01$

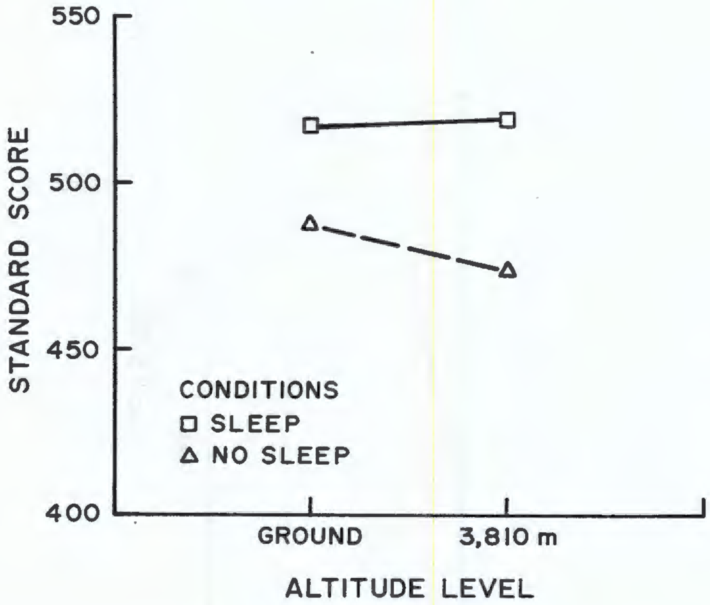

Figure 2. Mean overall performance as a function of sleep deprivation and altitude.

The form of the sleep by altitude interaction indicated that, while there was no important effect of altitude on performance in rested subjects, detrimental effects of altitude appeared when subjects were sleep deprived.

A significant second order interaction, which can be seen in Figure 3 for overall composite scores, involved the factors of age, sleep deprivation, and sessions. Performance in both the 30- to 39-yr and 60- to 69-yr groups maintained a fairly constant level over the 6 hours of performance during test days of both conditions in which subjects were not sleep deprived. When deprived of a night's sleep, the younger subjects maintained performance at a lower level that was similar in morning and afternoon sessions. In older subjects, however, there was a decline in performance from morning to afternoon when they were sleep deprived. This interaction was significant in the overall performance ($p < .028$) and in composite scores for active tasks ($p < .008$), but not in monitoring performance. Among individual tasks, the interaction of age, sleep deprivation, and session was significant for mental arithmetic ($p < .05$), problem solving ($p < .05$), and target identification ($p < .006$). Note in Figure 3 that, although performance declines with time in sleep-deprived older subjects, the decline in performance due to the combined effects of sleep deprivation and time is not greater in older subjects. The interaction of age, sleep deprivation, and time seems, rather, to be due to less effect of sleep deprivation in the morning session in older subjects than in younger subjects.

Workload had a significant main effect in almost all tasks but had interactions with other factors only in the case of monitoring performance. Figure 4 shows monitoring performance as a function of sleep deprivation, altitude, and workload separately for each age group. The interaction of age with workload was significant in monitoring composite scores ($p < .001$). Increasing workload had a greater adverse effect in older subjects. The sleep deprivation by

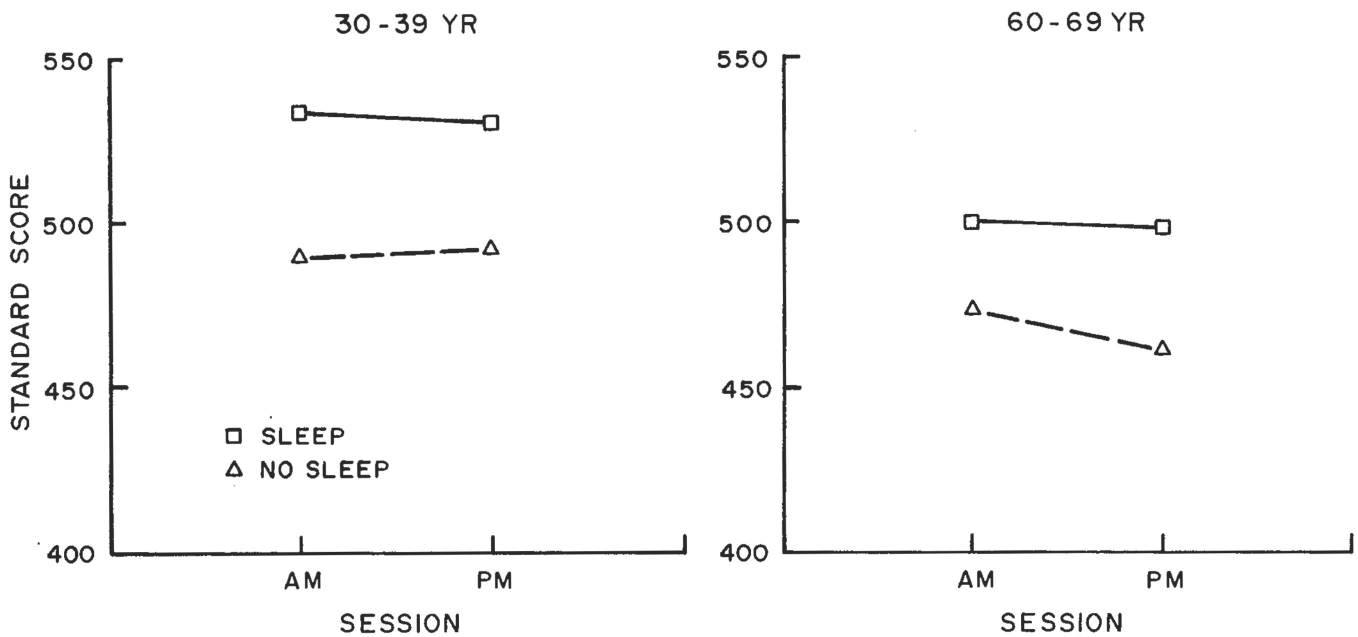

Figure 3. Mean overall performance as a function of age, sleep deprivation, and sessions.

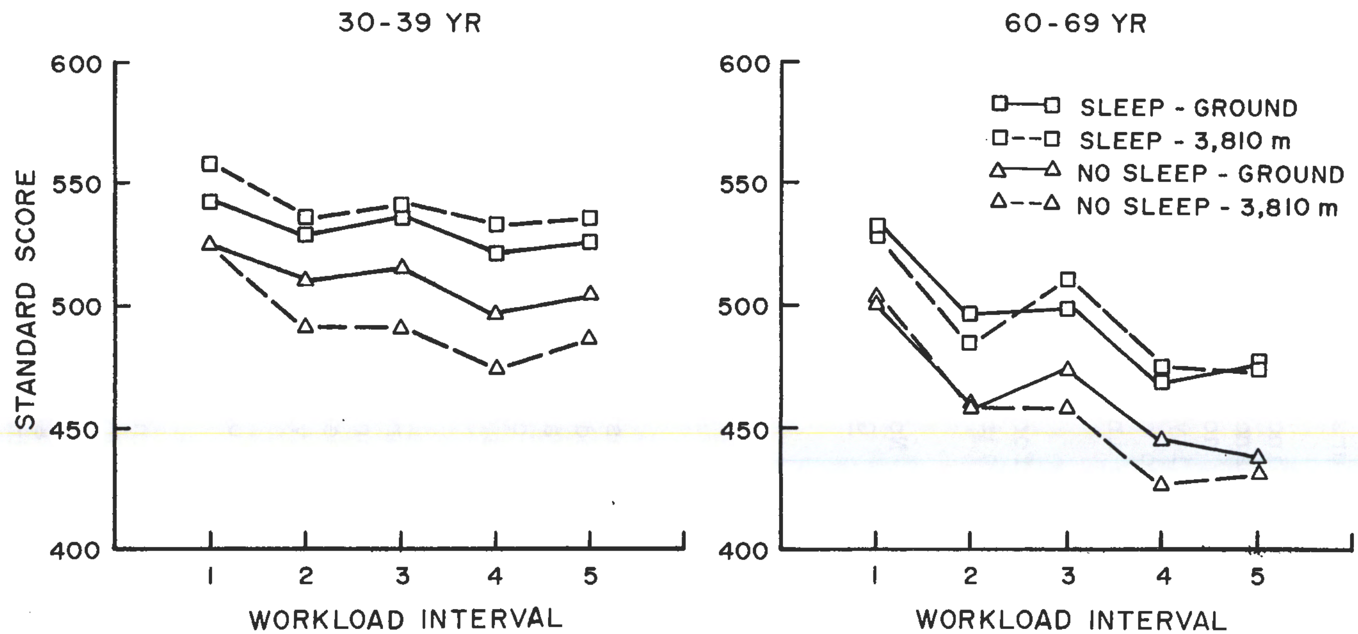

Figure 4. Mean monitoring performance as a function of age, sleep deprivation, altitude, and workload interval.

altitude by workload interaction was also significant ($p < .032$) in monitoring performance. The sleep by altitude interaction tended to appear at moderate or high workloads. The third order interaction of sleep deprivation, altitude, session period, and workload also was significant in the monitoring composite scores, indicating that the sleep by altitude by workload interaction was greatest in the second and third hours of the morning session.

Reliability of MTPB Performance. Since altitude variation as performed in this experiment had no effect on performance when subjects were rested, performance measurements for the two conditions not involving sleep deprivation provide an opportunity to examine the reliability of MTPB performance. The mean performance of subjects in those two conditions had a correlation of .93, as shown in Table III, which shows the intercorrelation of mean performance for the four experimental conditions.

TABLE III. Intercorrelation of Performance in the Four Sleep Deprivation/Altitude Conditions

	Sleep/ Altitude	No Sleep/ Ground	No Sleep/ Altitude
Sleep/Ground	.93	.73	.61
Sleep/Altitude		.68	.55
No Sleep/Ground			.90

The correlations among the six 1-h test periods of the ground-level condition not involving sleep deprivation ranged from a low of .84 for the first and fifth hours to a high of .93 for the first and second hours. Performance of rested subjects at the 3,810-m altitude had correlations among the six 1-hour periods that ranged from a low of .82 for the first and fifth hours to a high of .91 for the third and fourth hours.

The correlation of mean overall performance scores in the two sleep deprivation conditions was .90, similar to the correlation of performance in the two conditions involving rested performance. The correlations among means for 1-hour periods of the two sleep deprivation conditions were also comparable, ranging from .73 to .92. As shown in Table III, the correlations were lower between performance in conditions involving rested performance and performance in sleep-deprivation conditions.

Subjective Rating Responses. The main effects of age, sleep deprivation, altitude, and time (when responses were obtained during a session) on subjective rating responses are shown in Table IV for each rating scale. Compared to the younger group, subjects of the older group gave significantly higher ratings of attentiveness ($p < .05$) and significantly lower ratings of tiredness ($p < .001$) and boredom ($p < .05$).

TABLE IV. The Main Effects of Age, Sleep Deprivation, Altitude, and Time of Measurement on Subjective Rating Responses

Rating Scale		Age		Sleep		Altitude		Time		
		30-39	60-69	Yes	No	Gnd	Alt	0900	1200	1600
Attentiveness	Mean	4.8	5.4*	5.5	4.7***	5.1	5.1	5.4	5.1	4.8**
	S.D.	1.7	1.5	1.5	1.6	1.5	1.7	1.4	1.7	1.6
Tiredness	Mean	6.5	5.7***	5.0	7.2***	6.0	6.2	5.5	6.2	6.5***
	S.D.	1.8	1.8	1.6	1.4	1.7	1.9	1.9	1.7	1.7
Tenseness	Mean	4.5	4.6	4.3	4.8*	4.6	4.5	4.1	4.5	5.0***
	S.D.	2.0	1.5	1.6	1.9	1.7	1.8	1.6	1.8	1.8
Boredom	Mean	4.6	3.5*	3.7	4.5***	4.1	3.9	3.5	4.2	4.5***
	S.D.	1.9	1.6	1.7	1.9	1.8	2.0	1.5	2.0	2.0
Irritation	Mean	2.2	2.0	1.9	2.4*	2.1	2.1	1.7	2.2	2.6***
	S.D.	1.8	1.4	1.4	1.8	1.6	1.7	1.1	1.6	1.9

* p < .05
** p < .01
*** p < .001

Sleep deprivation had the significant effects of decreasing attentiveness ($p < .001$) and increasing tiredness ($p < .001$), tenseness ($p < .05$), boredom ($p < .001$), and irritation ($p < .05$). There was no significant effect of altitude on responses for any rating scale. The time that ratings were performed had a significant effect on all types of ratings. Attentiveness declined over the workday ($p < .01$), while tiredness, tenseness, boredom, and irritation increased significantly ($p < .001$).

Significant interactions in subjective rating data are shown in Tables V and VI. The significant interaction of sleep deprivation with altitude in ratings of attentiveness ($p < .05$) and boredom ($p < .05$) are in agreement with performance data; the adverse effect of sleep deprivation was greater at altitude than at ground level in both cases. The significant interaction of sleep deprivation, altitude, and time in attentiveness ($p < .05$) and tiredness ($p < .05$) ratings indicates that the interaction of sleep deprivation and altitude was strongest, if it appeared at all, at the end of the morning session. The significant interaction of age, sleep deprivation, and time of measurement in ratings of attentiveness ($p < .05$), tiredness ($p < .01$), and tenseness ($p < .05$), as shown in Table VI, indicates that the adverse effect of sleep deprivation on those ratings was greater in older subjects than in younger subjects at the time of the first rating of the day, and that the change in ratings over the course of the workday was less for the older group in sleep-deprived conditions and less for the younger group in rested conditions.

DISCUSSION

The present results provide empirical support for previous suggestions in the literature regarding a significant interaction of sleep deprivation and altitude. Both information processing and monitoring performance were sensitive to this interaction. This finding supports warnings in the aeromedical literature that the effects of sleep deprivation may be more important for pilots than for other occupations because of the altitude factor. The data of this study corroborate the validity of those warnings for altitudes in the general aviation range. Although a mild 3,810-m altitude may have no adverse effect on performance of rested pilots, fatigued pilots may suffer greater performance decrements when reaching that altitude than they would at lower altitudes or on the ground. It would be highly desirable to examine the practical significance of the interaction of sleep deprivation with altitude using flight task performance measures in an aircraft simulator.

The present findings confirm previous research findings of McFarland (1941) and of Mertens, Higgins, and McKenzie (1983), which indicated no interaction between age and altitude in rested performance, but the present findings do not indicate increased sensitivity to sleep deprivation in older subjects as found by Webb and Levy. A possible explanation of this disagreement could be the use of different amounts of sleep deprivation. Webb and Levy deprived subjects of sleep for 41 h before evaluating performance, whereas the present study involved an average of approximately 25.5 h of sleep deprivation before performance tests. It should be noted, however, that the level of sleep deprivation used in the present study was effective in producing a large performance decrement in

TABLE V. Significant Interactions ($p < .05$) in Subjective Responses as a Function of Sleep Deprivation, Altitude, and Time of Measurement

SLEEP DEPRIVATION/ALTITUDE

ATTENTIVENESS

		Sleep	No Sleep
Ground	Mean	5.4	4.8
	S.D	1.4	1.6
Altitude	Mean	5.6	4.5
	S.D.	1.5	1.6

BOREDOM

		Sleep	No Sleep
Ground	Mean	3.9	4.4
	S.D	1.7	1.7
Altitude	Mean	3.4	4.6
	S.D.	1.7	2.1

SLEEP DEPRIVATION/ALTITUDE/TIME

ATTENTIVENESS

		Sleep		No Sleep	
Time		Gnd	Alt	Gnd	Alt
0900	Mean	6.0	5.7	5.0	5.0
	S.D.	1.3	1.6	1.0	1.3
1200	Mean	5.2	5.9	5.2	4.1
	S.D.	1.5	1.5	1.7	1.8
1600	Mean	5.0	5.4	4.3	4.4
	S.D.	1.2	1.5	1.7	1.7

TIREDNESS

		Sleep		No Sleep	
Time		Gnd	Alt	Gnd	Alt
0900	Mean	4.2	4.3	6.9	6.7
	S.D.	1.5	1.8	1.3	1.2
1200	Mean	5.3	5.2	6.8	7.6
	S.D.	1.1	1.4	1.7	1.2
1600	Mean	5.4	5.8	7.3	7.5
	S.D.	1.5	1.7	1.1	1.5

TABLE VI. The Significant Interaction of Age, Sleep Deprivation, and Time of Measurement in Subjective Ratings of Attentiveness ($p < .05$), Tiredness ($p < .01$), and Tenseness ($p < .01$)

ATTENTIVENESS

		30-39 yr		60-69 yr	
Time		Sleep	No Sleep	Sleep	No Sleep
0900	Mean	5.5	4.8	6.2	5.3
	S.D.	1.0	1.2	1.8	1.0
1200	Mean	5.6	4.1	5.4	5.2
	S.D.	1.5	1.9	1.6	1.6
1600	Mean	5.3	3.8	5.1	5.0
	S.D.	1.5	1.8	1.2	1.3

TENSENESS

		30-39 yr		60-69 yr	
Time		Sleep	No Sleep	Sleep	No Sleep
0900	Mean	4.3	4.2	3.2	4.7
	S.D.	1.3	2.1	1.4	1.3
1200	Mean	4.1	4.5	4.5	5.0
	S.D.	1.9	2.3	1.3	1.4
1600	Mean	4.8	5.2	4.8	5.3
	S.D.	1.8	2.4	1.4	1.3

TIREDNESS

		30-39 yr		60-69 yr	
Time		Sleep	No Sleep	Sleep	No Sleep
0900	Mean	4.8	6.9	3.6	6.6
	S.D.	1.2	1.2	1.9	1.3
1200	Mean	5.3	7.6	5.2	6.8
	S.D.	1.5	1.5	0.9	1.4
1600	Mean	6.0	8.1	5.2	6.7
	S.D.	1.7	1.0	1.4	1.2

all tasks. The difference between amounts of sleep deprivation in the two studies remains as a possible explanation of the discrepancy between findings.

Other factors that might be considered as possible causes of different findings on the sleep deprivation by age interaction are task differences, differences in the amount of training on tasks, and time of day that performance was measured. The highly trained subjects of the present experiment may have been more resistant to the effects of stressors. The importance of task differences cannot be evaluated without further research. Webb and Levy measured the age-related effects of sleep deprivation in the early morning hours of the second night of sleep deprivation. In contrast, performance was measured during normal daytime working hours in the present research. The possible importance of circadian rhythm, or time of day, as a factor in age-related effects of sleep deprivation on performance should be considered.

Subjective ratings had some positive relation to trends in performance data regarding the effects of sleep deprivation and the interaction of sleep deprivation and altitude. There was no indication, however, of greater subjective experience of fatigue among older subjects, and there was no evidence of greater time-related changes for older subjects over the course of the workday in the sleep deprivation conditions, as was the case in performance. Age-related biases in the use of such rating scales may limit their usefulness in performance studies involving the age factor.

CONCLUSIONS

1. While there were age-related differences in performance, the present findings do not indicate significant variation in sensitivity to sleep deprivation, altitude, or their combined effects as a function of age. Future research should reexamine the age by sleep deprivation interaction with longer periods of sleep deprivation. That research should consider the possible importance of kind of task, amount of training, and circadian rhythms.

2. Age-related differences in performance were greatest at higher workloads. Future studies of the relation of age to pilot performance in operational or simulated operational situations should include systematic variation of workload.

3. The combination of age-dependent performance decrements with age-independent performance decrements due to altitude/sleep deprivation stressors may cause performance of older subjects to reach critical levels earlier under more stressful conditions. This possibility should be examined in future research on altitude/sleep deprivation/performance with performance measured in a more realistic aircraft simulator environment and with pilots of an age range similar to that of the subjects used in the present study.

4. Warnings in the aeromedical literature concerning the greater deleterious effects on performance of sleep deprivation with increasing altitude were supported. The present study emphasizes those warnings by providing an empirical example of that interaction effect at a simulated altitude within the operational range for unpressurized aircraft.

REFERENCES

1. Alluisi, E. A. Methodology in the use of synthetic tasks to assess complex performance. Human Factors, 1967, 9, 375-384.

2. Brezinova, V., Hart, V., and Vojtechnovsky, M. Sleep deprivation with respect to age: An EEG study. Activitas Nervosa Superior (Praha), 1969, 11, 182-187.

3. Chiles, W. D., and Alluisi, E. A. On the specification of operator or occupational workload with performance-measurement methods. Human Factors, 1979, 21(5), 515-528.

4. Chiles, W. D., Alluisi, E. A., and Adams, O. S. Work schedules and performance during confinement. Human Factors, 1968, 10, 143-196.

5. Institute of Medicine, National Academy of Science. 1981. Airline pilot age, health, and performance: Scientific and medical considerations. Washington, D.C., National Academy Press.

6. Jennings, A. E., Chiles, W. D., and West, G. Methodology in the measurement of human performance: Two-dimensional compensatory tracking. FAA Office of Aviation Medicine Report No. AM-72-21, 1972, Washington, D.C.

7. Johnson, L. C. Sleep deprivation and performance. In: W.B. Webb, (Ed.), Biological rhythms, sleep, and performance. 1982, New York, Wiley.

8. Lottig, V. H. Uber den Einfluss von Alkohol, Nikoin und Schlafmangel auf die Hohenfestigkeit. Luftfahrt-Medizinische Abhandlungen, 1938, 2, 218-233.

9. McFarland, R. A. The effects of oxygen deprivation (high altitude) on the human organism. Washington, D.C.: Civil Aeronautics Authority, Technical Development Report No. 11, 1941.

10. McFarland, R. A. Human factors in air transportation. New York, McGraw-Hill, 1953.

11. Mertens, H. W., Higgins, E. A. and McKenzie, J. M. Age, altitude, and workload effects on complex performance. FAA Office of Aviation Medicine Report No. AM-83-15, 1983, Washington, D.C.

12. Morgan, B. B. Jr., and Alluisi, E. A. Synthetic work: Methodology for assessment of human performance. Perceptual and Motor Skills, 1972, 35, 835-845.

13. Thackray, R. I., Bailey, J. P., and Touchstone, R. M. Physiological, subjective, and performance correlates of reported boredom and monotony while performing a simulated radar control task. In: R. R. Mackie (Ed.), Vigilance: Theory, operational performance and physiological correlates. London, Plenum Press, 1977.

14. Webb, W. B., and Levy, C. M. Age, sleep deprivation, and performance. Psychophysiology, 1982, 19, 272-276.