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Self-selected Exercise Intensity is Unchanged by Sleep Loss*

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Summary. Sleep loss alters the perceptual response to exercise: subjects describe constant external work loads as more severe after sleep deprivation. However, since subjects cannot be "blind" to their sleep status and have knowledge of previous exertional ratings, it remains unknown if this increase in perceived exertion merely represents expectations of increased difficulty of exercise after sleep loss. As one approach to this problem, we asked 24 subjects to produce equivalent "very hard" efforts, once after normal sleep, and once after 30 h without sleep. This was done by allowing the subject, while walking at constant speed, to adjust treadmill grade, without knowledge of the actual elevation. We found that exercise at equal perceived exertion was associated with the choice of a nearly equal absolute work load after sleep deprivation as after normal sleep (17.1 vs. 17.5% grade; p = n.s.). In addition, after 10 min of exercise at the self-selected intensity, subjects displayed identical ventilation, oxygen uptake, and CO_2 production. However, heart rate was significantly lower during exercise after sleep loss (170 ± 3 vs. $178 \pm 3\ \mathrm{b \cdot min^{-1}}$; $p < 0.001$). These results suggest that previously measured increases in perceived exertion during constant-load exercise after sleep loss may be spurious.

Key words: Oxygen uptake – Ventilation – Heart rate – Perceived exertion

Introduction

Exercise after sleep loss is a common occurrence. Nonetheless, the effects of sleep loss upon subsequent exercise remain incompletely understood. In part,

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this stems from inadequate definition of the function of sleep itself (Bonnet 1980; Webb and Agnew 1973).

Although the available evidence is mixed, there are suggestions that sleep deprivation may reduce performance of prolonged heavy exercise (Brodan et al. 1969; Copes and Rosentszweig 1972; Horne 1978; Martin 1981). The mechanism for this possible performance decrement remains unknown. One effect of acute sleep loss on subsequent exercise is an increase in ratings of perceived exertion (Martin 1981). It is tempting to suggest that this psychological effect of sleep loss decreases long-term exercise performance. However, it may be that increased perceived exertion during exercise after sleep deprivation arises from expectations that this should occur. To investigate this possibility, we performed experiments in which subjects controlled work intensity, and varied it to match perceptual responses in the normal and sleep deprived situations. Choice of lighter work by sleep deprived subjects would confirm that sleep loss indeed alters the perceptual response to exercise.

Methods

Twenty-four students (13 female, 11 male), between age 21 and 28 and all in excellent health, gave their informed consent to procedures that had been previously approved by a committee for protection of human subjects.

Experimental Design. Subjects were studied on three occasions: once for familiarization with experimental procedures, once after normal sleep, and once after 30 h without sleep. The sleep deprived and normal sleep (control) experiments were performed in random order and were separated by at least 4 days from one another. All experiments were performed between 10:30 and 13:00 h, and each subject was studied at the same time of day in both experiments.

Sleep Deprivation Protocol. The 30-h sleepless period included one night and the next morning before mid-day study. Subjects were asked to pursue minimal physical activity while remaining awake. Subjects remained awake in groups, which provided documentation of a continuously sleepless state. Subjects matched the time and amounts of food and caffeine intake in the control and sleep loss experiments. They resumed normal morning activities before mid-day study. Although we are confident that these guidelines were followed, and that all of the subjects achieved a continuously sleepless state prior to study, it must be noted that this protocol is not ideal. Interpretive problems with the present data could arise from at least three sources: (a) subjects may have slept more than usual during the night prior to the 30-h sleepless period; (b) they may have been inappropriately stimulated by the novelty of the sleep deprived condition (Horne 1978) and (c) our reliance on volunteer subjects may have led to study of persons relatively resistant to the effects of sleep loss.

Psychological Measurements. Each subject completed questionnaires profiling sleepiness (Stanford Sleepiness Scale; Hoddes et al. 1975), and mood (Profile of Mood States; McNair et al. 1971) (POMS), and Multiple Affect Adjective Check List (Zuckerman and Lubin 1965). The tests required about 10 min for completion. They were taken in a quiet room immediately before exercise, and again 10 min after the completion of exercise. The RIGHT NOW instructional set was used with the POMS both before and after exercise. Twenty-four subjects were studied to provide a reasonable opportunity to identify a possible correlation between sleepiness or mood, and work load selection.

Exercise Protocol. After completion of the initial psychological test, subjects walked on a motorized treadmill at a constant rate ($5.6 \text{ km} \cdot \text{h}^{-1}$), initially at a 7% grade. They then asked the experimentor to raise or lower the treadmill grade in amounts sufficient to cause them to rate their perceived exertion at 4 on a 1 to 5 scale. This scale represented a numerical simplification of the Borg scale (Borg 1974), with 1 (described as "very light work") corresponding to 6, and 5 ("maximal work") corresponding to 20, on the 6–20 Borg scale. The intermediate numbers 2, 3, and 4 were respectively described as "light", "moderately hard", and "very hard" work. This numerical scale, along with its verbal anchors, was displayed in front of the walking subject. Subjects were asked each minute if they required any changes of elevation to provide the appropriate perceived exertion. For most subjects, grades were raised several times in the first 2–4 min of work, with later adjustments, both up and down, relatively minor. It was presumed that both experimentors and subjects could bias the results if given immediate knowledge of chosen grade. To prevent this, subjects were never told the grades they had selected until completion of all experiments. In addition, the person adjusting the grade was unaware of actual elevation. This person also used value-free language while in dialogue with the subject.

After 8 min of exercise, treadmill inclination was held constant while minute ventilation ($\dot{V}_E$), oxygen uptake ($\dot{V}O_2$), and CO_2 production ($\dot{V}CO_2$) were measured by standard open-circuit techniques. Expired gas was channeled into a 5-l mixing chamber, from which mixed expired O_2 (Applied Technical Prod. Fuel Cell) and CO_2 (Beckman LB-2) fractions were measured. Both analyzers were regularly calibrated with a gas mixture established as standard by micro-Scholander analysis. A gas meter (Parkinson-Cowan CD-4) was used for $\dot{V}_E$ measurement. A Tissot spirometer was used to calibrate the gas meter. Heart rate was obtained from the ECG. After measurement of $\dot{V}_E$, $\dot{V}O_2$, $\dot{V}CO_2$, and heart rate for 1 min in the 10th min of exercise, the subject ceased work and rested for 10 min, before completing the psychological questionnaires a second time.

Statistical Analysis. Changes induced by sleep loss in physiological variables, and in the percentage inclination chosen, were analyzed by use of a Student *t*-test. The relationship of various aspects of mood, and of sleepiness, to work load selection, was analyzed by nonparametric rank correlation (Gibra 1973). Analysis for changes in psychological responses was performed by use of a Sign test (Gibra 1973). In all tests, $p < 0.05$ was regarded as significant.

Results

Sleep loss failed to change the mean treadmill inclinations chosen by the subjects at equal perceived effort (Table 1). There was no apparent influence of subject sex, or of experimental order, on this result. Of the 11 males in the study, six chose a greater external work rate after sleep loss. Similarly, of the 12 subjects who were studied first after sleep loss, six chose greater treadmill inclinations after sleep deprivation.

This lack of change in the work load required to elicit equivalent perceptual responses occurred in the face of alterations in mood after sleep loss. Before exercise began, subjects evidenced significantly greater fatigue, and lower vigor, scores on the Profile of Mood States (POMS: Table 1). In addition, subjects were more sleepy, and had greater POMS assessed tension and confusion, after sleep loss (Table 2). Sleep deprivation failed to change POMS assessed depression and anger (Table 2). The POMS also provides a total mood disturbance score which is obtained by adding the scores in the six mood categories, with vigor weighted negatively. This score was significantly elevated by sleep loss (Table 2). Changes in mood measured by the Multiple Affect Adjective Check List largely paralleled those measured by the POMS: sleep loss increased anxiety, depression, and hostility (all $p < 0.05$).

Ten minutes of "very hard" work had no effect on any aspect of mood in the control or sleep deprived experiments. The exercise slightly reduced sleepiness

Table 1. Effect of sleep deprivation on mean pre-exercise mood and work load selection ($n = 24$)

	Pre-exercise fatigue[a]	Pre-exercise vigor[a]	Treadmill grade chosen (%)
Control	38	57	17.5
Sleep-deprived	55	41	17.1
	$p < 0.01$	< 0.01	n.s.

[a] As assessed by Profile of Mood States (T score shown)

Table 2. Effect of sleep deprivation on pre-exercise sleepiness and various aspects of mood (means displayed; $n = 24$)

	Sleepiness[a]	Tension[b]	Depression[b]	Anger[b]	Confusion[b]	Total mood disturbance[c]
Control	2.0	38	40	41	37	−1
Sleep-deprived	3.4	42	41	41	46	19
p	< 0.01	< 0.05	n.s.	n.s.	< 0.01	< 0.01

[a] As assessed by the Stanford Sleepiness Scale (raw score shown)
[b] As assessed by the Profile of Mood States (T score shown)
[c] As assessed by the Profile of Mood States (raw score shown)

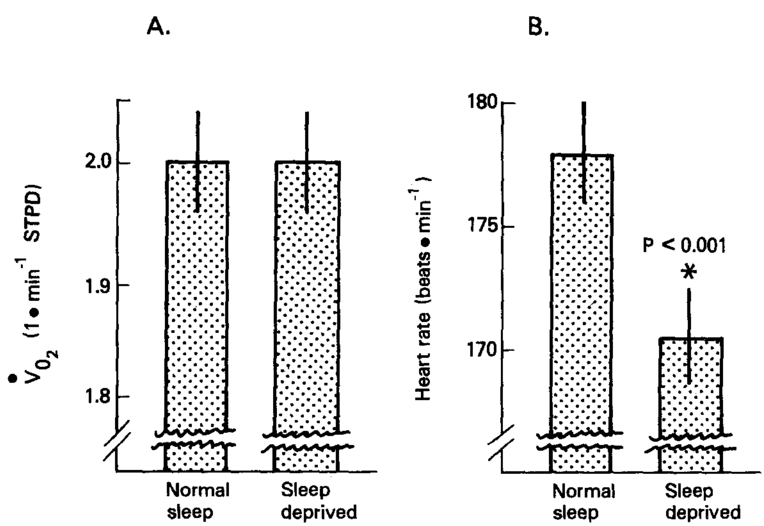

Fig. 1. Exercise after sleep loss, at equal self-selected external work load, resulted in **A** equal oxygen uptake and **B** reduced heart rate. $n = 24$

Table 3. Correlations of changes (from control to sleep loss conditions) in sleepiness and various aspects of mood with changes in work loads selected ($n = 24$)

Independent variable	Correlation coefficient	Non-parametric rank correlation with changes in selected treadmill grade
Change in sleepiness[a]	−0.30	n.s.
Change in pre-exercise fatigue[b]	−0.29	n.s.
Change in pre-exercise vigor[b]	+0.24	n.s.
Change in pre-exercise total mood disturbance[b]	+0.01	n.s.

[a] As assessed by Standford Sleepiness Scale
[b] As assessed by Profile of Mood States

in the sleep deprived condition (from 3.4 to 2.9 on the 1−5 Stanford Sleepiness Scale; $p < 0.05$), though the post-exercise value was still significantly greater than at an equivalent point in the control experiments (2.9 vs. 1.8; $p < 0.01$).

At the chosen external work loads in the control and sleep deprived conditions, $\dot{V}_E$, $\dot{V}O_2$, and $\dot{V}CO_2$ after 10 min of exercise were identical. $\dot{V}_E$ averaged $57 \pm 4\,l \cdot min^{-1}$ BTPS during exercise after normal sleep, and $56 \pm 3\,l \cdot min^{-1}$ after sleep loss (p = n.s.). Mean values of $\dot{V}O_2$ are shown in Fig. 1A; $\dot{V}CO_2$ provided similar results. In contrast, exercise heart rate was reduced in 20 of the 24 subjects during exercise after sleep loss ($p < 0.001$; Fig. 1B).

Individual changes in sleepiness or mood could not predict individual changes in work load selected to provide equal perceived effort after sleep loss (Table 3).

Discussion

In this study sleep loss had no effect upon work loads chosen to provide equal perceived exertion. After sleep loss, the chosen work level resulted in equal metabolic rate, but significantly lower heart rate. These findings hold for a single 10 min exercise period; repeated or prolonged exercise tests might have provided different results.

Several studies have examined variables that influence self-selection of exercise intensity (Evans 1963; Gerber and House 1969; Gerber et al. 1972; Holmgren and Harker 1967; Hughes and Goldman 1970). One of these investigations examined the relationship between sleep loss and exercise self-selection, and found that exercise sessions repeated at intervals over a 31-h sleepless period occurred at equal intensity, but with increasing perceived exertion (Soule and Goldman 1973). However, since studies such as this, a well as others (Opstad et al. 1978), combined sleep loss with prior exercise, the factors responsible for altered perceived exertion remained undefined. The present experiments were thus designed to specifically focus upon the effects of sleep loss.

The physiological inputs that underlie perceived exertion are complex. Included among these cues are those from working muscle, and those arising from the metabolic, cardiovascular, respiratory, thermoregulatory, and endocrine responses to exercise (Edwards et al. 1972; Patton et al. 1977). The relative importance of these factors, as well as their sum, may be modified by changes in exercise mode or protocol, by pharmacological intervention, or by alterations in environmental conditions (Ekblom and Goldbarg 1971; Horstman et al. 1979; Lollgen et al. 1977). Another possible input is sleep loss, which may raise perceived exertion during matched exercise (Martin 1981). This result predicted that work loads chosen to provide equal effort would be lower after sleep loss, not equal as was found in this study. Explanations for this discrepancy likely lie in the means by which perceived exertion is rated. In the previous study, subjects numerically expressed their own perceived exertion. They thus had knowledge of a previous rating to go with knowledge of their sleep status. This could have led to biased estimates of sensed effort based on subjective expectations. Conversation with the subjects prior to both studies provided clues that most expected to feel worse during exercise after sleep loss. However, in this study, subjects had no knowledge of previously chosen work rate.

Selection of equal external work for equal effort occurred in the face of a mood disturbance toward increased anxiety, depression, confusion, and fatigue, and decreased vigor, after sleep loss. These mood changes parallel those found in previous studies of sleep loss (Hord et al. 1975; Koller et al. 1966; Peeke et al. 1980). Our failure to find an association between these mood changes and work load selection contrasts with work showing that depressed or anxious patients overrate exercise intensity (Morgan 1973). However, this contrast of studies may be inappropriate, comparing as it does results obtained from normal persons with those gathered from hospitalized patients. It also may be that a more profound mood disturbance, engendered by lengthened sleeplessness, would have disrupted perception of effort in exercise. In addition, at least two other possible explanations for the present findings may be advanced. First, it may be that even grossly altered mood or sleepiness has a minor influence on ratings of perceived exertion when contrasted with the various physiological inputs. Second, it must be remembered that our measures of mood and sleepiness occurred before and after, not during, exercise, and that the physical movement itself may have mitigated these psychological effects and thus abolished their potential influence on perceived exertion.

In this study sleep loss reduced exercise heart rate at equal external work loads and at equal oxygen uptake. Some earlier work has found similar mild bradycardia after sleep loss, both at rest (Pickett and Morris 1975), and in exercise (Holland 1968), though this is by no means a universal finding (Koller et al. 1966). The mechanism and physiological significance of this heart rate reduction is unknown.

In summary, individual changes in mood or sleepiness induced by sleep loss could not be linked to individual changes in perceived exertion. In fact, the mean change in work level selected to provide equal effort after an acute 30-h sleepless period was zero. This result indicates that psychological changes in exercise induced by sleep loss may have been previously overestimated.

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