USAARL Report No. 98-35

The Effects of Exercise as a Countermeasure for Fatigue in Sleep Deprived Aviators

By

Patricia A. LeDuc
John A. Caldwell, Jr.
Peggy S. Ruyak
Brian Prazinko
Susan Gardner
Jose Colon
David Norman
Victor Cruz
Roger Jones
Mary Brock

Aircrew Health and Performance Division

August 1998

U.S. Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362-0577

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Human use

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRMC Reg 70-25 on Use of Volunteers in Research.

Reviewed:

for MORRIS R. LATTIMORE, JR.
LTC, MS
Director, Aircrew Health and Performance Division

JOHN A. CALDWELL, JR.
Chairman, Scientific Review Committee

Released for publication:

CHERRY L. GAFFNEY
Colonel, MC, SFS
Commanding

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release, distribution unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) USAARL Report No. 98-35	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Aeromedical Research Laboratory 6b. OFFICE SYMBOL (If applicable) MCMR-UAD	7a. NAME OF MONITORING ORGANIZATION U.S. Army Medical Research and Materiel Command
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 620577 Fort Rucker, AL 36362-0577	7b. ADDRESS (City, State, and ZIP Code) Fort Detrick Frederick, MD 21702-5012
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62787A	30162787A879	OC	DA336185

11. TITLE (Include Security Classification)
(U) The Effects of Exercise as a countermeasure for Fatigue in Sleep Deprived Aviators

12. PERSONAL AUTHOR(S)
PLeDuc, JCaldwell Jr, PRuyak, BPrazinko, SGardner, JColon, DNorman, VCruz, RJones, MBrock

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM TO	1998 August	32

16. SUPPLEMENTAL NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
06	04	
06	10	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Exercise, sleep, sleep deprivation

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
This study was designed to examine the efficacy of a nonpharmacological intervention, exercise, for sustaining performance despite a moderate amount of sleep loss. Twelve subjects were individually tested during two, 40-hour periods of sleep deprivation. Volunteers engaged in 10-minute bouts of exercise during one period and rested for an equivalent amount of time during the other period. Data included electroencephalography, Repeated Tests of Sustained Wakefulness, and Visual Analog Scale. Subjective changes in mood were examined using the Profile of Mood States. Cognitive evaluations were measured using the Multi Attribute Task Battery and Synthetic Work Battery. Flight performance was measured using the MINISIM, a flight simulation task. The results of this study indicate that exercise does have short-term alerting effects in sleep deprived subjects. Subjects were more alert immediately following exercise as evidenced by longer latencies to stage 2 sleep than when they did not exercise during sleep deprivation. However, the alerting effects of exercise were very short lived. EEG data collected 50 minutes following exercise or rest showed that exercise facilitated increases in slow-wave activity (signs of decreased alertness) above those seen during

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Chief, Science Support Center	22b. TELEPHONE (Include Area Code) (334) 255-6907 22c. OFFICE SYMBOL MCMR-UAX-SI

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

19. Abstract, Continued

rest. Cognitive deficits and slowed reaction times associated with sleep loss were equivalent in both the exercise and rest conditions. Taken together, the results from this study suggest that exercise may ameliorate some of the increases in sleepiness and fatigue associated with sleep loss for a short period of time (30 min) but will not prevent performance decrements. Additionally, less than one hour following exercise, significant increases in fatigue and sleepiness may occur.

Table of Contents

List of tables

List of figures

Introduction

The primary purpose of this investigation was to establish the efficacy of a non-pharmacological intervention, submaximal exercise, for sustaining performance despite moderate amounts of sleep loss. Earlier laboratory simulator and in-flight studies of pharmacological interventions with Dexedrine have yielded favorable results with few significant side effects. Despite these promising results, stimulants such as Dexedrine can produce adverse reactions such as palpitations, tachycardia, and elevated blood pressure. For these reasons, the Physician's Desk Reference (1996) suggests that a low test dose be administered to assess for potential adverse reactions prior to prescribing these drugs. Because units often deploy rapidly, flight surgeons may not have sufficient time to administer a test dose to each aviator prior to deployment. Even with sufficient time for prescreening, some aviators may exhibit adverse reactions to low doses and not be eligible to use this type of intervention. Additionally, many stimulants can be toxic at doses only slightly higher than the recommended dose and tolerance develops quickly with repeated use. For these reasons, some aviators may be unable or unwilling to use stimulants during periods of sustained operation despite sleep loss. Thus, it is important to find non-pharmacological interventions which can be used in cases where stimulants are contraindicated. Vigorous bouts of exercise have been shown to ameliorate some of the performance decrements associated with sleep loss (England et al., 1985). However, the effects of short bouts of submaximal exercise on aviation related tasks requiring high levels of alertness in subjects experiencing moderate sleep loss are unknown. To determine the effects of submaximal exercise on general levels of alertness, laboratory-based assessments of cognitive, psychological, and central nervous system status were conducted at regular intervals.

Military Relevance

According to current Army doctrine, aviation units may be required to operate around the clock during times of conflict. Technological advances in night vision apparati have removed many of the barriers associated with night operations. Due in part to these significant improvements, night helicopter operations now constitute a substantial component of the modern aviation mission. Continuous day-night operations provide obvious operational and tactical advantages on the battlefield (Department of the Army, 1989). Combining efficient day and night fighting capabilities across successive 24-hour periods places a significant strain on enemy resources and presents a clear tactical advantage for U.S. forces.

However, there are difficulties inherent in maintaining effective round-the-clock operations. Although aircraft can function for extended periods without adverse effects, human operators need periodic sleep for the restitution of both body and brain (Horne, 1978). Depriving humans of proper restorative sleep produces attentional lapses, slows reaction times and reduces arousal levels which are associated with poor performance (Kjelberg, 1977a; b; c; Krueger, 1989).

Because it is virtually impossible for aviation crews to receive adequate sleep and rest during combat operations, it is essential that the military explore countermeasures to offset the

performance decrements associated with sleep debt. Given that personnel resources are dwindling while mission demands are expanding and that pharmacological interventions are not always a viable option, non-pharmacological countermeasures to sleep deprivation must be explored.

Background

General

A variety of different strategies have been investigated to minimize fatigue-related performance decrements in various work settings (Babkoff and Krueger, 1992), but the combat situation remains problematic because it is intense and unpredictable. As Cornum (1994) has pointed out, while it is desirable to control the timing and duration of sleep periods via sleep management programs, this approach often is not feasible in the operational setting. One illustration of this fact was offered by recent research which suggested that despite commanders' best efforts to properly manage crew rest in the combat environment, sleep deprivation was a problem for many Army pilots during Desert Storm even though the combat period was short (Caldwell, 1992).

Sleep deprivation (SD) has repeatedly been shown to increase simple reaction time, decrease auditory and visual vigilance, and increase sleepiness and irritability. Numerous investigations have proven that amphetamines are effective countermeasures for sleep loss induced decrements in physical performance, vigilance, alertness, cognition, and military performance (Caldwell et al., 1996), but pharmacological intervention with amphetamines is not always possible. Thus, non pharmacological countermeasures for sleep deprived performance decrements must be examined.

In cases where subjects are required to perform sustained attention tasks such as monitoring radios and radar screens or routine tasks such as preflighting aircraft, short bouts of submaximal exercise may prove to be a useful cognitive arouser. The literature shows that exercise produces improvements or can reduce or delay the onset of decrements in auditory and visual vigilance tasks in sleep deprived subjects (England et al., 1985). However, of these studies, none have been aviation-related. When operational or medical constraints prevent the use of pharmacological countermeasures (stimulants) for the alleviation of aircrew fatigue, behavioral strategies such as short bouts of exercise may provide a safe alternative for maintaining aviator performance.

Sleep Deprivation

Tasks that place heavy demands on working memory, that call for sustained attention, or require creativity even for short durations are affected by sleep deprivation (Dinges and Broughton, 1989). In general, tasks that require sustained concentration and vigilance such as monitoring radar screens and control panels are the most susceptible to the influences of sleep deprivation. Sleep deprivation produces periods of slow performance and periods of non-performance or lapses. As the duration of sleep loss increases, the lapses increase in frequency

and duration. Williams, Lubin and Goodnow (1959) found that on a 10-minute monotonous vigilance test which is typically performed without difficulty, after 1 night of sleep loss performance began to degrade within 7 minutes. On this same task, after 2 nights without sleep, the degradation began after 2 minutes. Hockey (1970a; b) has shown that sleep deprivation produces slower reaction times on tracking tasks and that subjects become more easily distracted and have difficulty concentrating on sustained attention tasks such as card sorting.

Sleep Deprivation and Arousal

Studies which examine arousers such as noise on SD performance, typically find that decrements in performance are to some degree ameliorated. Wilkinson (1963) has reported that 100db of white noise reduced the error rate produced by 32 hours of SD on a serial reaction task. Similarly, 75db of pink noise improved speed of response at 0500 hours, the lowest point of the circadian dip, on a spatial memory test in subjects subjected to partial sleep deprivation (Tassi et al., 1993). While exercise is considered an arousing activity, little is known about the effects of exercise on alertness in SD subjects. To date, most sleep deprivation studies have employed exercise as an additional stressor (Angus, Heslegrave and Myles, 1985; Ryman, Naitoh and Englund, 1985; Englund et al., 1985; Plyley et al., 1987). The most commonly used schedules of exercise are bouts of 30 continuous minutes/hour or 1 continuous hour/3 hours, throughout the duration of sleep deprivation. Despite the strenuous exercise schedules used in the above mentioned studies, cognitive and physiological performance decrements in sleep deprived subjects were not compounded by exercise. In the case of Englund et al. (1985), vigilance decrements may have been delayed by as much as 8 hours when compared to nonexercising controls.

Exercise and Arousal

In spite of the extreme levels and durations of exercise typically used, there are some hints throughout the literature that exercise may be used in a practical manner, outside of the laboratory, as an effective method to increase alertness/arousal during periods of sleep deprivation. It has been shown that short bouts of submaximal exercise can improve cognitive performance in nonsleep deprived subjects (Davey, 1972; 1973). Davey (1973) examined the function of various amounts of exercise on a continuous attention task. Exercise had an inverted U shaped effect on performance. Low intensity exercise had little or no effect, moderate submaximal exercise enhanced performance and exhaustive exercise produced decrements in performance. These and other studies provide supporting evidence that moderate levels of exercise can affect cognitive performance by raising arousal levels. While evidence does exist for the arousing properties of acute submaximal exercise, few studies have been done which examine exercise induced arousal on cognitive performance in sleep deprived subjects.

Sleep Deprivation, Exercise and Arousal

The only study to date which directly examined the arousing effects of short bouts of submaximal exercise in sleep deprived/restricted subjects was conducted by Horne and Foster (1995). These researchers examined the effects of 10 minutes of exercise at four different levels, 0%, 20%, 40%, and 70% VO_2max, on performance of sleep restricted people. Subjects were

restricted to 4 hours of sleep on the previous night and subsequently were tested between 14:00-16:00. These authors used the Wilkinson Auditory Vigilance Test (purported to be extremely sensitive to changes in sleepiness/alertness). The 30-minute test was given prior to exercise and re-administered following 10 minutes of exercise and 5 minutes rest. Exercise at all levels (20, 40, and 70%) produced some improvement in vigilance. The only significant change, however, was seen in subjects who exercised at the highest level (70%). Postexercise vigilance measures were significantly better in the high exercise group. Self-rated alertness was improved in all exercise groups but the effects were short lived, lasting only 10-15 minutes in the low (20%) and middle conditions (40%). In the high exercise condition (70%), this effect was extended to 30 minutes. As self-rated measures of sleepiness and exertion are more highly correlated with performance than physiological measures (Angus, Heslegrave, and Myles, 1985; Martin, 1981; Plyley et al., 1987), it may be possible to capitalize on the alerting effects of short bouts of submaximal exercise in sleep deprived aviators.

Methods

Subjects

Twelve subjects (11 male and 1 female) were recruited to reside in the U.S. Army Aeromedical Research Laboratory (USAARL) for a period of 7 days. Aviators were individually tested on the designated tasks. The mean age of the volunteers was 29.9 (ranging from 25 to 35). Prior to beginning the study, all volunteers were briefed on the nature, duration, and purpose of the research. Subjects were also thoroughly briefed concerning their right to withdraw from the study at any time, without penalty, prior to giving their informed consent. Subjects all had current military flight physicals and were examined by a flight surgeon for any condition which might have excluded them from participation (e.g., orthopedic problems and spinal injuries). The examination included a review of the standard medical history and flight medical history.

Subjects were not permitted to consume alcohol, caffeinated beverages, or any type of medication (other than acetaminophen, ibuprofen, or naproxen sodium, as approved by the medical monitor) for the duration of the protocol. Participants who indicated they were caffeine users during initial telephonic interviews were asked to significantly reduce or completely eliminate caffeine consumption beginning several days prior to the study. Tobacco users were not excluded from this protocol, and 2 of the 12 subjects used some form of tobacco (1 used cigarettes, 1 used smokeless) on a regular basis prior to and during the study. Tobacco use was restricted to breaks between test sessions.

Apparatus

VO_2max assessment

Maximal oxygen uptake was measured by treadmill (Marquette Model 2000)* determination. This test involved the use of interrupted runs at a constant speed with progressively increasing grades in order to achieve a plateau in oxygen (O_2) consumption.

*See manufacturers list

Oxygen intake was measured by an on-line metabolic analysis system (SensorMedic Model 2900)* for the subsequent quantification of expired gas content and volume.

Sleepiness evaluations

Objective sleepiness/alertness was measured using the Repeated Test of Sustained Wakefulness (RTSW) (Hartse, Roth, and Zorick, 1982) in which subjects were instructed to remain awake in a darkened room. Electroencephalographic (EEG) data were monitored for up to 20 minutes using a Nihon Kohden electroencephalograph* to objectively determine if he/she successfully remained awake. Subjects were immediately awakened and removed from the room if they fell asleep. Records were scored in terms of the number of minutes from lights out until sleep onset (up to 20 minutes).

Subjective sleepiness/alertness was measured using the Visual Analog Scale (VAS). The VAS consists of eight 100mm lines centered over the adjectives "alert/able to concentrate," "anxious," "energetic," "feel confident," "irritable," "jittery/nervous," "sleepy," and "talkative" (Penetar et al., 1993). At the extremes of each line, "not at all" and "extremely" are printed respectively. Scores consist of the distance of the subject's mark from the left end of the line in mm. An additional three scales "Able to Effectively Control /Supervise a Flight Crew," "Able to Accurately Control Aircraft Flight Parameters," and "Able to Perform All Flight Duties" were added to the VAS for the purpose of examining the effect of sleep deprivation on subjective flight performance.

EEG evaluations

The EEG evaluations conducted during each subjects' waking periods were performed with a Cadwell Spectrum 32 neurometric analyzer*. This device collected seven channels of EEG data (Fz, C3, Cz, C4, Pz, O1, and O2) referenced to linked mastoids (A1 and A2) which were stored on an optical disk for subsequent analysis. During the data collection, the low filter was set at 0.53 Hz, the high filter was set at 70 Hz, and the 60 Hz notch filter was used. All test sessions were conducted in a dimly-illuminated, sound-attenuated chamber.

Mood evaluations

The subjective evaluations of changes in mood were made with the Profile of Mood States (POMS) (McNair, Lorr, and Droppleman, 1981). The POMS is a 65-item paper and pencil test which measures affect or mood on 6 scales: 1) tension-anxiety, 2) depression-dejection, 3) anger-hostility, 4) vigor-activity, 5) fatigue-inertia, and 6) confusion-bewilderment. The answers were scored by hand using scoring templates.

Cognitive evaluations

Changes in basic cognitive abilities were examined with the Multi-Attribute Task Battery (MATB) and the Synthetic Work Battery (SYNWORK). The MATB required that subjects perform a tracking task concurrent with monitoring simulated indicators of fuel levels, pump

status, engine performance, and other aspects of "aircraft status." Subjects were also required to periodically change radio frequencies. The SYNWORK consisted of a Sternberg memory task, an arithmetic task, a visual monitoring task, and an auditory monitoring task that were presented simultaneously in four quadrants of the computer screen. Data on speed and accuracy were automatically calculated. These tests were administered via a Zenith 486 computer with a 13-inch color monitor.

Flight performance measures

The desktop flight simulation task (MINISIM) consisted of the Microsoft Flight Simulator 4.0®, combined with a custom-designed, timed flight course (Microsoft Aircraft and Scenery Designer®). This task was run on an IBM 486 computer with VGA graphics. Flight control was via a Virtual Pilot flight yoke (CH Products®), with system interface using a keyboard.

Procedure

General

Subjects reported to the USAARL on Saturday for medical examination, VO_2max determination, EEG electrode hook up, and an adaptation sleep period. Subjects had four practice sessions, at 0730, 1130, 1530, and 1930 on Sunday. Test sessions were conducted at 0730, 1130, 1530, 1930, and 2330 on Monday and Wednesday and at 0330, 0730, 1130, 1530, and 1930 on Tuesday and Thursday (the sleep deprivation periods). Subjects had one test session beginning at 0730 on Friday and were released at 1230. Lights out on all nondeprivation nights was at 2300. The table provides a complete schedule of testing.

VO_2max testing

This test involved the use of interrupted runs at a constant speed with progressively increasing grades in order to achieve a plateau in O_2 uptake. The rubber face mask was presented to the subject during a 3-minute familiarization walk. The walk was conducted at a speed of 3.5 mph at 0% grade. Oxygen intake was measured by having the volunteer breathe normally, while wearing the mask, into an on-line metabolic analysis system for quantification of expired gas content and volume. Subjects were given an initial warm up run of 5 mph at 0% grade for 6 minutes followed by a 5-minute rest period. Oxygen uptake was measured for the last 1 minute of each run. Additional runs were conducted for 3-minute intervals followed by 3-minute rest periods. Exercise intensity was increased in progressive steps by raising the treadmill incline 2.5°, with speed remaining constant. A plateau or decrease in O_2 uptake, with increasing exercise intensity, indicated that VO_2max had been reached. A plateau was defined as an increase of less than 2.0 ml/kg/min through two successive exercise steps. The procedure lasted from 15 to 45 minutes and yielded a VO_2max level for each subject. The range of VO_2max values was 31.7 to 60.1 $ml \cdot kg^{-1} \cdot min^{-1}$ (mean=49.6).

Submaximal exercise

Subjects engaged in 10-minute bouts of exercise at 70% VO_2max. This score was calculated from each individual's VO_2max test. Subjects engaged in 10 minutes of exercise or rest every 2 hours, beginning at 0100 and ending at 1900 on test days (Tuesday and Thursday). To counterbalance the study design, half of the subjects exercised during the first sleep deprivation period (Tuesday) while the other half of the subjects rested for an equivalent amount of time. The rest condition consisted of the subjects sitting quietly for 10 minutes in a room separate from the exercise equipment. The treatments were reversed during the second sleep deprivation period (Thursday). Exercise was suspended for the last 4 hours prior to lights out to prevent any influence on recovery sleep. Two subjects complained of muscle cramping in their calves from the elevation of the treadmill. The elevation of the treadmill was lowered and the speed was increased to maintain the same heart rate recorded at 70% VO_2max exercise level. For one subject, elevation was lowered during the last two exercise bouts and for the second subject, elevation was lowered during the last five bouts.

Sleepiness evaluations

RTSWs occurred every 4 hours. On practice and baseline days, test times were 0930, 1330, 1730 and 2130. On deprivation days, tests were given at 0130, 0530, 0930, 1330, 1730, and 2130. One RTSW occurred at 0930 on Friday prior to release. During the RTSWs, subjects were required to lie on a bed in a quiet, dark room. They were instructed as follows "lie as still as possible with your eyes closed and do your best to remain awake." Throughout the duration of the test, EEG data were recorded from electrode sites C3, C4, O1, and O2, referenced to the contralateral mastoid. Subjects were allowed to remain in bed until 20 minutes had elapsed or until he/she entered stage 2 sleep as evidenced by a k complex or sleep spindle. The elapsed time from lights out to stage 2 sleep was recorded.

VAS were given every 2 hours, beginning at 0725 and ending at 2125 on Sunday, the practice day. One additional VAS was given at 2325 on baseline days (Monday and Wednesday). VAS were administered every 2 hours from 0125 to 2125 during the deprivation periods. The subjects were given a sheet containing a series of 100 mm lines drawn horizontally with adjectives at each end. He/she marked on the line his/her present feelings. This test took approximately 5 minutes.

EEG evaluations

Each EEG session lasted approximately 12 minutes and began with a check to ensure that electrode impedances were 5000 ohms or less. Any impedance problems were corrected by rotating a blunted needle gently inside of the problem electrode until an adequate signal was obtained. Subjects were instructed to relax, but to remain awake and to look at a fixed point on the wall in front of them. They were asked via an intercom to close and open their eyes

alternately every 2 minutes for a total of 12 minutes (three cycles eyes open/eyes closed). On practice and baseline days, test times were 1000, 1400, 1800 and 2220. On deprivation days, tests were given at 0200, 0600, 1000, 1400, 1800, and 2200. One EEG session occurred at 1000 on Friday, prior to release.

The EEGs for each eyes-open and eyes-closed interval (6 per session) were visually scanned for three relatively artifact-free 2.5-second epochs on which absolute power values were calculated for each of four bands. The results were averaged together to produce one set of power values for each EEG electrode site under eyes open and eyes closed separately. The activity bands were defined as follows: delta (1.0-3.5 Hz), theta (3.5-8.0 Hz), alpha (8.0-13.0 Hz), and beta (13.0-20.0 Hz).

Mood evaluations

POMS were given every 2 hours beginning at 0720 and ending at 2120 on Sunday, the practice day. One additional POMS was given at 2320 on baseline days (Monday and Wednesday) and every 2 hours from 0120 to 2120 during the deprivation periods. Subjects were presented with a series of 65 words which describe mood states. For each "mood state," the subject indicated on a standardized answer sheet how well it described the way he/she was presently feeling. This test took approximately 5 minutes to administer and yielded scores on the factors of tension-anxiety, depression-dejection, anger-hostility, vigor-activity, fatigue-inertia, and confusion-bewilderment.

Cognitive performance tasks

The MATB (30-minute sessions) was administered every 4 hours. On the practice day, test times were 0730, 1130, 1530, and 1930. An additional test was administered at 2330 on the baseline days (Monday and Wednesday). During the deprivation periods, tests were given at 0300, 0730, 1130, 1530, and 1930. One MATB was given on Friday morning at 0730, prior to release. The MATB required subjects to simultaneously monitor and respond to several tasks which were presented at various locations on the computer screen. The test is an aviation-oriented simulation which presents indications of fuel levels, engine conditions, and pumps which the subject must correctly monitor to ensure normal "flight operations." In addition, the subject was required to concurrently perform a psychomotor tracking task and respond to instructions to periodically change radio frequencies. This test yielded a variety of speed and accuracy scores for each subtask.

The SYNWORK also was administrated every 4 hours. On the practice day, SYNWORK test times were 1030, 1430, and 1830. An additional test was administered at 2230 on the baseline days. Tests were given at 0230, 0630, 1030, 1430, and 1830 on deprivation days. During the 20 minute battery, the memory, arithmetic, visual and auditory monitoring tasks ran concurrently in four quadrants of a computer screen. The Sternberg memory task, in the upper left corner, presented subjects with six letters which were removed from view a few seconds after

presentation. Letters were then presented one at a time and subjects were required to indicate if each letter was part of the initial six letter set. A three column addition task, presented in the upper right hand corner, required subjects to add two numbers totaling less than 1000. The visual monitoring task, presented in the lower left corner, required the subject to reset a pointer, which moved from the center of a scale in either direction, prior to it reaching the end. The auditory monitoring task, presented in the lower right corner, required subjects to respond when a high tone was presented among a series of low tones. A subject's score was visible in the center of the screen providing constant feedback.

Flight performance

Following the SYNWORK, subjects completed a 20-minute MINISIM session. The test was given at 1100 and 1600 on the practice and baseline days, and at 2400, 0400 and 1600 on test days. One desktop flight simulation session occurred at 1100 on Friday, prior to release. This task required subjects to fly a timed course consisting of 21 "gates" positioned at various altitudes and headings. The first 15 gates were flown under nonturbulent conditions, while gates 16-21 were made more difficult by the addition of 20-knot winds emanating from various directions. This task produced a summary score at the conclusion of each "flight." The score was calculated automatically from the elapsed time it takes to fly the course, the number of gates missed, and the precision with which the subjects flew through each of the gates.

Testing schedule

The subjects reported to the Laboratory on Saturday and signed the informed consent statement prior to medical records review. VO_2max testing and EEG electrode attachment occurred prior to the adaptation sleep period. On Sunday, the aviators received four training sessions on each of the computerized tests. Afterwards they retired for the evening. On Monday, there were four test sessions (five MATBs) which were used to determine baseline performance. The aviators were not allowed to go to sleep in the evening. Instead, subjects began the first 10-minute bout of exercise or rest at 0100. Subsequent exercise or rest periods occurred at 2-hour intervals throughout the Tuesday deprivation period (0100, 0300, 0500, 0700, 0900, 1100, 1300, 1500, 1700, and 1900). There were six test sessions (five MATBs) during the deprivation period. On Tuesday, test sessions ended at 2300 and the aviators retired for the day. On Wednesday, the aviators repeated the same schedule which was used on Monday--there were four test sessions (five MATBs) during the day, and, as was the case on Monday night, they were not allowed to go to sleep. Instead, the subject followed the same schedule as was used during the first deprivation period, but in the opposite condition (exercise or rest). His/her first exercise bout commenced at 0100, and testing ended with a sleep period at 2300. On Friday, the aviators awoke at 0700, were subjected to one test series, and released.

Table
Testing schedule.

Time	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
2400-0100				MINISIM		MINISIM	
				Repairs		Repairs	
0100-0200				Ex/Rest/Vit/PV		Ex/Rest/Vit/PV	
				RTSW		RTSW	
0200-0300				EEG		EEG	
				SYNWORK		SYNWORK	
0300-0400		Sleep	Sleep	Ex/Rest/Vit/PV	Sleep	Ex/Rest/Vit/PV	Sleep
				MATB		MATB	
0400-0500				MINISIM		MINISIM	
				Repairs		Repairs	
0500-0600				Ex/Rest/Vit/PV		Ex/Rest/Vit/PV	
				RTSW		RTSW	
0600-0700				EEG		EEG	
				SYNWORK		SYNWORK	
0700-0800		Wake/Vit/PV	Wake/Vit/PV	Ex/Rest/Vit/PV	Wake/Vit/PV	Ex/Rest/Vit/PV	Wake/Vit/PV
		MATB	MATB	MATB	MATB	MATB	MATB
0800-0900		Breakfast	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
		Repairs	Repairs	Repairs	Repairs	Repairs	Repairs
0900-1000		Vitals/PV	Vitals/PV	Ex/Rest/Vit/PV	Vitals/PV	Ex/Rest/Vit/PV	Vitals/PV
		RTSW	RTSW	RTSW	RTSW	RTSW	RTSW
1000-1100		EEG	EEG	EEG	EEG	EEG	EEG
		SYNWORK/Vit	SYNWORK/Vit	SYNWORK/Vit	SYNWORK/Vit	SYNWORK/Vit	SYNWORK/Vit
1100-1200		MINISIM/PV	MINISIM/PV	Ex/Rest/Vit/PV	MINISIM/PV	Ex/Rest/Vit/PV	MINISIM/PV
		MATB	MATB	MATB	MATB	MATB	Unhook
1200-1300		Lunch	Lunch	Lunch	Lunch	Lunch	Release
		Repairs	Repairs	Repairs	Repairs	Repairs	
1300-1400		Vitals/PV	Vitals/PV	Ex/Rest/Vit/PV	Vitals/PV	Ex/Rest/Vit/PV	
		RTSW	RTSW	RTSW	RTSW	RTSW	
1400-1500		EEG	EEG	EEG	EEG	EEG	
		SYNWORK	SYNWORK	SYNWORK	SYNWORK	SYNWORK	
1500-1600		Vitals/PV	Vitals/PV	Ex/Rest/Vit/PV	Vitals/PV	Ex/Rest/Vit/PV	
		MATB	MATB	MATB	MATB	MATB	
1600-1700		MINISIM	MINISIM	MINISIM	MINISIM	MINISIM	
		Repairs	Repairs	Repairs	Repairs	Repairs	
1700-1800	Arrival	Vitals/PV	Vitals/PV	Ex/Rest/Vit/PV	Vitals/PV	Ex/Rest/Vit/PV	
	Med Review	RTSW	RTSW	RTSW	RTSW	RTSW	
1800-1900	EEG	EEG	EEG	EEG	EEG	EEG	
	Hook	SYNWORK	SYNWORK	SYNWORK	SYNWORK	SYNWORK	
1900-2000	Up	Vitals/PV	Vitals/PV	Ex/Rest/Vit/PV	Vitals/PV	Ex/Rest/Vit/PV	
	and	MATB	MATB	MATB	MATB	MATB	
2000-2100	VO2 Max	Dinner	Dinner	Dinner	Dinner	Dinner	
	Testing	Shower	Shower	Shower	Shower	Shower	
2100-2200	Dinner	Vit/Repair/PV	Vit/Repair/PV	Vit/Repair/PV	Vit/Repair/PV	Vit/Repair/PV	
	Lab	RTSW	RTSW	RTSW	RTSW	RTSW	
2200-2300	Tour/	EEG	EEG	EEG	EEG	EEG	
	Familiarization	ElecPlacemt	SYNWORK	ElecPlacemt	SYNWORK	ElecPlacemt	
2300-2400	Lights Out	Lights Out	Vit/Repair/PV	Lights Out	Vit/Repair/PV	Lights Out	
	Sleep	Sleep	MATB	Sleep	MATB	Sleep	

Vit=Vitals, PV=POMS and VAS, Ex=Exercise.

Data analysis

All of the data from this investigation were analyzed with BMDP4V repeated measures analysis of variance (ANOVA). Where there were significant interactions, analysis of simple effects were employed to pinpoint the factor level of interest. Afterward, multiple pairwise comparisons were performed using the F-test (contrast) procedure in BMDP4V. All ANOVAs consisted of at least the 2 within-subjects factors of condition (10 minutes of exercise, 10 minutes of rest) and session (1 baseline, 3-11 tests). The number of sessions varied based upon how many times per day each test was administered.

Prior to analysis, the data were examined for completeness, and any missing data were estimated with BMDPAM. At that time, normality was checked. Once the ANOVAs were conducted, the results were examined to determine whether there were sphericity violations of sufficient magnitude to warrant the use of Huynh-Feldt adjusted degrees of freedom (dfs). If appropriate, the adjusted dfs were employed.

Descriptive statistics were calculated and examined for each of the measures collected. At a minimum, these included sample sizes, means, and standard deviations for each dependent variable at each level of each independent variable.

Results

General

Due to the fact that there were not sufficient cases to produce meaningful multivariate tests, univariate ANOVAs were conducted on the data from each of the categories of dependent measures examined in this study. Although counterbalancing was used to control for any impact of exercise order (exercise/rest and rest/exercise), the data were examined to determine whether or not there appeared to be order effects. One between-subject factor, condition order (two levels), and two within-subject factors, deprivation period (two levels), and number of baseline sessions (two-nine) were used in these analyses. During these examinations, tests revealed that the baseline measures obtained prior to each deprivation period were significantly different. Main effects for deprivation periods were found for all tests excluding the awake EEGs and MINISIM. There were no main effects for condition order or interactions with deprivation periods on the MATB, SYNWORK, POMS, or VAS. Examination of the MATB and SYNWORK data showed a practice effect where subjects continued to improve from the first to the second baseline period. Tests revealed that several self-rated measures of mood (POMS) and sleepiness (VAS) from the second baseline period did not return to the levels reported during the first baseline. These differences suggest that subjects did not feel fully recovered from 40 hours of sleep loss despite 8 hours of sleep. An order by baseline interaction was seen with the RTSWs. No differences between the first and second baselines were found for the group that exercised first. However, the average RTSW was significantly lower during the second baseline period in the group who rested first. As with the POMS and VAS, these differences suggest that 8 hours of sleep may have been insufficient for RTSW times to recover. Thus, data excluding the awake EEGs and MINISIM were transformed to Change Scores using the formula Change Score = Test Score - Baseline Score. Data obtained from the last session (1930-2330) on Monday were used to obtain change scores for Tuesday's test sessions and those from

Wednesday (1930-2330) were used to transform Thursday's deprivation tests. Data obtained from the last session of the awake EEGs and MINISIM (1930-2330) were used as baseline for those tests (change scores were not used).

Sleepiness Assessments

RTSW

The data from the RTSWs were analyzed using repeated measures ANOVA with two within-subject factors, condition (two levels) and time (six levels). Analysis revealed a main effect for condition ($F(1,11)=15.42$, $p=.0024$). As illustrated in figure 1, while the length of time subjects remained awake decreased from baseline in both conditions, this decrease was significantly more pronounced during the rest condition (mean=-13.15) than was evidenced during the exercise condition (mean=-7.93). A significant time of day effect was also seen ($F(2.43, 26.76)=13.9$, $p<.0001$). As can be seen in figure 2, a sharp and significant decrease in the subjects ability to remain awake was seen between the 0120 and 0530 session. This trend continued, with the decrease from baseline reaching its low at the 0930 session. While a slight increase was observed across the 1330-2130 tests, wakefulness remained well below that of baseline and the first deprivation test (0130). Changes across time were not, however, impacted by condition (no condition-by-time effect).

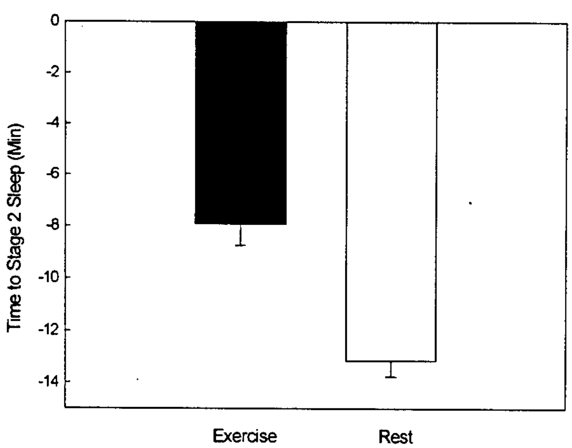


Figure 1. Effects of condition on RTSW.

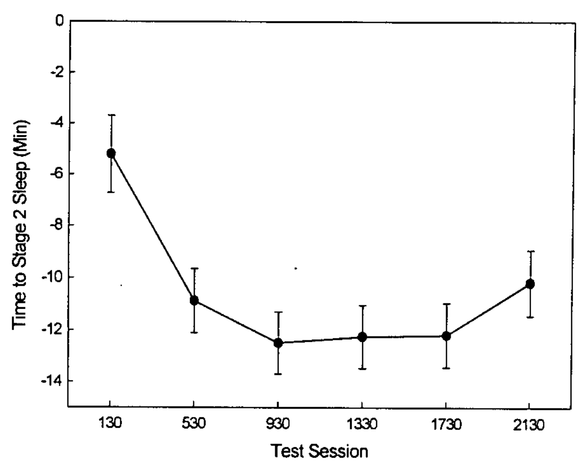


Figure 2. Effects of time of day on RTSW.

VAS

The VAS were hand-scored to obtain one score per adjective: 1) concentration 2) anxiety, 3) energy, 4) confidence, 5) irritability, 6) jitteriness, 7) sleepiness, 8) talkativeness, 9) supervision, 10) control, and 11) performance. Each adjective was analyzed separately in a 2-way ANOVA using the factors condition (exercise and rest) and time (11 tests, every 2 hours from 0120 - 2120).

Concentration

No condition or condition-by-time effect on subjective, self-rated, concentration was found. Figure 3 depicts the significant changes across the test times ($F(10,110)=4.32$, $p<.0001$). The

scale on the Y axis of figure 3 depicts change scores from 0 to -25. The higher the bar on the graph, the greater the change from baseline (in this case, a decrease). Subjects felt that their ability to concentrate significantly declined following the 0320 test session. They reported a slight increase in their ability to concentrate during the early afternoon sessions (1320 and 1520), but this recovery was short lived as evidenced by the sharp and significant decline at 1720.

Energy

The 2-way ANOVA showed no condition or condition-by-time effect on subjective energy levels. A main effect for time was found ($F(10,110)=3.26, p<.001$). As illustrated in figure 3, subjects felt that their energy level declined across the test sessions. All energy scores, with the exception of 0320, were significantly lower than those of the first deprivation test at 0120. Additionally, energy levels continued to decline such that scores at 0520 and 0720 were significantly lower than those from 0320 test. While subjects reported slight increases in their energy levels from the 0920-1520 sessions, none of the scores approached that from the first test session. Even this slight recovery was short lived as evidenced by the sharp decline in energy at 1720 and further decline at 2120.

Talkativeness

As with concentration and energy, data analysis found only a time of day effect ($F(10,110)=1.92, p=.05$). Subjects felt less talkative as the deprivation period lengthened. Subjects reported being the least talkative on the 0720 questionnaire. A significant increase in talkativeness was seen during the 1320-1520 sessions, returning nearly to baseline. This recovery was, however, short-lived as evidenced by the sharp decline in talkativeness during the 1720 through 2120 sessions. There was no condition or condition-by-time interaction.

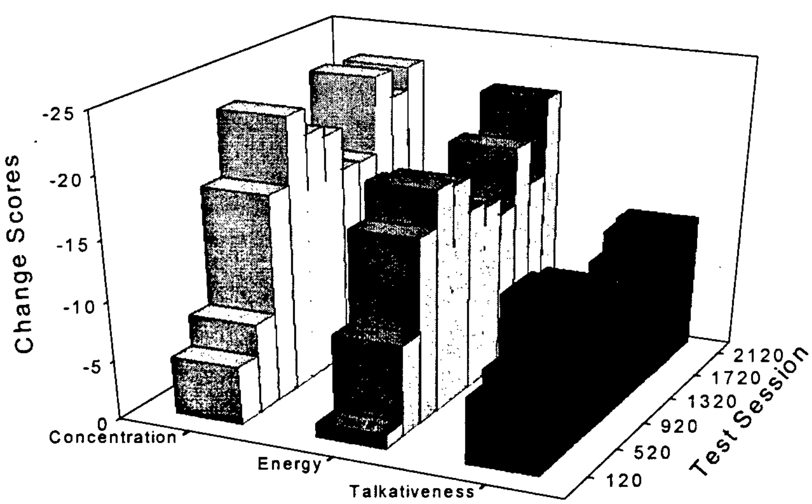


Figure 3. Effects of time on VAS concentration, energy, and talkativeness scores.

Anxiety

The repeated measures ANOVA revealed a significant condition-by-time interaction ($F(10,110)=1.95$, $p=.045$) as well as a main effect for time ($F(10,110)=3.22$, $p=.0011$) on VAS anxiety scores. Simple effects tests for the interaction showed that there was no significant change in anxiety scores throughout the day during the exercise deprivation period. As illustrated in figure 4, differences were only observed during the rest condition. Anxiety scores during the rest condition increased significantly from the 0120 to the 0320 session. This increase was followed by a decrease in anxiety scores at the 0520 session. This 2-hour, cyclic, increase-decrease pattern was seen through the 1120 test session. Anxiety scores remained significantly elevated from those reported at 0120, throughout the deprivation period. Contrasts on the time main effect showed that with both conditions collapsed, changes in anxiety scores followed the similar 2-hour cyclic pattern seen during the rest condition until the 1320 session. From 1320 through 2120, change scores remained significantly higher than those of the first deprivation period 0120 (figure 5).

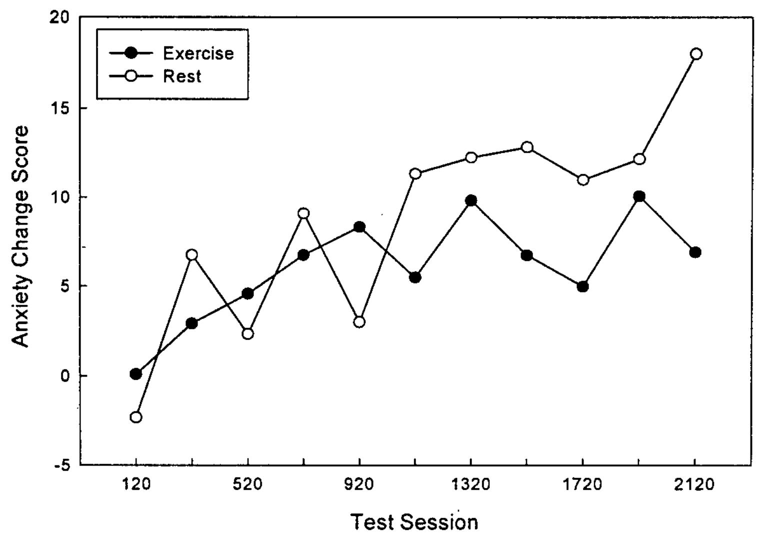


Figure 4. Interaction of condition and time on VAS anxiety scores.

Sleepiness

The 2-way ANOVA showed no condition or condition-by-time effect on subjective sleepiness levels. A main effect for time was found ($F(10,110)=6.27$, $p<.0001$). As illustrated in figure 5, sleepiness scores rose significantly following the 0320 test session. Subjects reported a slight but significant decrease in sleepiness during the 1120 to 1520 sessions. Despite this decrease, sleepiness ratings remained significantly higher than the 0120 and 0320 test sessions. Scores again increased at 1720 to the highest rating of the deprivation period. Again a slight recovery in self-reported sleepiness was seen at 1920, but it did not remain throughout the last session at 2120.

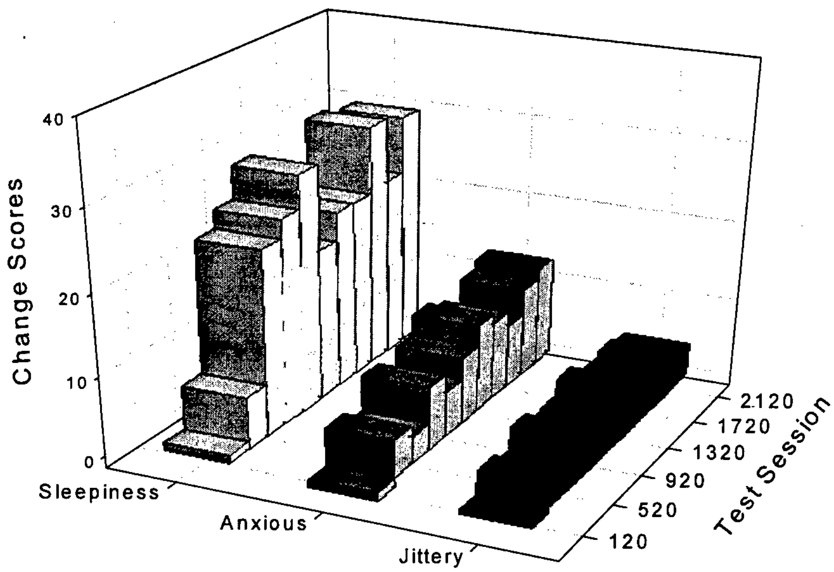


Figure 5. Effects of time on VAS sleepiness, anxiety, and jitteriness scores.

Jitteriness

The repeated measures ANOVA on jitteriness scores revealed a significant condition-by-time interaction (F(10,110)=2.16, p=.0258) as well as a main effect for time (F(10,110)=2.60, p=.0071). As shown in figure 6, jitteriness scores during both conditions increased significantly from the 0120 to the 0320 session. Scores from the two conditions then changed in opposite directions for most of the remaining test sessions. Simple effects tests showed that as a result of these changes, subjects reported being much more jittery during the early morning (0520 and 0720) and mid afternoon (1520) during the exercise deprivation period than during the rest condition. Contrasts on the time main effect showed that jitteriness scores significantly increased following the 0120 session and remained elevated throughout testing (figure 5).

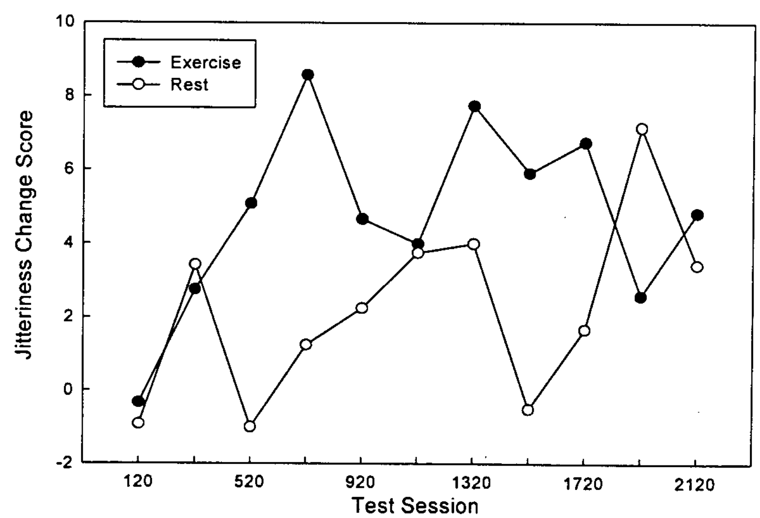


Figure 6. Interaction of condition and time on VAS jitteriness scores.

Confidence

No significant main effects or interactions were seen for subjective confidence or irritability scores.

Irritability

As with confidence scores, the 2-way ANOVA showed no condition, time, or condition-by-time effects.

EEG evaluations

The absolute power values from the resting EEGs were analyzed using repeated measures ANOVA to determine the effects of condition (exercise, rest), session (2200 baseline , 0200, 0600, 1000, 1400, 1800, and 2200), and eyes (open, closed) at C3, C4, O1, O2, Cz, Fz, and Pz. Significant effects were followed up with appropriate simple effects and/or contrast analyses.

Delta activity

The repeated measures ANOVA revealed a significant condition-by-time-by-eyes interaction for electrode C4 ($F(6,66)=2.32$, $p=.043$). As can be seen in figure 7, the differences in delta activity across sessions between eyes-open and eyes-closed were much more pronounced during the exercise condition than during rest. Simple effects tests showed that these differences were significant only in the exercise condition. Delta activity during the eyes open portions of the tests increased as deprivation time lengthened such that power at 1400 and 1800 was significantly higher than the power at baseline. Delta activity then showed a significant decrease from the 1800 to the 2200 session, returning nearly to predeprivation baseline. Delta activity during the eyes closed portions of the exercise tests also increased across sessions. However, significant increases in power were seen as early as the 0200 session and were maintained through 1800. As with eyes open, delta activity showed a significant decrease from the 1800 to the 2200 session with eyes closed.

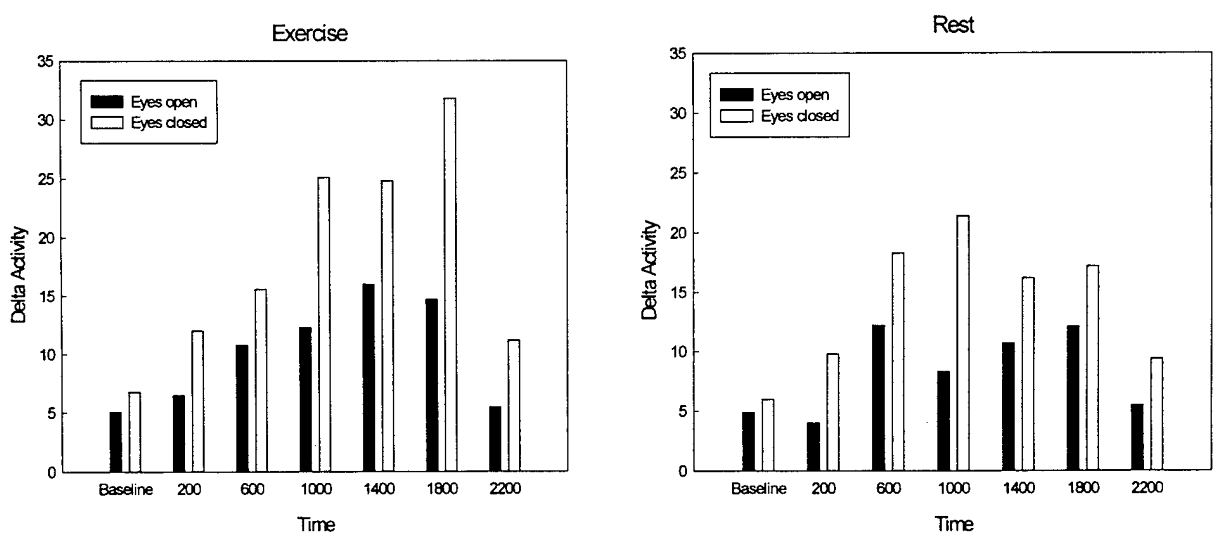


Figure 7. Interaction of condition, time, and eyes for delta activity.

A significant condition-by-eyes interaction was observed for electrode C4 ($F(1,11)=5.10$, $p=.045$) as well as Fz ($F(1,11)=4.95$, $p=.048$). As can be seen in figure 8, delta activity was significantly higher during eyes closed than eyes open during both exercise and rest conditions. While delta was higher during the exercise condition than during rest for both C4 and Fz, significant differences were only observed during the eyes closed condition. Analysis also revealed a significant time-by-eyes interaction for electrodes C3 ($F(6,66)=3.75$, $p<.003$); C4 ($F(6,66)=4.01$, $p<.002$); O1 ($F(6,66)=2.42$, $p<.04$); Cz ($F(6,66)=4.71$, $p<.001$); Fz ($F(6,66)=2.74$, $p<.02$); and Pz ($F(6,66)=3.42$, $p<.006$). Simple effects tests showed that delta activity was significantly higher during eyes closed than eyes open at all times on these electrode sites. Data contrasts also showed that during eyes open, delta activity increased sharply and significantly at the 0600 session at these sites. Activity then plateaued throughout the 1800 session and decreased nearly to baseline levels during the final test. In comparison, delta activity for eyes closed showed an additional increase during the 1000 on these electrodes. Activity then plateaued throughout the 1800 session and decreased during the final test.

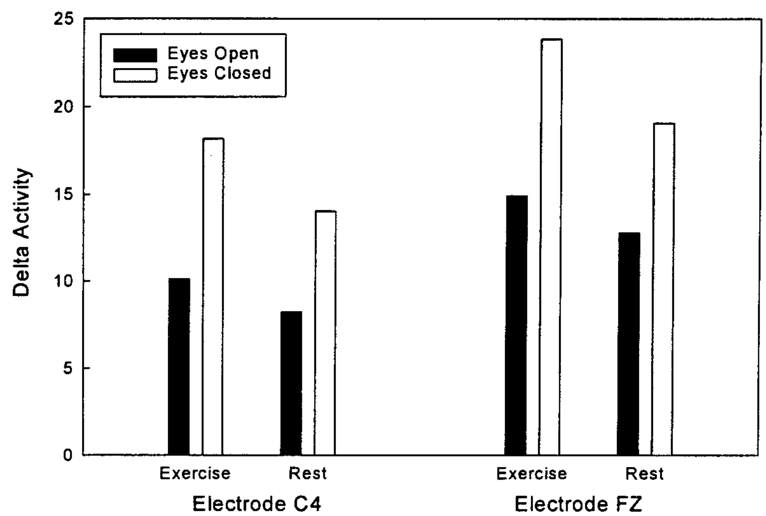


Figure 8. Interaction of condition and eyes for delta activity.

Overall, delta activity was higher during the exercise condition than during rest at C4 ($F(1,11)=5.75$, $p=.035$), O1 ($F(1,11)=5.89$, $p=.034$), and Pz ($F(1,11)=4.75$, $p=.05$). There was also a main effect for time at all electrode sites (C3 ($F(6,66)=8.40$, $p<.001$); C4 ($F(6,66)=7.86$, $p<.001$); O1 ($F(6,66)=5.14$, $p<.001$); O2 ($F(6,66)=5.02$, $p<.001$); Cz ($F(6,66)=10.56$, $p<.001$); Fz ($F(6,66)=8.63$, $p<.001$); and Pz ($F(6,66)=8.11$, $p<.001$)). All sites showed a similar pattern of change across sessions with delta steadily increasing from baseline until the 1000 session. Delta activity plateaued through the 1800 session and then declined sharply at the 2200 session. Despite the decline during the last test session, delta activity at all electrodes, with the exceptions of O1 and O2, remained significantly higher than the original baseline measure. Activity was also significantly higher on all electrodes (C3 ($F(1,11)=41.15$, $p<.001$); C4 ($F(1,11)=28.98$, $p<.001$); O1 ($F1,11)=26.50$, $p<.001$; O2 ($F1,11)=26.17$, $p<.001$; Cz ($F1,11)=48.99$, $p<.001$; Fz ($F(1,11)=17.21$, $p<.002$); and Pz ($F(1,11)=61.87$, $p<.001$)) during the eyes closed portion of testing when compared to eyes open (main effect for eyes).

Theta activity

A significant condition-by-time interaction was observed for electode Pz (F(6,66)=2.54, p=.028). During the exercise condition, theta activity remained relatively unchanged from baseline throughout the 0600 session, while an increase at 0600 was seen during the rest condition. As illustrated in figure 9, theta activity was lower during the exercise condition than at rest during the 0600 test session, whereas the reverse was true at most other times. Theta activity remained elevated above baseline levels throughout the 1800 session under both conditions and then declined at 2200. The decline during the final session was only significant in the exercise condition.

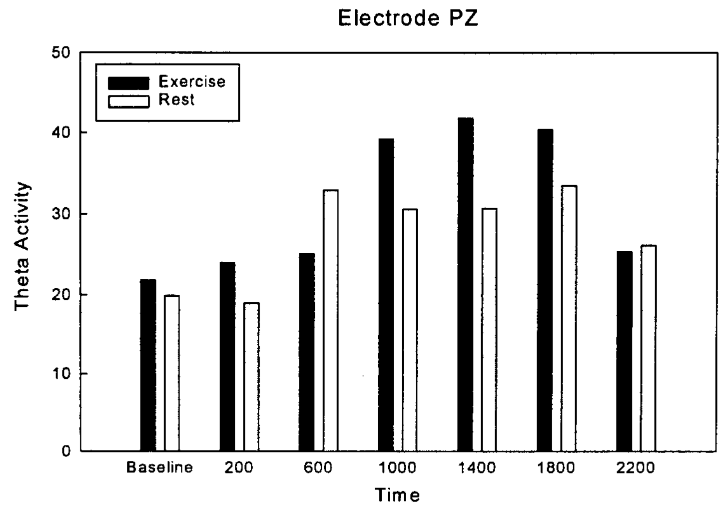


Figure 9. Interaction of condition and time for theta activity.

The analysis further indicated that condition had a significant effect on theta activity. Theta was higher during the exercise condition than during rest at electrodes C3 (F(1,11)=5.33, p=.041), C4 (F(1,11)=5.51, p=.039), and Pz (F(1,11)=6.59, p=.026). There was also a main effect for time on all electrodes (C3 (F(6,66)=8.44, p<.001); C4 (F(6,66)=8.03, p<.001); O1 (F(6,66)=6.11, p<.001); O2 (F(6,66)=7.12, p<.001); Cz (F(6,66)=11.91, p<.001); Fz; (F(6,66)=11.55, p<.001); and Pz (F(6,66)=7.08, p<.001)). All sites showed similar patterns of change across sessions with delta steadily increasing from baseline until the 1800 session. Theta activity then declined sharply at the 2200 session. Activity was also significantly higher on all electrodes during the eyes closed portion of testing when compared to eyes open (C3 (F(1,11)=44.55, p<.001); C4 (F(1,11)=34.05, p<.001); O1 (F(1,11)=46.27, p<.001); O2 (F(1,11)=35.79, p<.001); Cz (F(1,11)=55.37, p<.001); Fz; (F(1,11)=31.05, p<.001); and Pz (F(1,11)=46.89, p<.001)).

Alpha activity

A condition-by-time interaction was seen at C4 (F(6,66)=2.31, p=.044). Simple effects tests found that the only difference to approach significance (.06) was at the 1400 session. Alpha activity during this test session was slightly higher under the exercise condition than rest.

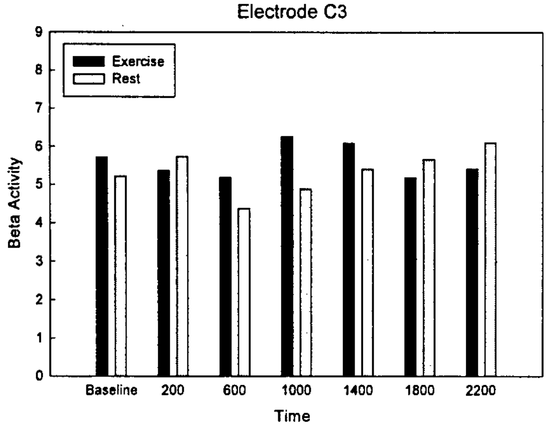
The interaction of time and eyes had a significant impact on alpha activity at all electrode sites ((C3 (F(6,66)=4.77, p<.001); C4 (F(6,66)=3.93, p<.002); O1 (F(6,66)=5.38, p<.00)1; O2 (F(6,66)=3.97, p<.002); Cz (F(6,66)=4.33, p=.001); Fz; (F(6,66)=4.43, p<.001); and Pz (F(6,66)=2.61, p<.03)). However, simple effects tests confirmed that only three electrodes, O1, O2, and Pz, differed across sessions under the eyes open condition. Activity at all three sites decreased steadily from baseline to the 1000 session. Activity then began to increase such than no differences from baseline were observed during the 1400 to 2200 sessions. Analysis showed that under the eyes closed portion of the tests, alpha activity showed similar trends at all electrode sites. Activity continually declined from baseline throughout the 1400 test session. A slight increase began during the 1800 session and continued at 2200, however, alpha activity remained significantly below baseline levels at both of these test times.

The ANOVA additionally showed that there were main effects for time and eyes but not condition. The main effect for time was observed at all electrode sites (C3 (F(6,66)=6.89, p<.001); C4 (F(6,66)=4.06, p<.002); O1 (F(6,66)=7.68, p<.001); O2 (F(6,66)=5.74, p<.001); Cz (F(6,66)=6.19, p<.001); Fz; (F(6,66)=6.23, p<.001); and Pz (F(6,66)=8.08, p<.001)). All sites showed a similar pattern of change across sessions with activity steadily decreasing from baseline through the 1000 session, after which it plateaued through the 1800 session, remaining well below baseline levels. A sharp increase was seen at the 2200 session where all electrodes, with the exceptions of C4 and O1, returned to baseline levels. The main effect for eyes was due to the significantly higher levels of alpha activity on all electrodes during the eyes closed portion of testing when compared to eyes open (C3 (F(1,11)=9.04, p<.02); C4 (F(1,11)=8.71, p<.02); O1 (F(1,11)=7.48, p<.02); O2 (F(1,11)=5.69, p<.03); Cz (F(1,11)=6.65, p<.03); Fz; (F(1,11)=7.98, p<.02); and Pz (F(1,11)=9.92, p<.01)).

Beta activity

A condition-by-time interaction was seen at electrodes C3 (F(6,66)=2.53, p=.029) and Pz (F(6,66)=2.71, p=.021). As seen in figure 10, for both electrodes, beta slowly decreased from baseline to 0600 in both conditions. By the 1000 session, however, differences between the exercise and rest conditions became apparent. In the rest condition, beta began a slow increase back toward baseline levels, which was maintained throughout testing. Beta levels in the exercise condition, however, sharply increased to above baseline at the 1000 session. These levels were also significantly higher than those of the rest condition. Beta activity began a second decline such that activity during the last session was both below baseline and significantly lower than the rest condition.

The ANOVA also revealed a condition-by-eyes interaction for electrode C4 (F(1,11)=5.79,p<.04). Eyes closed levels of beta activity were significantly higher than eyes open during both conditions. Eyes open beta activity was significantly higher during rest than during exercise, but eyes closed beta activity was unaffected by condition. Additionally, there was a time-by-eyes interaction on electrodes O1 and O2. Levels of beta activity during the eyes closed portions of the baseline and 0200 sessions were significantly higher than those of eyes open. Differences between eyes open and eyes closed were not observed after the 0200 session.



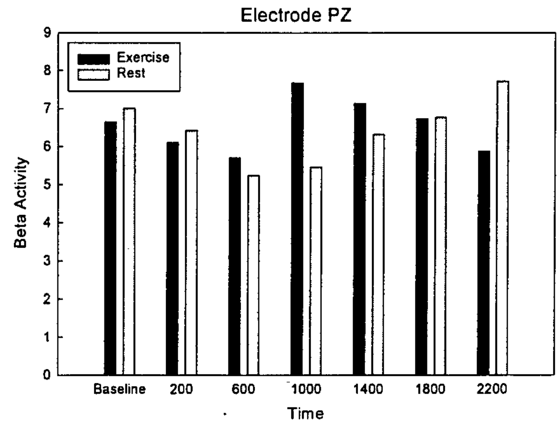


Figure 10. Interaction of condition and time for beta activity.

Similar to alpha, there were main effects for session and eyes but not condition. The main effect for session was observed at electrode sites O1 ($F(6,66)=4.38$, $p<.001$), O2 ($F(6,66)=4.41$, $p<.001$), and Pz ($F(6,66)=2.45$, $p=.034$). These three sites showed a similar pattern of change across sessions. Beta activity steadily decreased such that activity during the 0600 session was significantly lower than baseline. Beta activity remained below baseline levels on electrodes O1 and O2 during session 1000 and 1400 before returning to baseline levels at 1800 and 2200. Activity at Pz rebounded to baseline at the 1000 session and remained at that level throughout testing. The main effect for eyes was due to the significantly higher levels of beta activity on all electrodes during the eyes closed portion of testing when compared to eyes open (C3 ($F1,11)=12.34$, $p<.005$; C4 ($F1,11)=8.09$, $p<.02$; O1 ($F1,11)=14.04$, $p<.004$; O2 ($F1,11)=10.98$, $p<.007$; Cz ($F1,11)=17.13$, $p<.002$; Fz; ($F1,11)=15.81$, $p<.003$; and Pz ($F1,11)=12.95$, $p<.005$).

Mood evaluations

POMS were collected following each exercise or rest period and at 2120 on both deprivation days. The POMS were hand-scored to obtain one score per mood factor: 1) tension-anxiety, 2) depression-dejection, 3) anger-hostility, 4) vigor-activity, 5) fatigue-inertia, and 6) confusion-bewilderment. Each factor was analyzed separately in a 2-way ANOVA using the factors condition (exercise, rest) and session (11, every 2 hours from 0120 -2120). Change scores were used in these analyses.

Tension-anxiety

The 2-way ANOVA on the tension-anxiety scale, which reflects musculoskeletal tension, indicated that there was a main effect for condition ($F(1, 11)=2.92$, $p<.05$). Volunteers reported being significantly more tense-anxious after exercising for 10 minutes (mean=2.1) than following rest sessions (mean=1.0). The was no condition-by-session interaction nor did tension-anxiety scores change as a function of time of day.

Depression-dejection

Analysis of the scores on the depression-dejection scale, which measures despondence and sadness, indicated no main effects or interactions.

Anger-hostility

The 2-way ANOVA on anger-hostility scores, which assesses anger and antipathy toward others, indicated no main effects or interactions.

Fatigue-inertia

Significant increases in weariness and tiredness, as indicated by changes on the fatigue-inertia scale, were seen as a function of time of day ($F(10,110)=7.12$, $p<.001$). Figure 11 illustrates the changes in self-rated fatigue-inertia across the test sessions. Subjects reported being significantly less tired at 0120 than at all other times throughout the day. Ratings from the 0320 session were also lower than those from the remainder of the deprivation period. No significant changes in fatigue-inertia ratings were seen from 0520 through 2120. No main effect for condition or condition-by-time effects were observed.

Confusion-bewilderment

The 2-way ANOVA on confusion-bewilderment scores, which assessed increased difficulties in mental abilities, revealed a time of day effect ($F(10,110)=2.26$, $p<.02$). Volunteers reported having significantly fewer problems with mental abilities at 0120 than at 0720, 0920, 1120 (figure 11). Additionally, ratings at 0320 were less than those at 0920 and 1120. A slight decrease in scores during the 1320 and subsequent tests indicated that confusion and bewilderment scores no longer differed significantly from the 0120 or 0320 scores. No condition or condition-by-time effects were observed.

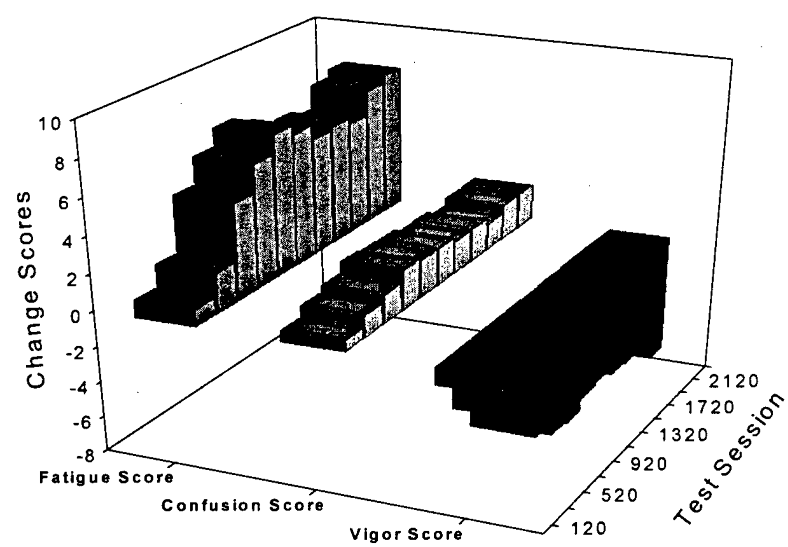


Figure 11. Effects of time of day on POMS fatigue-inertia, confusion-bewilderment, and vigor-activity scores.

Vigor-activity

Examination of the vigor-activity scores, gauging energy levels, revealed a time of day effect ($F(10,110)=6.54$, $p<.001$). No main effect for condition or condition-by-time effects were observed. Figure 11 illustrates the change in self-rated vigor-activity across the test sessions. Ratings from the 0320 session through the 2120 session were all significantly lower than those reported at 0120, and all but those at the 1320 test were lower than those at 0320.

Cognitive evaluations

MATB

Data from the MATB were analyzed in separate ANOVAs for each subtask (monitoring, tracking, resource management, and communications). The variables of interest were speed and accuracy. The change scores for these variables were analyzed in a 2-way ANOVA with two levels of the first factor (exercise/rest), and five levels of the second (session).

Monitoring

The monitoring task which required monitoring simulated gauges and warning lights was assessed in terms of response time to lights, response time to dial deviations, and time out errors for both. The ANOVA indicated that there were session main effects on the mean response time for dials ($F(4,44)=5.00$, $p=.0021$) and the standard deviation of response time for dials ($F4,44)=4.00$, $p=.0075$). As can be seen in figure 12, the mean response time for dials was significantly faster at 0330 and 1930 than it was at 0730 and 1530. A similar pattern was found in the standard deviation data indicating much less response variability during the 0330 and 1930 test sessions. The ANOVA also indicated that there were session main effects on the mean response time for lights ($F(4,44)=6.14$, $p=.0005$) and the standard deviation of response time for lights ($F4,44)=4.87$, $p=.0024$). Differences in the mean response time for lights mirrored those seen for dials, with significantly faster response times at 0330 and 1930 than at 0730 and 1530. A similar pattern was found in the standard deviation scores, with the exception that the standard deviation during the 1130 session was also lower than that at 0730 or 1530. No main effect for condition or condition-by-session interaction was observed.

Tracking

Performance on the tracking task, which required subjects to maintain a target at the center of the tracking window by use of a joystick, was examined in terms of root mean square tracking error. As with the monitoring data, a session main effect ($F(4,44)=6.47$, $p=.0003$) was found and no condition or condition-by-session effects were seen. Also similar to the monitoring data, the session effect was attributable to significantly lower tracking errors 0330 and 1930 than at 0730, 1130, and 1530.

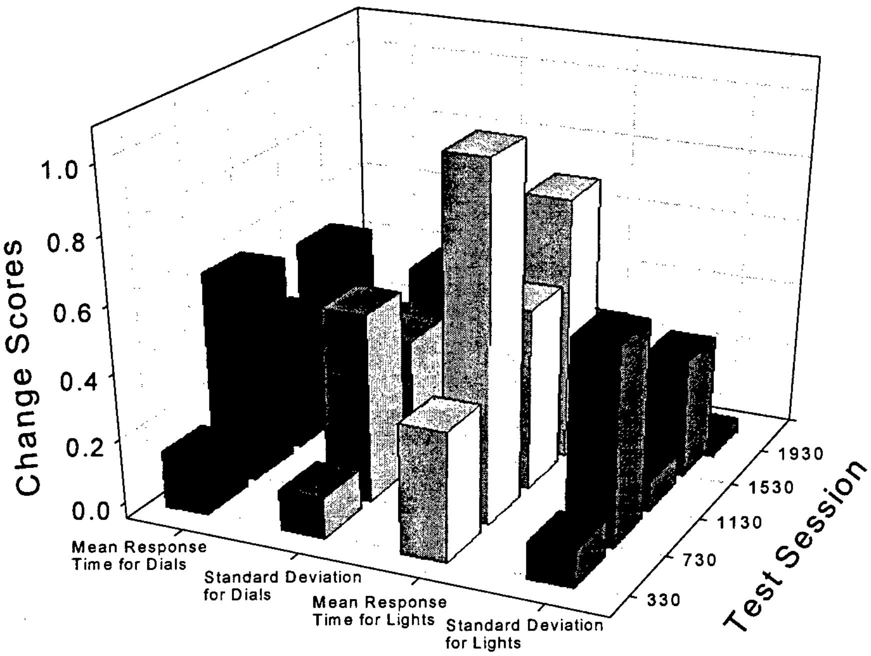


Figure 12. Effects of time of day on MATB systems monitoring reaction time and standard deviation for lights and dials.

Resource management

The resource management task, which required subjects to maintain the levels in two "fuel tanks" at 2500 units, was evaluated in terms of absolute deviation of tanks one and two from 2500 units, the mean number of units maintained in tank one, and the mean number of units maintained in tank two. The 2-way ANOVA on this task indicated that there were no main effects for condition or time, nor a condition-by-time interaction.

Communications

The communication task, which involved the subjects monitoring headphones and adjusting "radio frequencies" when instructed to do so, was analyzed in terms of the mean response time for correct responses, the standard deviation for correct responses, total number of errors (responding to the wrong call sign, changing to the wrong frequency, etc.), and number of false alarms, time outs, and incorrect responses. The analyses of the data indicated that there was no main effect for condition and no condition-by-time interaction. There was, however, a main effect for time on correct response times ($F(4, 44)=3.92$, $p=.008$) and standard deviation for correct responses ($F(4, 44)=2.86$, $p=.034$). Subjects responded faster and with less deviation during the 0330 session than at baseline (figure 13). The response time for correct responses and standard deviation increased significantly during the 0730 session with a further increase observed at the 1130 session. Response time and standard deviation then began to decrease toward baseline at the 1530 session and returned to baseline (or below) by the final session of the deprivation periods.

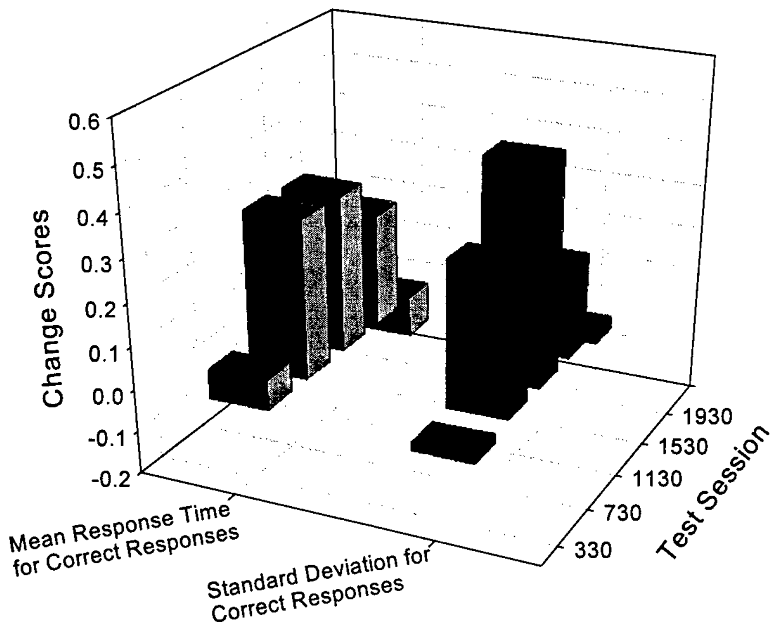


Figure 13. Effects of time of day on MATB communications response time and standard deviation for communications response.

SYNWORK

Composite scores representing overall performance on each of the SYNWORK tasks (Sternberg memory, arithmetic, visual monitoring, and auditory monitoring) were separately analyzed using a repeated measures analysis of variance. The factors were condition (two levels) and session (five levels). The 2-way ANOVAs on the composite scores from the SYNWORK showed no significant effects for condition, time, or condition-by-time on the Sternberg memory, arithmetic, visual monitoring, or auditory monitoring tasks.

Flight performance measures

MINISIM

Data from this surrogate flight simulation task were analyzed in a repeated measures ANOVA in which the factors were condition and session. The variables analyzed were the composite time and accuracy score from each iteration of the "flight." No effects for condition, time, or condition-by-time were found.

Subjective flight performance

Analysis of self-rated ability to coordinate/supervise a flight crew found no main effect for condition or condition-by-time interaction. As illustrated in figure 14, the aviators perceived ability to coordinate/supervise a flight crew changed significantly over time ($F(10,110)=5.14$, $p<.0001$). The scale on the Y axis depicts change scores from 0 to -30. The higher the bar on the graph, the greater the change from baseline (in this case, a decrease). Subjects felt that their

ability to supervise a flight crew had become significantly impaired by the 0520 test session. Changes in the aviators' self-rated ability to control all flight parameters mirrored those of flight crew supervision scores ($F(10,110)=5.58$, $p<.0001$). As with supervision and flight control, perceived ability to perform all flight duties was also affected by time of day ($F(10,110)=4.76$, $p<.0001$). Changes in these scores followed the same trend as the other two subjective flight performance measures.

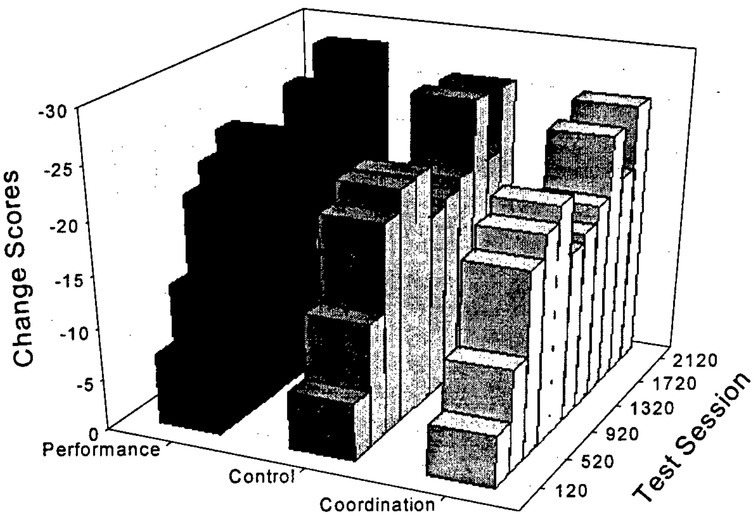


Figure 14. Effects of time of day on subjective flight performance, control, and coordination.

Discussion

Sleepiness and mood

The results from the Repeated Tests of Sustained Wakefulness indicated that exercise significantly increased the subject's ability to remain awake during a 40-hour period of continuous wakefulness under conditions designed to make this very difficult (lying down in a dark, quiet room). While subjects were able to remain awake much longer when exercising throughout the deprivation period, they still entered stage 2 sleep approximately 9 minutes faster than when they were not sleep deprived. Regardless of condition, the ability to stay awake declined as the deprivation period lengthened. A slight recovery was seen during the last RTSW, at 2130, probably due to the fact that subjects knew that this and the EEG were the final tests prior to bed time.

Scores obtained from the RTSW, an objective measure of sleepiness/alertness, did not match the self-reported sleepiness/alertness scores from the VAS, a subjective measure of sleepiness. Subjects reported being less sleepy at 1320 than at 0920, yet were not able to stay awake longer during the 0930 RTSW. Subjects also reported being significantly more tired at 2120 than at 1320, yet they were able to remain awake longer during the 2130 RTSW. Similar trends were observed when examining the concentration, energy, and talkative scales from the VAS. Subjects reported that they were able to concentrate better, that they had more energy, and that they felt more talkative during the early afternoon at 1320 than in the early morning at 0920, yet

this was not reflected in an increased ability to remain awake during the 1330 RTSW. Subjects also reported that they were less able to concentrate, less energetic, and less talkative at 2120 than at 1320, yet they remained awake longer during the final RTSW of the deprivation period.

The fatigue-inertia, confusion-bewilderment, and vigor-activity mood scales from the POMS followed similar patterns of change across time as were seen on the VAS. The results of the subjective measures and objective measures of sleepiness/alertness are somewhat at odds. However, these results are in agreement with others who have examined the correlation between subjective and objective measures of sleepiness. Paper and pencil self-report tests such as the VAS and Stanford Sleepiness Scale are easy to administer and correlate well with each other (Johnson et al., 1991). However, when objective measures of sleepiness/alertness such as the RTSW and Multiple Sleep Latency Test are used in addition to self-report data, correlation between the two types of measures is poor (Johnson et al., 1991; Chervin, Kraemer and Guilleminault, 1995; Caldwell and Ruyak, 1997).

Anxiety, tension, and jitteriness

Anxiety scores on the VAS increased significantly throughout the sleep-deprivation period during the rest condition. While slight increases across time were seen during the exercise condition, none of the increases were significant. Exercise has and is currently being prescribed as a method of stress reduction. It has been shown that many of the hormonal, neuroendocrine, and psychological changes associated with stress can be ameliorated with exercise (Aldana et al., 1996; Crews and Landers, 1987; Nieman, 1990). Thus, it is not surprising that, in this case, exercise reduced the anxiety associated with sustained wakefulness. While exercise reduced anxiety, jitteriness scores on the VAS during the early morning and mid afternoon were much higher during the exercise condition than during rest. Additionally, tension scores from the POMS were significantly higher during the exercise condition than during rest. At first glance, these findings appear to be at odds. However, it should be noted that 10 minutes of treadmill running at 70% VO_2max is physically strenuous, as evidenced by increased blood pressure and pulse rate. As POMS and VAS were given immediately following exercise, this probably accounted for the heightened reports of tension and jitteriness. Both of these scales, jitteriness and tension (reflecting levels of musculoskeletal tension), reflect the subject's feeling about his/her present physical condition. Ratings on the anxiety scale reflect the subject's state of mind or mental condition. As subjects had just completed an exercise bout and knew that another was not scheduled for 2 hours, may have contributed to the lower anxiety scores during the exercise condition. Thus, the results from this study suggest that exercise can increase self-reported physical stress but may decrease self-reported mental stress in sleep deprived people.

EEG

The results from the resting eyes-open/eyes-closed EEGs indicated that condition did have a significant impact on absolute power of both slow-wave (delta and theta) and fast-wave (alpha and beta) activity. Delta activity at the central site C4 showed significant elevations during the exercise condition as the deprivation period lengthened, this increase was much more apparent during the eyes-closed portion of the test. Delta activity also showed a decrease towards baseline levels during the last test session of the deprivation period (2200). Delta activity at sites C4 and Fz was also much higher during both the eyes-open and eyes-closed portions of the exercise tests

than during the rest condition. Exercise also produced significantly higher levels of theta activity than were seen during the rest condition at several electrode sites (C3, C4, and Pz). Additionally, there were substantial elevations from baseline in theta activity during both deprivation periods. The elevation was, however, most pronounced during the late morning and early evening tests during exercise. As with delta, theta activity decreased towards baseline levels during the last test session of the deprivation period (2200). The increased delta and theta activity evidenced by main effects of exercise and the differences produced by exercise across test sessions suggests that subjects were more relaxed and less alert when exercising than during the rest condition. This notion is in direct conflict with the data obtained from the RTSWs which showed that exercise lessened the decrements produced by sleep deprivation. It should be remembered though, that the awake EEGs were conducted 50 minutes following exercise while the RTSWs began 20 minutes after exercise.

Regardless of condition, the pattern of change across the deprivation period of both delta and theta activity mirrored those observed with the RTSWs. Delta and theta slow-wave activity, indicative of increased relaxation/decreased arousal, increased as time to stage 2 sleep on RTSWs decreased. Especially interesting was the significant increase in the subject's ability to remain awake seen during the last RTSW test session at 2130 and the corresponding decrease of delta and theta activity at 2200. Taken together, the results from the RTSWs and theta and delta activity indicate that subjects were more alert following nearly 40 hours of sleep deprivation than 25 hours. However, this increase in alertness was more than likely due to the fact that the subject knew that the RTSW and EEG were the final tests prior to bedtime.

Exercise also produced some changes in faster, alpha and beta activity. Condition had a slight effect on alpha activity across sessions at one electrode, C4. However simple effects tests found that differences between exercise and rest at the various test times only approached significance. Beta activity recorded across sessions at C3 and PZ was also affected by exercise. Beta was lowest at 0600 during both conditions. The significant rise in beta during the 1000 and 1400 exercise sessions was puzzling as delta activity at C4 and theta at Pz were still increasing at the 1000 and 1400 sessions and that slow-wave changes are normally mirrored by fast wave-changes. One reasonable explanation for these conflicting results is that, given the still increasing slow-wave at 1000 and 1400 during the exercise condition, subjects were probably most relaxed at these times. Therefore, the increases in beta may have been due to increased muscle artifact (which contaminates the beta band) as a function of the subjects struggling to stay awake.

Cognitive performance

Time of day effects were seen on visual and auditory monitoring tasks of the MATB. Performance measures generally worsened after the 0330 session but did show signs of recovery at 1130 on visual tasks and at 1930 on both visual and auditory tasks. Similar to many of the other tests, these measures tended to return to baseline during the final session in the deprivation periods. Neither condition nor time of day had any effect on SYNWORK scores. Given the results of these tests, it appears that short bouts of submaximal exercise do not reduce or compound the effects of sleep deprivation on cognitive performance as assessed with the MATB and SYNWORK.

Flight performance

Similar to SYNWORK, the MINISIM was not influenced by condition or time of day. However, the subjective measures of flight performance from VAS did change as a function of time of day. The changes across time on subjective flight performance, control, and coordination were very similar to the changes seen on the other VAS scale. Ratings declined during the early morning hours, some recovery was evidenced during the early afternoon, and a second decline was seen during the evening hours. As with the cognitive measures, exercise did not increase or decrease the effects of sleep deprivation on flight performance.

Conclusions

Exercise does have some short-term alerting effects in sleep deprived subjects but does not protect subjects from performance decrements. Cognitive tests evidenced no difference between the two conditions. Subjects were more alert immediately following exercise as evidenced by longer RTSWs than when they did not exercise during sleep deprivation, but the effects were very short lived. In fact, EEG data show that as early as 50 minutes after exercise bouts, slow-wave activity was actually increased above that seen during rest. Taken together, the results from this study suggest that given just a short period of time after exercise, less than 1 hour, the subjects were less alert after exercising than resting. This may pose a big problem for travelers who believe that exercise will help keep them awake while driving or flying tired. It may give them 30 minutes of "enhanced alertness" (more awake than if they had continued to drive or fly) but will not return alertness to predeprivation levels. Additionally, as enhanced slow-wave EEG activity was seen soon after exercise completion, drivers or flyers who try this intervention may end up more apt to nod off if they continue their trip for much over 30 minutes.

References

Aldana, S. G., Sutton, L. D., Jacobson, B. H., and Quirk, M. G. 1996. Relationships between leisure time physical activity and perceived stress. Perceptual and Motor Skills. 82(1): 315-321.

Angus, R. G., Heslegrave, R. J. and Myles, W. S. 1985. Effects of prolonged sleep deprivation, with and without chronic physical exercise, on mood and performance. Psychophysiology. 22:276-282.

Babkoff, H., and Krueger, G. P. 1992. Use of stimulants to ameliorate the effects of sleep loss during sustained performance. Military psychology. 4(4): 191-205.

Caldwell, J. A. 1992. A brief survey of chemical defense, crew rest, and heat stress/physical training issues related Operation Desert Storm. Military medicine. 157(6): 275-281.

Caldwell, J. A., Caldwell, J. L., Lewis, J. A., Jones, H. D., Reardon, M. J., Jones, R., Colon, J., Pegues, A., Dillard, R., Johnson, P., Woodrum, L., and Higdon, A. 1996. An in-flight investigation of the efficacy of dextroamphetamine for sustainment of helicopter pilot. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 97-05.

Caldwell, J. A. and Ruyak, P. S. 1997. Predicting the ability to maintain alertness during sleep deprivation: The accuracy of subjective evaluations. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 97-05.

Chervin, R. D., Kraemer, H. C., and Guilleminault, C. 1995. Correlates of sleep latency on the multiple sleep latency test in a clinical population. Electroencephalography and Clinical Neurophysiology. 95: 147-153.

Cornum, K. G. 1994. Extended air combat operations: F-15s over Iraq. Aerospace Medical Association 65th annual scientific meeting program, A49. Alexandria: Aerospace Medical Association.

Crews, D. J. and Landers, D. M. 1987. A meta-analytic review of aerobic fitness and reactivity to psychosocial stressors. Medicine and Science in Sports and Exercise. 19: 114-130.

Davey, C. P. 1972. Mental performance after physical activity. Australian Journal of Sports Medicine. 4: 25-33.

Davey, C. P. 1973. Physical exertion and mental performance. Ergonomics. 16: 595-599.

Department of the Army 1989. Army aviation in combat operations. U.S. Army field manual, FM 1-100. Washington, DC: U.S. Government Printing Office.

Dinges, D. F., and Broughton, R. J. 1989. Sleep and alertness: Chronobiological, behavioral, and medical effects of napping. New York, NY: Raven Press.

Englund, C. E., Ryman, D. H., Naitoh, P., and Hodgdon, J. A. 1985. Cognitive performance during successive sustained physical work episodes. Behavior Research Methods, Instruments, & Computers. 17: 75-85.

Hartse, K. M., Roth, T., and Zorick, F. J. 1982. Daytime sleepiness and daytime wakefulness: The effect of instruction. Sleep. 5: S107-S118.

Horne, J. A. 1978. A review of the biological effects of total sleep deprivation in man. Biological Psychology. 7: 55-102.

Horne, J. A., and Foster, S. C. 1995. Can exercise overcome sleepiness? Sleep Research. 24A: 437.

Hockey, G. J. R. 1970a. The effect of loud noise on attentional selectivity. Quarterly Journal of Experimental Psychology. 22: 28-36.

Hockey, G. J. R. 1970b. Changes in attention allocation in a multi component task under sleep loss. British Journal of Psychology. 61: 473-480.

Johnson, L. C., Freeman, C. R., Spinweber, C. L., and Gomez, S. A. 1991. Subjective and objective measures of sleepiness: Effect of benzodiazepine and caffeine on their relationship. Psychophysiology. 28: 65-71.

Kjelberg, A. 1977a. Sleep deprivation and some aspects of performance. I. Problems of arousal changes. Waking and Sleeping. 1: 139-143.

Kjelberg, A. 1977b. Sleep deprivation and some aspects of performance. II. Lapses and other attentional effects. Waking and Sleeping. 1: 145-148.

Kjelberg, A. 1977c. Sleep deprivation and some aspects of performance. III. Motivation, comment and conclusions. Waking and Sleeping. 1: 149-153.

Krueger, G. P. 1989. Sustaining military performance in continuous operations: Combatant fatigue, rest and sleep needs, In Gal R., and Mangelsdorff, A. D. (Eds.), Handbook of military psychology, 255-277. New York: John Wiley and Sons.

McNair, D. M., Lorr, M., and Droppleman, L. F. 1981. Manual for the profile of mood states. San Diego: Educational and Industrial Testing Service.

Martin, B. J. 1981. Effects of sleep deprivation on tolerance of prolonged exercise. European Journal of Applied Physiology. 47: 345-354.

Neiman, C. D. 1990. Fitness and sports medicine: an introduction. Palo Alto: Bull Publishing Company.

Penetar, D., McCann, U., Thorne, D., Kamimori, G., Galinski, C., Sing, H., Thomas, M., and Belenky, G. 1993. Caffeine reversal of sleep deprivation effects on alertness and mood. Pharmacology. 112: 359-365.

Physicians' desk reference. 1996. Dexedrine (brand of dextroamphetamine sulfate.) Pp 2474-2476. Oradell: Medical Economics Co., Inc.

Plyley, M. J., Shepard, R. J., Davis, G. M., and Goode, R. C. 1987. Sleep deprivation and cardiorespiratory function. Influence of intermittent submaximal exercise. European Journal of Applied Physiology. 56: 338-344.

Ryman, D. H., Naitoh, P., and Englund, C. E. 1985. Decrements in logical reasoning performance under conditions of sleep loss and physical exercise: The factor of sentence complexity. Perceptual and Motor Skills. 61: 1179-1188.

Tassi, P., Nicolas, A., Seegmuller, C., Dewasmes, G., Libert, J. P., and Muzet, A. 1993. Interaction of the alerting effects of noise with partial sleep deprivation and circadian rhythmicity of vigilance. Perceptual and Motor Skills. 77: 1239-1248.

Wilkinson, R. T. 1963. Interaction of noise with knowledge of results and sleep deprivation. Journal of Experimental Psychology. 66: 332-337.

Williams, H. L., Lubin, A., and Goodnow, J. J. 1959. Impaired performance with acute sleep loss. Psychological Monographs: General and Applied. 73: 1-26.

Appendix

Manufacturer's list

Cadwell Laboratories
909 North Kellogg Street
Kennewick, WA 99336

CH Products
970 Park Center Drive
Vista, CA 92083

Marquette
8200 West Tower Avenue
Milwaukee, WI 53223

Microsoft
1 Microsoft Way
Redmond, WA 98952

Nihon Kohden
17112 Armstrong Avenue
Irvine, CA 92714

SensorMedics
22705 Savi Ranch Parkway
Yorba Linda, CA 92687