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J. E. YEAGER

R. P. CRISMAN

A. A. SUCEC

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THE EFFECT OF SLEEP DEPRIVATION AND MODERATE INTERMITTENT EXERCISE

ON MAXIMAL AEROBIC CAPACITY[*]

John E. Yeager[1]

Ronald P. Crisman[2]

Anthony A. Sucec[1]
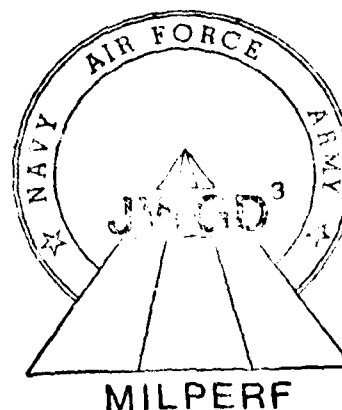
[1]Department of Ergonomics

Naval Health Research Center

P.O. Box 85122

San Diego CA 92138-9174

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SUMMARY

Both military and civilian organizations require work schedules which depart from the usual daily work routines of 0800 to 1700 hours. During contemporary military operations, long term or sustained operations frequently occur necessitating mental and/or physical activity over several days. However, little is known about the effect of sleep loss on maximum aerobic capacity (VO2max), a measure of aerobic fitness. The purpose of this study was to determine if maximum aerobic power is affected by two consecutive 20-hour work periods of sustained intermittent work (IW).

Thirty male Marines from Camp Pendleton, CA volunteered to be subjects in this study. They averaged 21 years of age, 75 kilograms bodyweight and 15% body fat.

The subjects underwent three VO2max tests consisting of walking on a treadmill at 3.5 mph and 0% grade carrying 47 pounds of gear in a backpack. The grade was increased 3% every two minutes until volitional exhaustion. These tests took place on Monday morning (I), at the end of the IW (II), and after 8 hours recovery sleep (III).

For the IW's, the subjects performed psychological tests of reaction time, visual vigilance, logical reasoning and mood. One subject of the pair tested each week walked on the treadmill at 30% of his previously determined VO2max for thirty minutes of each hour for 34 of the 40 hours of IW. The two 20-hour work periods were separated by a three hour nap.

There was a significant difference in the change in VO2max from test I to test II in favor of the subjects who exercised (+2.5%) over those who did not (-3.5%). However, treadmill test times and other indices of effort were not different between groups.

It is concluded that submaximal intermittent exercise will counteract sleep loss-induced decrements in VO2max.

INTRODUCTION

Both military and civilian organizations require work schedules which depart from the usual daily work routines of 0800 to 1700 hrs and impinge upon normal sleep habits. During contemporary military operations, long term or sustained operations frequently occur necessitating mental and/or physical activity over several days. Frequently there will be bursts of physical activity which may accelerate the onset and/or intensity of fatigue. Consequently, mental and physical performance will likely deteriorate with time and a concomitant loss of effectiveness of the soldier will follow.

Historically, the duration of effective military operations has been limited by three factors: 1) limited night vision; 2) equipment reliability, and 3) man's limited endurance capacity (17). However, with the advancement of technology, the first two categories have been effectively eliminated from consideration. Thus, sustaining military effectiveness (i.e., the ability to carry out sustained work loads) may now simply be a matter of the maintenance of physical stamina and the ability to tolerate sleep deprivation if sleep is not or cannot be properly managed. Sustained work has been defined by Alluisi (1) as "the more or less continuous performance of tasks, sets of tasks or jobs during four or more hours a day over several weeks, months or years." Further discussion may be found in Englund and Krueger (5).

Many studies have examined the effects of partial or total sleep deprivation (PSD and TSD, respectively) on psychological performance (16). Likewise, several studies have been completed which report on the effect of PSD and TSD on biochemical and physiological variables (11). Reviews by Wilkinson (24) and Naitoh (16) draw the common conclusion that both PSD and TSD have a profound effect upon psychological performance but little effect on biochemical and/or physiological measures. Yet a common explanation for the necessity of sleep is its possible role of body restitution which may relate to, among other things, energy metabolism and the ability to do physical work (12).

If sleep loss does inhibit the body's ability to restore its full capacity to provide energy for emergencies or hard physical work, then an associated reduction in an individual's VO2max might be expected. The findings on this question are inconsistent. Martin and Gaddis (15) report no significant drop in VO2max scores using the cycle ergometer for six college-aged subjects following 30 hrs of TSD but without any exercise except for some submaximal testing (less than 60 mins total). Plyley, et al., (19), however, found a significant drop of 6.9% in VO2max using the treadmill for 12 young males after 64 hrs of TSD and exercising at 25% of VO2max for one hour out of every three hours. Further, Vogel and Gleser are cited in Harris and O'Hanlan (7) as finding that three males showed an average drop of 4.3% in VO2max as measured on the cycle ergometer following 72 hrs of TSD and submaximal tests at 35% of VO2max. (No mention of statistical significance of the decrement was made by the authors; however, a dependent t ratio was calculated from the data in the article and the reported decrement was found to be significant. No data were reported on the duration or frequency of the submaximal testing.)

Moderate to heavy work, intermittent or continuous in nature, over a period of time is known to cause decrements in physical performance (2). On the other hand, if moderate intermittent exercise (e.g., 25 to 40% of VO2max) is performed in conjunction with PSD or TSD such that recovery may occur

between exercise bouts, it may provide an arousal effect which might help to maintain both psychological and physiological performance by off-setting the fatiguing effects of PSD and TSD. Supporting this hypothesis are the findings of Davey (4), who showed that there was an inverted "U" relationship between short term submaximal exercise of 30 secs to 2 mins duration at varying intensities and performance on the Brown and Powlton Test of Attention. Also, the well known relationship between endurance and physical fitness (2) suggests that individual's with higher physical fitness levels (i.e., high VO2max scores) would tolerate sleep loss and associated fatigue better than less fit individuals. The more fit subjects should also show a smaller percentage or absolute decrement in post sleep deprivation VO2max tests compared to the less fit subjects even though working at equal fractions of their VO2max.

There may be a circadian rhythm effect on VO2max. Wojtczak-Jaroszowa and Banaszkiewcz (25) have reported a decrement of 5% for VO2max measured during the night (between 0100 and 0500 hrs) compared to the results for daytime measurements (0900 to 1300 hrs). They exercised fifty young males on a cycle ergometer using a progressively increasing work rate and employed the Astrand-Ryhming equation (2) to determine VO2max. However, Faria and Drummond (6) failed to observe any variation in VO2max as measured periodically at different times of the day and night for 31 college students (eight females and 23 males). A progressive treadmill test was used to determine VO2max. Both reports collected data over a period of weeks and months rather than during a single 24 hr period. Thus no data are available on possible circadian rhythm effects occurring within a limited time span.

PURPOSE

The purpose of this study was to determine if maximal aerobic power (VO2max) was affected by two consecutive 20 hr work periods of sustained intermittent work (IW). The sustained IW consisted of alternating exercise and mental tasks with a three hour nap inserted between the two IW periods. While the combination of physical and mental work was nearly continuous, the physical exercise was done only half of the time or 30 mins out of each hour, thus the title's reference to moderate intermittent exercise.

Auxiliary purposes of this study were to determine: 1) the role of exercise as a potential facilitory or arousal agent in maintaining maximal aerobic capacity (VO2max) following PSD; 2) if initial maximal aerobic capacity affects the subject's ability to maintain his VO2max following PSD, and 3) if the time of day (specifically, noon or midnight) subjects start the experimental sequence affects VO2max following two IW's.

METHODS

Subjects

Thirty male Marines from Camp Pendleton, CA, volunteered to be subjects in this study. All subjects signed informed consent forms prior to participation. The descriptive statistics for the subjects are found in Table 1.

Materials

The study was conducted at the Environmental Physiology Laboratory at the Naval Health Research Center (NHRC), San Diego, CA. The laboratory was environmentally controlled at 21 degrees celsius and 50% relative humidity.

Oxygen uptake measurements were collected using an open circuit spirometry technique with the subject breathing into a Rudolph non-breathing valve (2700) with a saliva trap (32mm ID) and Collins mouthpiece (35mm OD) into corrugated tubing (32mm ID). Expired CO_2, O_2, and volume were measured using a Sensormedics LB-2, Applied Electrochemistry S-3A, and Rudolph 3800 pneumotachometer respectively, interfaced with a Digital Equipment Corporation Minc 11 computer. The CO_2 and O_2 were temporally aligned with expired volume and the VO2 measures were averaged into 15 second values throughout the collection period. A Performance Assessment Battery (NHRC PAB) consisting of a number of psychological tasks was also administered using the Minc system and is described elsewhere by Ryman, et al., (21). Heart rate was constantly monitored with a Marquette Mac I ECG with electrodes in the CM5 configuration.

Procedure

The subjects reported in pairs on Monday morning. They were oriented to the laboratory and were briefed on all tasks which they would undertake for the remainder of the week. Medical histories were reported and the subjects underwent a physical examination. The pair of subjects was randomly assigned to one of two groups: Noon (N) (N=16) or Midnight (M) (N=14) start time for the sleep loss protocol described below. See Figure 1 for a schematic of the scheduling of various procedures.

All subjects then underwent a maximal oxygen consumption test. The subjects wore standard issue Marine fatigues, boots and backpacks. The total load was 47 pounds (21.3 kg). The test began with four minutes of quiet standing on the treadmill (Quinton, model 18-60). The treadmill speed was then set at 3.5 miles per hour and zero percent grade. The grade was increased three percent every two minutes until volitional exhaustion (NHRC protocol). The high and low fitness groups were determined by equally dividing the exercise and control groups on the basis of their VO2max scores.

The remainder of the day on Monday was spent at rest learning the NHRC PAB with regular meal breaks and rest intervals. Midnight groups went to bed at 1900 hrs Monday and Noon groups at 0400 hrs Tuesday. Day 2 consisted of a baseline testing day with no exercise. Midnight groups' bedtime was 1500 hrs and Noon groups' was 0400 hrs Wednesday.

Upon waking on day three (Wednesday), the first of two 20 hr sessions of continuous mental work began. The physical work, as mentioned above, was intermittent. The start time was 0000 hrs for Midnight groups and 1300 hrs for Noon groups. Each 20 hr period was separated by a three hour nap: 2000-2300 hrs for Midnight groups and 0900-1200 hrs for Noon groups. Each 20 hour workday (IW1 and IW2) consisted of 17 one hour test sessions with three, one hour meal breaks.

One of the pair of subjects was randomly assigned to the exercise group and the other was a non-exercising control. The subjects performed identical psychological tasks. The exercising subjects walked on the treadmill for 30 minutes of each hour of the IW carrying 47 pounds of gear. The treadmill speed and grade were adjusted such that oxygen uptake was maintained at 30% of the previously determined VO2max. During this time both the exercise and control subjects performed a visual vigilance task.

The timing for the sustained operation (SUSOP) intervals is shown in Figure 1. At the end of the two 20 hour periods of intermittent work (separated by a three hour nap), a second VO2max test (T2) was administered from 30 mins to two hours following IW2. The subjects then slept for eight hours after which time a third VO2max test (T3) was performed within two hours after awakening.
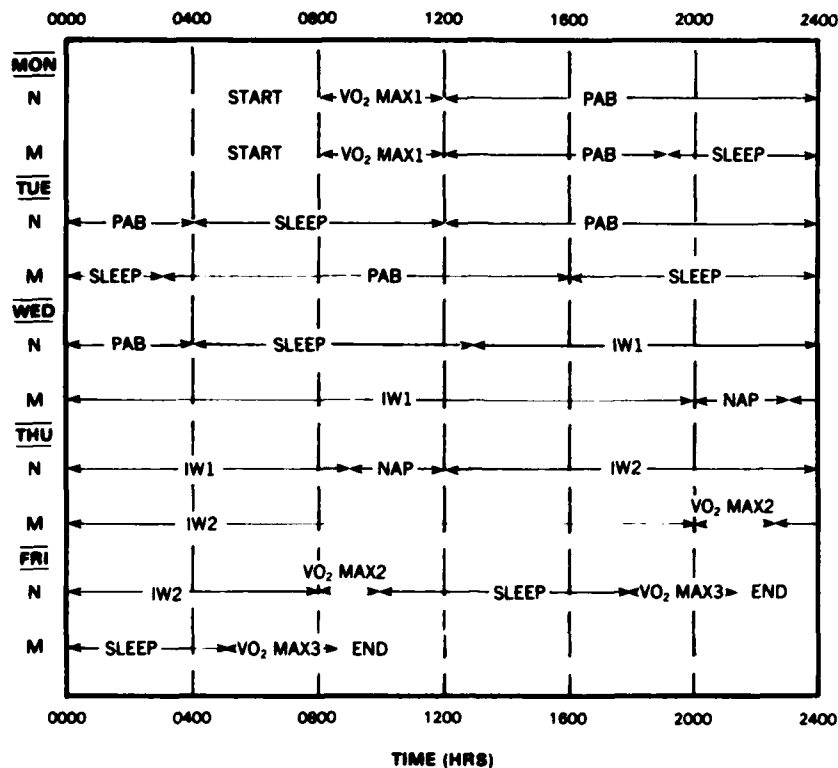
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TIME (HRS)

Figure 1. Activity schedule for Noon (N) and Midnight (M) groups during experimental (intermittent work or IW) and control conditions. Control subject's schedule was the same as experimental's except that the former rested during the IW phases. All subjects participated in cognitive testing (PAB) which is briefly described in text. These tests were administered each hour of the IW with the exception of three meal hours.

Statistical Analysis

Analyses were accomplished with a Digital Equipment Computer VAX 11/780 using the SPSS-X 2.1 statistical packages including repeated measures ANOVA and t ratios. The level of significance was set at $P < 0.05$.

RESULTS

The descriptive statistics for the subjects physical characteristics may be found in Table 1. The 30 subjects had a mean age of 21.2 yrs, height of 176.55 cm, weight of 74.88 kg and relative fat of 15.28%. There were no significant differences found for any of the descriptive characteristics from sub-group to sub-group.

The initial VO2max (T1) tests showed no differences ($P > 0.05$) for various comparisons with the exception of the low-high fitness comparison (see Table 2). Aside from the low ($45.70 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) and high ($54.30 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) fitness means, the average VO2max scores of all subgroups were within $1.8 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ of the total group mean of $50.00 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Measures associated with VO2max (Table 2) such as maximum minute volume (VEmax), maximum heart rate (HRmax), maximum respiratory exchange ratio during exercise (Rmax) and maximum treadmill walk time (WT) had means of 129.67 $1 \cdot \text{min}^{-1}$, BTPS, 197.0 bts.min^{-1}, 1.12 and 12.67 mins for VEmax, HRmax, Rmax and WT, respectively for the total group with similar values for all subgroups. However, the high fit group did show a longer mean walking time on the treadmill than did the low fit group (13.35 mins vs 11.98 mins, $p < 0.05$) which was consistent with the VO2max findings. The Midnight start group also produced a longer WT than the Noon group with mean scores of 13.29 and 12.13 mins ($P < 0.05$), respectively.

Table 1. Descriptive statistics for the subject's characteristics for the total group and sub-groups including the exercise and control groups, high and low fit groups and noon and midnight groups.

GROUP	N	AGE (yrs)	HEIGHT (cm)	WEIGHT (kg)	RELATIVE FAT* (percent)
Total	30				
Mean		21.20	176.55	74.88	15.28
SD		1.98	8.11	10.12	6.60
Exercise	15				
Mean		21.67	177.97	78.34	15.57
SD		2.47	8.36	11.07	7.07
Control	15				
Mean		20.67	175.12	71.35	15.00
SD		1.23	7.87	7.46	5.55
High fit	15				
Mean		21.60	174.71	72.35	15.42
SD		2.53	6.64	7.23	2.17
Low fit	15				
Mean		20.73	178.39	77.34	15.14
SD		1.16	9.21	12.10	6.23
Noon	16				
Mean		20.19	175.34	72.38	13.96
SD		0.83	9.95	11.18	5.60
Midnight	14				
Mean		22.29	177.92	77.66	16.79
SD		2.34	5.35	8.25	7.52

* Determined from circumference measures after Hodgdon and Beckett (10).

Table 2. Initial (T1) descriptive statistics for maximal oxygen uptake and associated measures for the total group (N=30) and sub-groups which include the exercise (N=15) and control (N=15) groups, the high (N=15) and low (N=15) fit groups and the noon (N=16) and midnight groups (N=14).

GROUP	VO2MAX(STPD) ($l \cdot min^{-1}$)	VO2MAX(STPD) ($ml \cdot kg^{-1} \cdot min^{-1}$)	VEMAX(BTPS) ($l \cdot min^{-1}$)	HRMAX ($bts \cdot min^{-1}$)	RMAX (VCO2/VO2)	WALK TIME (mins)
Total						
Mean	3.718	50.00	129.67	197.0	1.12	12.67
SD	0.481	5.64	17.67	9.81	0.05	3.98
Exercise						
Mean	3.819	49.20	131.55	194.60	1.12	12.82
SD	0.520	6.80	20.90	9.75	0.05	1.31
Control						
Mean	3.616	50.81	127.79	199.40	1.13	12.52
SD	0.443	4.28	14.24	9.59	0.05	1.17
High fit						
Mean	3.927	54.30*	134.84	197.13	1.10	13.35*
SD	0.481	4.07	14.05	10.38	0.05	1.20
Low fit						
Mean	3.508	45.70*	124.50	196.87	1.15	11.98*
SD	0.405	3.14	19.81	9.58	0.04	0.83
Noon						
Mean	3.487	48.49	124.87	201.25	1.13	12.13**
SD	0.435	3.68	17.81	10.51	0.05	0.99
Midnight						
Mean	3.981	51.73	135.76	192.14	1.12	13.29**
SD	0.410	7.03	16.42	6.30	0.05	1.22

* $p < .05$, Low fit vs. High fit
** $p < .05$, Noon vs. Midnight

The Effect of Partial Sleep Loss

The combined group (N=30) displayed no change in VO2max as a result of the experimental treat-ment (i.e., T1 = T2). The VO2max scores averaged 50.00 $ml\cdot kg^{-1}\cdot min^{-1}$ for T1 and 49.78 for T2 (p>0.05) as is shown in Tab!: 3. The average WTs were also unchanged (12.67 vs 12.24 mins, p>0.05) as were the mean Rmax values (1.12 and 1.09, p>0.05). The mean increase in the VO2 scores for the last two minutes of exercise was 2.25 and 2.15 $ml\cdot kg^{-1}\cdot min^{-1}$ for T1 and T2, respectively. The failure of WT, Rmax and VO2 scores to change indicates that the subjects made equally hard efforts for each test.

However, the comparison between the exercise and non-exercise groups did show a change (paired t ratio) in favor of the exercise group (P<0.05). There was a mean improvement in VO2max in the exercise group of 1.29 $ml\cdot kg^{-1}\cdot min^{-1}$ (+2.5%), while there was an average decrement in the control group's scores of 1.73 $ml\cdot kg^{-1}\cdot min^{-1}$ (-3.5%). Thus the sum of the differences between T1 and T2 for the two groups was 6.0%. The results for the variables which are indicators of achieving VO2max support the contention that, on the average, the subjects made equally strong efforts to achieve VO2max. For instance, there was no change in the WTs, Rmax for T1 and T2 for either group as shown in Table 3. Moreover, the mean changes for the last minutes of exercise were nearly identical 2.13 $ml\cdot kg^{-1}\cdot min^{-1}$ for T1 and T2 for the exercise group and 2.36 and 2.17 $ml\cdot kg^{-1}\cdot min^{-1}$, respectively, for T1 and T2 for the control group.

Table 3. Descriptive statistics for maximal oxygen uptake (VO2MAX), treadmill walk time and respir-atory exchange ratio (R) maximal value during exercise for all three maximal oxygen uptake tests (T1, T2, T3). These data are arranged for the total group (N=30) and sub-groups which are the exercise (N=15) control and (N=15) groups, the high (N=15) and low (N=15) fit groups and the noon (N=16) and midnight (N=14) groups.

GROUP	VO2MAX(STPD) ($ml\cdot kg^{-1}\cdot min^{-1}$)			WALK TIME (mins)			R MAX (VCO2/VO2)		
	T1	T2	T3	T1	T2	T3	T1	T2	T3
Total									
Mean	50.00	49.78	50.69	12.67	12.24	12.38	1.12	1.09	1.10
SD	5.64	7.21	6.91	3.98	1.69	1.63	0.05	0.06	0.06
Exercise									
Mean	49.20	50.49	50.63	12.82	12.33	12.42	1.12	1.06	1.08
SD	6.80	9.15	8.44	1.31	2.04	1.99	0.05	0.03	0.05
Control									
Mean	50.81	49.08	50.75	12.52	12.15	12.35	1.13	1.12	1.12
SD	4.28	4.80	5.27	1.17	1.33	1.25	0.05	0.06	0.07
High fit									
Mean	54.30	54.40	55.32	13.35	13.10	13.08	1.10	1.09	1.08
SD	4.07	5.92	5.55	1.20	1.60	1.43	0.05	0.06	0.05
Low fit									
Mean	45.70	45.16	46.05	11.98	11.38	11.68	1.15	1.10	1.12
SD	3.14	5.21	4.71	0.83	1.34	1.56	0.04	0.06	0.06
Noon									
Mean	48.49	47.69	48.74	12.13	11.59	11.69	1.13	1.10	1.10
SD	3.68	5.75	4.34	0.99	1.39	1.49	0.05	0.06	0.06
Midnight									
Mean	51.73	52.17	52.92	13.29	12.98	13.18	1.12	1.09	1.09
SD	7.03	8.15	8.65	1.22	1.75	1.45	0.05	0.06	0.06

The recovery sleep following t. PSD increased the VO2max scores, nonsignificantly from 49.08 to 50.75 ml·kg^{-1}·min^{-1} in the control group matching their T1 mean of 50.81 ml·kg^{-1}·min^{-1}. The exercise group maintained their baseline scores (50.49 vs 50.63 ml·kg^{-1}·min^{-1}) as is illustrated in Figure 2.

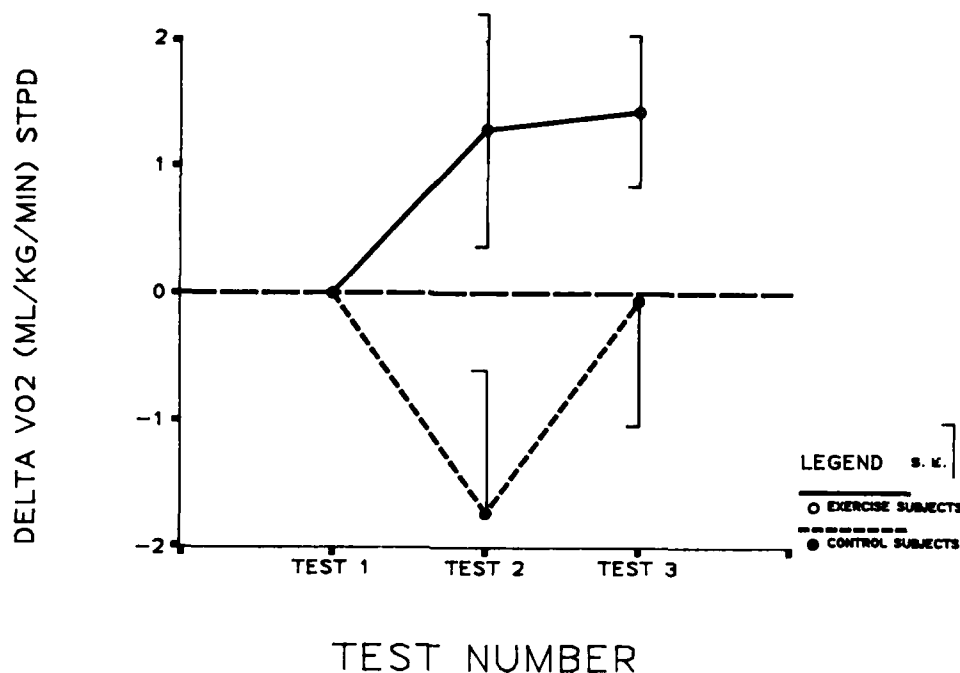Figure 2. Mean maximal oxygen uptake (ml·kg^{-1}·min^{-1}) changes (delta scores) for the exercise (N=15) and control (N=15) groups between tests 1 and 2 and 1 and 3. The vertical bars represent the standard error of the means.

The hypothesis that individuals with high aerobic capacities would maintain their VO2max scores better than low fit individuals following PSD with or without exercise was not supported as there were only small changes between T1 and T2. The means for the low fit group were 45.70 and 45.16 ml kg^{-1}·min^{-1} for T1 and T2, respectively, while the averages for the high fit subjects were 54.30 and 54.40 ml·kg^{-1}·min^{-1} for T1 and T2 (Table 3). Again, the WTs, Rmax and increase in VO2max the last two minutes of exercise all suggest that the subjects made equally hard efforts to achieve VO2max in spite of 45 hrs of PSD.

There was no evidence of any effect of time of day on maximal aerobic capacity. This statement is based upon the small changes found between T1 and T2 for the groups that were started at 1300 and 0000 hrs. The Noon group scores averaged 48.49 and 47.69 ml·kg^{-1}·min^{-1} for T1 and T2, respectively, while the Midnight group's means were 51.73 and 52.17 ml·kg^{-1}·min^{-1} for tests 1 and 2 (Table 3). As with earlier comparisons, indicators of effort such as WTs, Rmaxs and changes in VO2 the last two minutes of exercise were consistent between the two groups (refer to Table 3).

DISCUSSION

Based on findings for the total group, 45 hrs of PSD did not induce a loss of maximal aerobic capacity. Of the three known studies that have measured the effect of TSD on VO2max only the finding of Martin and Gaddis (15) are in agreement. Their subjects showed no changes in VO2max following 30 hrs of TSD. In contrast, Plyley, et al., (19) found a decrement of 6.9% (mean change for the exercise and control conditions combined) for 12 young males following 64 hrs of TSD, and Vogel and Gleser (7) reported a mean reduction of 4.3% in VO2max for three males after 72 hrs of TSD. However, there are several differences between their protocols and this study. The most important difference appears to be the nature and length of sleep deprivation. That is, the two latter studies employed TSD for 64 and 72 hrs respectively, while the present study used 45 hrs of PSD.

There are also differences in the exercise incorporated in these protocols. Vogel and Gleser did not exercise their subjects during TSD, except for some submaximal tests (less than an hour of exercise). The subjects of Plyley, et al., underwent an exercise and no exercise condition, acting as their own controls. The intensity of their intermittent exercise condition was similar to the present study (28% vs 30% VO2max). However, the work to rest ratios and duration of the work and rest intervals were different. The subjects of Plyley, et al., exercised one hour out of every three hours compared to 30 mins each hr which is a 1:3 ratio as compared to 1:2 for our study. The conflicting findings may be the result of the discrepancies in the nature, i.e., total or partial, and duration of the sleep deprivation. In addition, the use or absence of exercise may contribute to the differences. If exercise is used, the interval length, work to rest ratio and capacity of that exercise could play important roles.

Some studies have reported a reduction in heavy or maximal work performance following TSD; however VO2max was not measured. Our findings seem inconsistent with their results for the maximal walk or run. For instance, Martin (13) studied eight college-aged subjects who were required to be passive for 36 hrs of TSD. They could run on a treadmill at 80% of VO2max for only 89% of the duration that they managed prior to the start of TSD. These subjects were required to be passive during the PSD. Holland (9) observed a drop of 9.7% in the physical work capacity on a cycle ergometer for 24 college-aged males following only 24 hrs of TSD with little physical activity. A third study, Martin and Chen (14), also reported a decline in performance; they found that after 50 hrs of TSD, the run time to exhaustion was reduced by 20%. The subjects in this study were allowed to move about and play games to maintain wakefullness.

Theoretically, it is expected that VO2max and endurance performance would show similar changes (2), yet there could be a diminution of this normally close relationship due to effects of PSD or TSD. For example, increased feelings of fatigue and drowsiness associated with TSD or PSD could contribute to poor performance without an attendant decrement in VO2max; that is, loss of motivation alone could account for reduced performance yet VO2max could still be achieved since an individual does not have to walk to exhaustion to achieve VO2max (2). This appears to be the case for our study. We found that the correlation coefficient for WT1 vs WT2 was only $r=.66$ compared to $r=.82$ for VO2max (T1 vs T2) suggesting that there is a greater increase in variability from T1 to T2 for the walk performance than for VO2max. Based on these coefficients, 34 percent of the variance is unaccounted for in performance time while only 18% cannot be explained for maximal aerobic capacity.

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Therefore, one can only speculate as to how VO2max would have been effected in the three studies above. The literature (2) suggests that a decrement of this magnitude in WT would be associated with a reduction in VO2max.

The discrepancies among the findings of the previously discussed investigations into the effects of sleep deprivation on VO2max may relate to the durations of sleep deprivation used. That is, there may be a threshold duration, after which a decrement in VO2max would be expected. This could explain why investigations on the effects of TSD of relatively short duration, i.e., less than 36 hrs, would find no changes in VO2max, while studies of longer TSD would evidence such a drop in VO2max. Presumably the threshold value for PSD will be longer than that for TSD depending upon the length and frequency of the naps. With our protocol more than 45 hrs of PSD appears to be required before a significant decrease occurs. Consistent with this, Pleban, et al., (18) found no decrement after a 60 hr PSD/intermittent exercise period.

It appears, also, that exercise during the sleep deprivation period may influence the threshold value. Changes in VO2max between the exercise and control groups from T1 to T2 were significantly different. The exercise group improved and the control showed a decrement (see Table 3). This finding supports the hypothesis that moderate, intermittent exercise may act as an arousal or facilatory agent for maintaining maximal aerobic capacity. Plyley, et al., (19) found decrements in both their exercising and non-exercising groups but reported a greater drop for the non-exercising group (8.4 vs 5.3%). The greater decrements in VO2max found by the latter study may be due to the nature (total vs partial) and length (64 vs 45 hrs) of the sleep loss. An additional contributing factor may be that the work to rest ratio for exercise was less, i.e., 1:3 compared to 1:2, and that the rest interval between exercise periods was four times longer (2 hrs vs 30 mins) in the Plyley, et al., study. If exercise does, in fact, act as a facilitating agent to maintain VO2max, the longer periods of inactivity may diminish this effect following increasing exposure to TSD.

Takeuchi, et al., (23), studied different physical performances in the same subjects as Plyley, et al. They observed a decrease in vertical jump performance, a measure of leg anaerobic power, following 64 hrs of TSD. However, with the combination of TSD and exercise, (one hr of treadmill walking at 28% of VO2max every 3 hr period) performance did not decline. Also, no changes were found for the 40 yard dash and isometric handgrip force following TSD, with or without exercise. These findings are consistent with our finding that the exercise group improved their VO2max by 2.5% while the control group mean dropped by 3.5%.

The work of Pleban, et al., (18) is also consistent with our findings. They studied 16 males whose age averaged 21 yrs. These subjects participated in high intensity ranger operations with limited sleep (PSD) for 60 hrs and a fitness battery which included the 2 mile run, step test, as well as other measures of fitness. There was no reported change in VO2max in this within group design. Unfortunately, they did not have controls for comparison.

The comparison of the low and high fitness groups did not support the hypothesis that superior levels of aerobic fitness would result in smaller decrements and/or maintenance of VO2max. Thus, Pleban, et al.'s (18) findings for 16 ROTC cadets showing a relationship between fitness (based on a five item fitness test) and performance following 60 hrs of PSD, primarily for cognitive tasks, was not confirmed. The present findings cannot be used to support or contradict Hegge's (8) suggestion that physical fitness could play a role in slowing the rate of performance decrement during

sustained combat operations. He suggested that fit individuals would be working at a lower fraction of their aerobic capacity. However, all our exercise subjects worked at 30% of VO2max.

No differences in the T1 and T2 means for VO2max were found for the Noon and Midnight groups. This is consistent with the observations of Reilly and Brooks (20) who reported minimal differences in resting oxygen uptake as measured at various times of the day and night. They also found no differences in VO2 for submaximal and maximal exercise when expressed in $ml \cdot kg^{-1} \cdot min^{-1}$, thus taking into account small weight changes over a 24 hr period. In contrast, Wojtczak-Jaroszowa and Banaszkiewics (25) found a 5% variation in estimated VO2max, expressed as $L \cdot min^{-1}$, in favor of late morning (0900 to 1300 hrs) measurement over VO2max measured at early morning (0100 to 0500 hrs).

While the eight hr recovery sleep brought the control group back to baseline levels for VO2max (see Table 3, T3) and maintained the mean scores for VO2max for the exercise group, some studies have found that other physiological measures take longer to recover following PSD or TSD. For instance Brodan, et al., (3) found an increased HR recovery response to the Harvard Step Test for 50 males indicating a slowed recovery from exercise the first two recovery days following 120 hrs of TSD. Lubin and associates (12) reported that oral temperature on the first recovery day was well below baseline means after 40 hrs of TSD. However, this finding seems to be in conflict with Sawka, et al., (22) who observed a reduction in sweat response and an increase in esophageal temperature with 33 hrs of TSD. Sawka and associates speculate that a possible mechanism for an alteration in sweat response and level of cutaneous vasodilation following TSD may be an altered output signal from the hypothalamus brought on by a change in the concentration of monoamines in the hypothalmus.

In summary, it is concluded that 45 hrs of PSD does not reduce VO2max for the total group when exercise and non-exercise groups are combined for analysis. However, there is a facilitory effect from intermittent exercise which provides a 6% advantage in VO2max for the exercising group but leaves treadmill walk time unaffected. There is no measurable effect of fitness in withstanding the potential negative effects of PSD nor is there any difference in the changes in VO2max when determined in the morning or late evening.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)
The purpose of this study was to determine the effects of moderate intermittent work (IW), partial sleep deprivation (PSD) and 8 hrs. of recovery sleep (RS) on maximal oxygen uptake (VO2max). The IW consisted of two 20 hr. periods separated by a 3 hr. nap. Thirty male subjects with the following mean characteristics (age = 21.2 yrs., height = 176.6 cm., and weight = 74.9 kg.) were randomly assigned to a non-exercising group (C), or an exercising group (E). Subjects were further randomly assigned to Noon (N) or Midnight (M) start times. Comparisons of low (L) and high (H) fitness levels based on baseline VO2max were also made. All groups underwent PSD with E walking on a treadmill at 30% of VO2max for 30 mins/hr. VO2max, maximum heart rate (HRmax) and maximal treadmill walk times (WT) were measured three times; baseline (T1), after IW (T2) and after RS (T3). The L and H means for VO2max were 45.7 and 54.3 $ml/kg^{-1}/min^{-1}$, respectively, while all other group means were within 2 $ml/kg^{-1}/min^{-1}$ of 50 $ml/kg^{-1}/min^{-1}$, STPD. Following PSD VO2max dropped 3.5% in C and increased 2.5% in E (P 0.05). The HRmax means were within 5 bts/min^{-1} of 197/min^{-1} for all groups, and the mean WTs were between 12.0 and 12.8 mins. with only the H and M groups demonstrating (over)

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19. ABSTRACT (continued)

~any differences with means of 13.4 and 13.3 mins., respectively. The changes in C and E following PSD support the hypothesis that moderate IW counteracts PSD induced decrements in VO2max. Neither fitness level nor start time altered the effects of PSD on VO2max. Keywords; Physical fitness.

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