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EFFECT OF DAYTIME EXERCISE ON SLEEP EEG AND SUBJECTIVE SLEEP

Y. Sasazawa, T. Kawada and Y. Kiryu

Department of Public Health, Gunma University School of Medicine, Showa 3, Maebashi 371, Japan

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This study was designed to assess the effects of daytime physical exercise on the quality of objective and subjective sleep by examining all-night sleep EEGs. The subjects were five male students, aged 19 to 20 years, who were in the habit of performing regular daytime exercise. The sleep polygraphic parameters in this study were sleep stage time as a percentage of total sleep time (%S1, %S2, %S(3 + 4), %SREM, %MT), time in bed (TIB), sleep time (ST), total sleep time (TST), sleep onset latency (SOL), waking from sleep, sleep efficiency, number of awakenings, number of stage shifts, number of spindles, and percentages of α and δ waves, all of which were determined by an automatic computer analysis system. The OSA questionnaire was used to investigate subjective sleep. The five scales of the OSA used were sleepiness, sleep maintenance, worry, integrated sleep feeling, and sleep initiation. Each sleep parameter was compared in the exercise and the non-exercise groups. Two-way analysis of variance was applied using subject factor and exercise factor. The main effect of the subject was significant in all parameters and the main effect of exercise in %S(3 + 4), SOL and sleep efficiency, among the objective sleep parameters. The main effects of the subject, except sleepiness, were significant, as was the main effect of exercise on sleep initiation, among the subjective sleep parameters. These findings suggest that daytime exercise shortened sleep latency and prolonged slow-wave sleep, and that the subjects fell asleep more easily on exercise days. There were also significant individual differences in both the objective and subjective sleep parameters.

1. INTRODUCTION

Many studies on the relation between exercise and sleep have been conducted in several laboratories in the last 20 years. Some are of the opinion that regular daytime exercise has positive effects on nocturnal sleep [1–3]. Slow-wave sleep (SWS) has been reported to increase and have the function of promoting recovery from the fatigue that occurs as a result of daytime activity [4, 5]. In contrast, others have concluded that SWS after exercise does not change, or even decreases. According to Horne [6], these discrepancies are caused by differences in the reliability of sleep EEG evaluation among researchers by differences in exercise conditions. A highly skilled person is needed to evaluate sleep EEGs, since considerable differences in judgement are often found even among researchers in the same laboratory. In regard to exercise conditions, there have been differences in the kind of exercise performed and the exercise load imposed, e.g., in duration and intensity, as well as in subject fitness.

A microcomputer sleep analysis system [7] was used to evaluate the sleep EEG in the present study, as visual analysis results in major differences. This method yielded reliable evaluations and provided rapid analyses.

Most previous studies have used aerobic exercise as a basis for determining $\dot{V}O_2$ max, even though some subjects were not used to such exercise. The present study, on the other

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hand, gives priority to the subjects' customary form of exercise in the expectation that the subjects would experience less stress than if they were exposed to an exercise load to which they were unaccustomed.

Oguri *et al*. [8] suggested that consideration should also be given to subjective sleep in addition to the EEG in evaluating the quality of sleep. Sleep is not only a physiological phenomenon but a mental and social one as well. Horne [6] suggested the necessity of measuring subjective sleep parameters to properly evaluate objective sleep parameters, and the OSA questionnaire developed by Oguri *et al*. used to investigate subjective sleep was used in this study.

Few studies have included assessments of both subjective and objective sleep. This study was designed to assess the effects of daytime physical exercise on the quality of objective and subjective sleep in subjects who are in the habit of exercising in a karate club.

2. METHODS

The subjects were five healthy male college students (A, B, C, D, and E) aged 19 to 20 years who had normal sleep–wake cycles and were in the habit of performing regular daytime exercise. They engaged in karate exercise four days a week in a university sports club. Four subjects were assessed in 1992 and one in 1993. The experiment was carried out from May to July and September to December to avoid winter and summer, since previous studies [9–11] have suggested that temperature influences sleep parameters. Each subject slept in an experimental room in our laboratory for 12 non-consecutive nights. Data obtained the first night was not used for analysis [12]. Whenever there was mechanical trouble, the data were discarded, but all of the data targeted were obtained on eight to ten nights in every subject. All subjects were told to live their life as usual during the experimental period. Drinking alcohol and taking medicine were prohibited.

All subjects engaged in karate exercise for three hours, from 17:00 to 20:00, on exercise days. The exercise included warming-up, basic form practice, game, strength exercises, and so on. The exercise load was assessed by the heart rate reserve method using Heart Rate Memory (VINE Corporation) and on the basis of heart rate during exercise and rest; thus % heart rate reserve = (heart rate during exercise − heart rate rest)/(heart rate maximum − heart rate rest) × 100. Maximum heart rate was estimated as $210 - 0{\cdot}8 \times \text{age}$.

Subjects came to the sleep laboratory at 22:00 to have the electrode attached, and their sleep EEGs were recorded according to the standard method of Rechtschaffen and Kales

TABLE 1

The five subjects' age, resting HR, *and mean, minimum, and maximum* %HR *reserve during exercise*

Subject	Age (years)	HR rest (beats/min.)	%HR-reserve during exercise		
			Mean	Max.	Min.
A	19	60	56·5	71·5	20·5
B	19	62	50·7	76·6	21·7
C	19	66	55·8	77·0	23·1
D	20	70	56·4	78·5	22·3
E	19	68	62·1	82·4	24·9
Mean	19·2	64·8	56·3	77·2	22·5
S.D.	0·40	4·12	3·61	3·51	1·47

TABLE 2

Comparison of average sleep stage composition (%) *and standard deviation in the five subjects on nights after exercise days* (+) *and non-exercise days* (−); SWS: *slow-wave sleep* (Stage 3 + Stage 4); SREM: *stage of rapid eye movement*; MT: *movement time*; *figures in parentheses are standard deviations*; S *and* E *are the main effects of subject and exercise*, *respectively*, *and* I *is interaction*, *by two-way analysis of variance*; ∗∗ · · · ·, $p < 0{\cdot}01$, ∗ · · · ·, $p < 0{\cdot}05$

Subject	Exercise	Sample (N)	%Stage 1	%Stage 2	%SWS	%SREM	%MT
A	+	4	1·2(0·62)	64·1(2·85)	12·9(1·82)	17·4(2·99)	4·3(0·69)
	−	4	1·3(0·66)	63·7(3·79)	12·9(0·75)	16·7(1·89)	5·3(1·80)
B	+	7	3·6(1·34)	71·0(4·03)	4·0(0·66)	16·8(3·32)	4·4(1·45)
	−	3	2·6(0·61)	71·2(1·70)	3·6(0·71)	17·8(2·29)	3·8(1·36)
C	+	4	4·3(0·47)	69·0(1·86)	9·9(0·58)	15·1(2·12)	1·6(0·29)
	−	6	4·5(1·87)	70·7(4·50)	7·2(2·54)	15·8(4·37)	1·8(0·25)
D	+	4	3·7(1·68)	65·6(4·21)	6·0(1·22)	22·7(2·71)	2·0(0·72)
	−	6	5·7(3·51)	56·7(2·11)	3·6(0·90)	31·1(3·45)	2·8(0·54)
E	+	5	4·5(2·10)	68·3(3·40)	3·1(1·20)	19·1(3·16)	4·9(1·65)
	−	4	4·0(1·21)	69·5(7·67)	1·8(1·66)	20·6(4·56)	3·9(1·94)
Total	+	24	3·5(1·69)	68·1(4·08)	6·6(3·86)	18·0(3·67)	3·6(1·71)
	−	23	3·9(2·52)	65·7(7·19)	5·8(4·08)	21·0(7·13)	3·3(1·66)
			S∗ ∗	S∗∗I∗	S∗∗E∗∗	S∗∗E∗I∗	S∗∗

[13]. The subjects went to bed at 23:00 and were awakened at 07:00 by an alarm clock. All subjects were exposed to recorded passing truck noise with a duration of 20 s at four peak levels of 45, 50, 55 and 60 dB(A) at 15 min intervals throughout the night. The background sound level in the experimental room was L_{eq} 30 dB(A).

An EEG with leads positioned at C_3-A_2, an electromyogram (EMG) with leads on the lower jaw, and left and right electrooculograms (EOGs) were recorded using a telemetry system (Nihon Kohden Company, Japan). The sleep polygraphic parameters in this study were sleep stage times as a percentage of total sleep time (%S1, %S2, %S(3 + 4), %SREM,

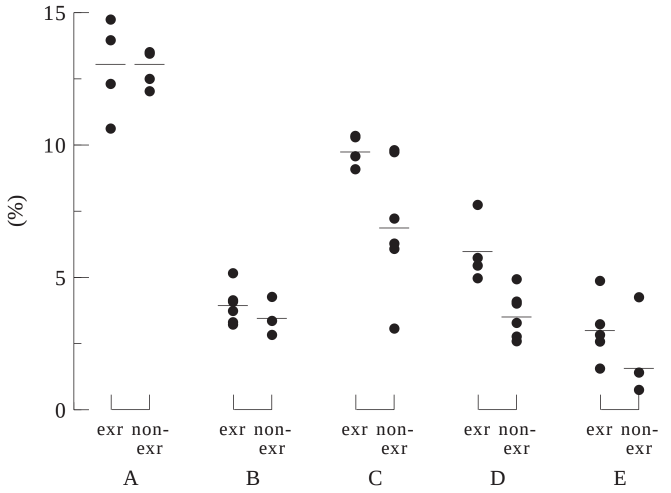

Figure 1. Comparison of mean % stage of slow-wave sleep on nights after exercise days (+) and non-exercise days (−) in five subjects, A, B, C, D and E.

Table 3

Comparison of average sleep parameters except sleep stages on nights after exercise days (+) and non-exercise days (−). Figures in the parentheses are standard deviations; S *and* E *are main effects of subject and exercise, respectively, and I is interaction by two-way analysis of variance;* ** · · · · , $p < 0{\cdot}01$, * · · · · , $p < 0{\cdot}05$

Subject	Exercise	No. of nights studied (N)	Time in bed (min)	Sleep time (min)	Total sleep time (min)	Sleep onset latency (min)	Waking from sleep (min)
A	+	4	462·0(43·44)	450·8(44·03)	450·8(44·03)	11·2(3·05)	0·0(0·00)
	−	4	500·0(2·94)	476·0(5·56)	475·9(5·51)	23·9(6·71)	0·1(0·17)
B	+	7	488·6(10·34)	451·9(30·08)	450·4(29·45)	38·2(26·8)	1·5(2·15)
	−	3	485·3(26·31)	455·2(33·40)	449·3(32·54)	36·0(8·29)	5·9(4·62)
C	+	4	486·8(5·91)	474·8(7·77)	474·6(8·08)	12·0(2·54)	0·3(0·32)
	−	6	486·3(18·11)	453·1(31·80)	452·4(31·83)	33·8(23·57)	0·6(0·25)
D	+	4	495·0(4·40)	481·7(2·92)	481·7(2·92)	13·3(1·70)	0·0(0·00)
	−	6	495·5(8·41)	468·9(18·40)	468·6(18·38)	26·9(14·81)	0·3(0·33)
E	+	5	475·4(6·02)	447·7(28·01)	446·7(27·73)	28·7(24·72)	1·0(1·60)
	−	4	445·3(38·01)	363·2(90·90)	362·1(90·22)	83·3(63·33)	1·0(1·78)
Total	+	24	482·2(20·32)	459·6(28·66)	458·9(28·65)	23·2(20·86)	0·7(1·45)
	−	23	483·8(26·63)	445·8(55·84)	444·6(55·75)	39·2(34·39)	1·2(2·45)
			S*I*	S**I*	S**I*	S*E**	S**E*I*

Subject	Exercise	Sleep efficiency (%)	No. of awakenings (/night)	No. of stage shifts (/h)	No. of spindles (/h)	α wave (%)	δ wave (%)
A	+	97·6(0·73)	0·0(0·00)	27·8(1·48)	413·0(44·68)	37·1(0·88)	7·0(0·50)
	−	95·2(1·29)	0·3(0·50)	30·6(2·04)	436·8(46·81)	37·3(1·35)	7·6(0·38)
B	+	91·8(5·44)	3·3(3·15)	27·0(2·81)	261·0(42·91)	25·6(1·01)	3·9(0·29)
	−	91·3(2·51)	14·0(11·14)	30·3(4·10)	264·7(14·50)	26·5(1·27)	3·7(0·32)
C	+	97·5(0·61)	0·8(0·96)	27·8(1·18)	167·5(15·11)	26·4(0·45)	5·6(0·19)
	−	92·9(4·80)	1·8(0·75)	24·6(1·67)	185·5(8·92)	27·4(0·74)	4·3(0·91)
D	+	97·3(0·34)	0·0(0·00)	21·1(1·68)	208·0(28·93)	22·8(0·92)	4·0(0·21)
	−	94·5(3·02)	0·8(0·98)	19·4(2·57)	179·5(26·67)	22·0(1·17)	2·9(0·33)
E	+	93·8(5·21)	2·2(3·90)	25·7(5·05)	272·8(34·59)	30·6(0·58)	3·3(0·46)
	−	80·4(16·31)	2·5(4·36)	20·2(5·28)	226·5(38·83)	28·7(1·39)	2·7(0·63)
Total	+	95·0(4·37)	1·5(2·70)	26·0(3·60)	264·4(84·46)	28·2(4·82)	4·6(1·34)
	−	91·3(8·50)	3·0(5·82)	24·3(5·46)	245·1(98·18)	27·8(5·20)	4·1(1·81)
		S**E**	S**E*I*	S**I*	S**	S**I*	S**E**I**

%MT), time in bed (TIB), sleep time (ST), total sleep time (TST), sleep onset latency (SOL), waking from sleep, sleep efficiency, number of awakenings, number of stage shifts, number of spindles, and percentages of α and δ waves. These were determined by our automatic computer analysis system using the method described by Aoki *et al.* [7], although the EEG during sleep onset latency was corrected by visual analysis. The criterion for sleep onset was continuation of stage 1 or stage 2 for five minutes.

The OSA questionnaire, which is often used in Japan, was administered the next morning to investigate subjective sleep [8]. Scale scores of five factors—sleepiness, sleep maintenance, worry, integrated sleep feeling, and sleep initiation—were calculated from the replies to the OSA questionnaire. An increase in the score of each of these factors means improvement of sleep quality.

In addition, simple reaction time was measured by Terry 84 (WHO) [14] to assess the subject's arousal condition in the morning.

Each sleep parameter was compared in the exercise and the non-exercise groups. Two-way analysis of variance was applied using subject factor and exercise factor, and NAP statistical software [15].

3. RESULTS

The average percent heart rate reserve, calculated on the basis of heart rate during exercise, was 56.3%, with maximum and minimum percent heart rate reserve values of 77·2% and 22·5%, respectively (see Table 1).

Average sleep stage composition (%) and the standard deviations in the five subjects on the nights of exercise days and non-exercise days are shown in Table 2. A main effect of the subject by ANOVA was significant in %S1, %S2, %S(3 + 4), %SREM and %MT ($p < 0{\cdot}01$), and that of exercise in %S(3 + 4) and %SREM ($p < 0{\cdot}05$). The interactions were also significant in %S2 and %SREM ($p < 0{\cdot}05$). All subjects, except subject A, showed higher percentages of S(3 + 4) on nights of exercise days than on those of non-exercise days (see Figure 1).

The average values for the sleep parameters, except sleep stages, in the five subjects on the nights after exericse days and non-exercise days are shown in Table 3. A main effect of the subject by ANOVA was significant in TIB, ST, TST, SOL, waking from sleep, sleep efficiency, number of awakenings, number of stage shifts, number of spindles, percentage of α waves, and percentage of δ waves ($p < 0{\cdot}05$), and a main effect of exercise was significant in SOL, sleep efficiency, and percentage of δ waves ($p < 0{\cdot}01$), while interactions were significant in TIB, ST, TST, waking from sleep, number of awakenings, number of stage shifts, number of spindles, percentage of α waves, and percentage of δ waves ($p < 0{\cdot}05$). All subjects, except subject B, showed shorter SOL on nights of exercise days

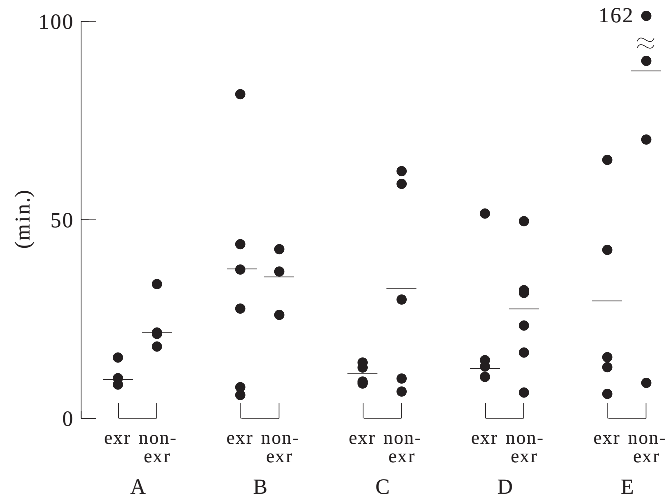

Figure 2. Comparison of sleep onset latency on nights after exercise days (+) and non-exercise days (−) in five subjects, A, B, C, D and E.

Table 4

Comparison of average sleep stage composition (min.) *and the standard deviation of the five subjects during the* 180 min *after the onset of sleep latency on nights of exercise days* (+) *and non-exercise days* (−); SWS: *stage of slow-wave sleep* (Stage 3 + Stage 4); REM: *stage of rapid eye movement*; MT: *movement time*; *all units are in minutes*, *figures in parentheses are standard deviations*; S *and* E *are the main effect of subject and exercise*, *respectively*, *by two-way analysis of variance*; ∗∗ · · · ·, $p < 0{\cdot}01$, ∗ · · · ·, $p < 0.05$

Subject	Exercise	Sample(N)	Stage 1	Stage 2	SWS	REM	MT
A	+	4	0·9(0·96)	107·8(4·79)	51·5(8·45)	12·1(5·43)	7·7(2·74)
	−	4	1·1(1·10)	117·8(5·48)	42·7(4·36)	5·3(4·14)	13·3(6·83)
B	+	7	4·1(2·31)	142·4(5·94)	13·5(2·98)	12·8(4·83)	6·9(2·04)
	−	3	4·4(1·39)	135·4(9·64)	11·0(5·24)	17·3(11·68)	7·9(3·42)
C	+	4	3·9(4·29)	122·3(11·32)	36·3(0·98)	14·2(7·80)	3·3(0·79)
	−	6	3·3(2·40)	123·5(14·73)	27·4(11·94)	22·5(10·40)	3·2(0·27)
D	+	4	4·9(5·50)	131·2(10·26)	27·2(5·94)	12·8(8·58)	3·9(1·77)
	−	6	10·6(12·26)	130·0(11·17)	16·8(5·11)	18·2(15·82)	4·9(1·50)
E	+	5	4·5(2·78)	141·0(9·73)	12·9(5·05)	14·4(7·87)	7·2(4·37)
	−	4	5·3(2·17)	135·7(4·11)	5·6(4·75)	27·6(8·16)	5·1(1·45)
Total	+	24	3·8(3·32)	131·1(15·08)	25·8(15·42)	13·2(6·26)	6·0(3·00)
	−	23	5·3(6·96)	127·7(11·67)	21·4(14·31)	18·6(12·51)	6·3(4·56)
				S∗∗	S∗∗E∗∗		S∗∗

than on those of non-exercise days (see Figure 2). All subjects had shorter sleep efficiency during nights of exercise days than on those of non-exercise days.

Average sleep stage composition (minutes) and the standard deviations of the five subjects during the three hours after sleep onset on nights after exercise days and

Table 5

Comparison of subjective sleep quality based on the OSA *questionnaire on nights of exercise days* (+) *and non-exercise days* (−); *figures are standardized scores*, *with the mean value set equal to* 50; *the higher each score*, *the higher the quality of subjective sleep*; *figures in the parentheses are standard deviations*; S *and* E *are the main effect of subject and exercise*, *respectively*, *by two-way analysis of variance*; ∗∗ · · · ·, $p < 0{\cdot}01$, ∗ · · · ·, $p < 0.05$

Subject	Exercise	Sample	Sleepiness	Sleep maintenance	Worry	Integrated sleep rating	Sleep initiation
A	+	4	43·2(5·18)	46·3(3·14)	43·5(6·04)	46·9(10·06)	53·8(2·84)
	−	4	41·3(3·01)	44·6(1·34)	41·5(3·59)	49·7(6·87)	48·1(5·14)
B	+	7	48·5(4·94)	40·3(3·47)	50·9(3·54)	43·1(4·24)	43·3(3·81)
	−	3	51·6(2·93)	39·4(5·13)	54·2(0·00)	47·1(6·02)	43·1(2·67)
C	+	4	49·1(4·46)	44·3(2·02)	53·2(3·60)	52·2(1·94)	46·4(1·56)
	−	6	43·7(1·48)	41·2(3·03)	48·3(3·19)	44·3(2·37)	42·5(4·70)
D	+	4	44·9(11·78)	41·1(6·86)	51·8(2·82)	47·8(7·66)	47·6(10·78)
	−	6	42·8(8·67)	37·2(6·74)	50·8(2·85)	43·5(7·70)	35·4(7·25)
E	+	5	43·2(11·37)	39·6(3·97)	46·0(7·67)	40·0(5·87)	47·6(6·86)
	−	4	42·7(4·26)	36·7(3·04)	43·0(4·01)	36·0(9·13)	38·2(6·00)
Total	+	24	46·1(7·73)	42·0(4·51)	49·2(5·81)	45·4(7·04)	47·2(6·39)
	−	23	43·9(5·65)	39·8(4·96)	47·6(5·26)	44·0(7·40)	40·9(6·81)
				S∗∗	S∗∗	S∗	S∗∗E∗∗

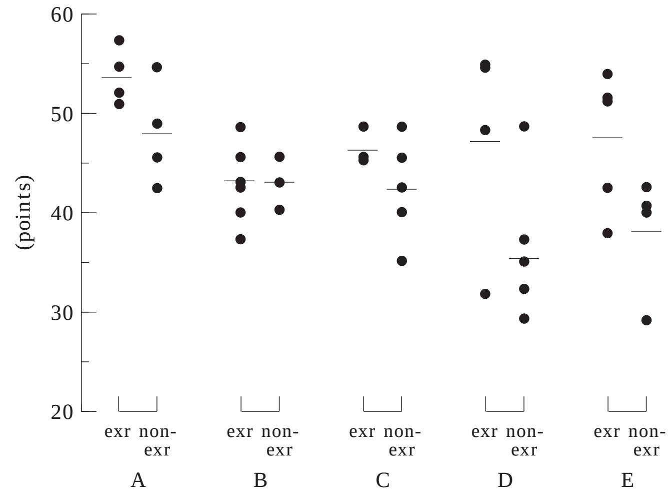

Figure 3. Ease in falling asleep in terms of scale score (standardized points) of the OSA self-rating sleep questionnaire in subjects A, B, C, D and E.

non-exercise days are shown in Table 4. A main effect of the subject by ANOVA was significant in S2, S(3 + 4) and MT ($p < 0{\cdot}01$), and a main effect of exercise was significant in S(3 + 4) ($p < 0{\cdot}01$), but the interaction was not significant. During the 180 min after sleep onset, all subjects showed higher SWS on nights of exercise days than on those of non-exercise days.

Table 5 shows the five scale scores of the OSA questionnaire, which was used to examine subjective sleep quality. A main effect of the subject by ANOVA was significant in sleep maintenance, worry, integrated sleep feeling, and sleep initiation ($p < 0{\cdot}05$), and a main effect of exercise was significant in sleep initiation ($p < 0{\cdot}01$), but the interaction was not

TABLE 6

Comparison of mean reaction time in seconds immediately after waking on nights after exercise days (+) and non-exercise days (−); figures in parentheses are standard deviations; S *and* E *are the main effect of subject and exercise, respectively, and* I *is interaction by two-way analysis of variance;* $**\cdots\cdot$, $p < 0.01$, $*\cdots\cdot$, $p < 0.05$

Subject	Condition	Sample (N)	Reaction time
A	+	4	0·265(0·013)
	−	4	0·245(0·015)
B	+	7	0·209(0·008)
	−	3	0·220(0·010)
C	+	4	0·245(0·004)
	−	6	0·252(0·022)
D	+	4	0·271(0·016)
	−	6	0·264(0·020)
E	+	5	0·359(0·026)
	−	4	0·325(0·018)
Total	+	24	0·266(0·056)
	−	23	0·262(0·036)
			S**I*

significant in any sleep ratings. All subjects showed earlier sleep onset on nights of exercise days than those of non-exercise days (see Figure 3).

Mean reaction time (in seconds) immediately after waking is shown in Table 6. A main effect of exercise by ANOVA was not significant, but a main effect of subject ($p < 0{\cdot}01$) and the interaction ($p < 0{\cdot}05$) were significant.

4. DISCUSSION

Some previous studies have reported that SWS increases significantly after exercise [9, 16–23], while others have concluded either that SWS does not change after exercise [24–32] or that it even decreases [33, 34]. Horne [6] suggested that heavy and long exercise alters sleep polygraphic parameters, but that light and short exercise does not.

Most previous studies have employed aerobic exercise, although Browman [35] used hand dynamometer anaerobic exercise to examine subjects, and has concluded that SWS increases after exercise. In this study, the subjects engaged in karate exercise, to which they were accustomed. This type of exercise stresses not only anaerobic exercise but aerobic exercise as well. Studies by Paxton *et al*. [29] and Tosvall *et al*. [36] involved exposure of subjects to their customary exercise (athletics, soccer, field hockey, squash, and rowing), and results have shown that SWS did not increase significantly after exercise. The present research, on the other hand, showed a significant increase in SWS, which was caused by exposure of the subjects to a heavy exercise load to which they were accustomed. Studies by Paxton and Tosvall did not describe the exercise load in detail. In the present study, the exercise load was a 56·3% heart rate reserve which is equivalent to 70% $\dot{V}O_2$max with a duration of three hours. This exercise load was considered heavier than that in most reported studies, even though the subjects were accustomed to the exercise.

Some other studies [9, 16, 18, 21, 22, 33, 35] have found increased SWS during the first half of sleep after exercise, and the results of this study showed the same, i.e., that SWS increased during the first 180 min (3 h) of sleep. According to Horne [37], from a biological standpoint, the first three sleep cycles of human sleep are the most important, the second half of sleep being less important. He defined the first three sleep cycles as "core sleep", and the second half of sleep as "optional sleep". The authors believe that daytime exercise has a greater effect on the first half of sleep.

Several studies have reported decreasing [9, 21, 35, 38, 39] or increasing [25, 32, 40] SOL after exercise. Matsumoto *et al*. [21] suggested that increasing SOL was caused by the stress effect of late exercise time extending almost until sleeping time, which leads to a stronger arousal tendency. Adamson [41] and Walker [26] indicated that morning or early afternoon physical exercise has a significant effect on sleep onset. In this study, the exercise time was between 17:00–20:00 i.e., three hours before sleep, and is thus considered late exercise time. Nevertheless, SOL decreased after exercise, and this was thought to be due to adaptation and the subjects' custom of engaging in exercise late in the day. According to results of the subjective sleep assessment [3], late time and heavy load exercise have the worst effect on subjective sleep. Previous studies [32, 42, 43] also found that the SOL of fit subjects is shorter than the SOL of unfit subjects. For example, Shapiro *et al*. [20] measured the EEG of male army recruits at the beginning, middle, and end of their 18-week basic training program and found that increasing fitness leads to a decrease in SOL. Meintjes *et al*. [44], on the other hand, concluded that there are no significant changes in any sleep parameters in female subjects. The present study shows that when fit subjects engaged in their usual exercise, the SOL decreased, and when they did not perform their usual exercise, their SOL increased.

The present study also reveals that sleep efficiency increased after exercise days as compared with non-exercise days, and that this is caused by the decreasing SOL after exercise. Exercise days were also followed by a low percent of waking from sleep in all subjects.

Three questions about sleep onset were asked on the OSA questionnaire: "Do you think that getting to sleep last night was easier than usual?" "Were the temperature and humidity last night more comfortable than usual?" "Did you experience less "shallow sleep" than on a usual night?" These three questions are targeted at assessing sleep onset latency. The results of this study show that sleep onset latency on exercise days tended to be shorter than on non-exercise days, and that subjective sleep onset on exercise days was better than on non-exercise days. Understanding subjective feelings about sleep onset is important for evaluating integrated sleep. Similar findings have also been reported by other investigators [3, 45, 46]. Vuori *et al.*[3] investigated the effects of exercise on sleep in an epidemiological survey of 1600 middle-aged subjects. On the basis of the questionnaire they devised, they found that exercise was the main factor (about 30%) in promoting sleep and improving sleep quality, whereas the instantaneous effect of early evening exercise (16:00–20:00) contributed to the feeling of greater ease in falling asleep, deeper sleep, and feeling better or more alert in the morning. The present study led to the same conclusion as reached by Vuori *et al.* concerning subjective sleep onset, but different conclusions regarding deeper subjective sleep or feeling better or more alert the next morning. Reaction time in a performance test after sleep was measured and no difference was found between exercise days and non-exercise days. Nor was any difference between arousal tendency on exercise days and non-exercise days found.

When the sleep parameters of individual subjects on exercise day were examined, one found that subjects C and D had shorter SOL, fewer awakenings from sleep, and increased SWS; subject A had shorter SOL, fewer awakenings from sleep, and no change in SWS; subject B had a larger SOL, greatly decreased awakenings from sleep, and increased SWS; subject E had greatly increased SOL, unchanged awakenings from sleep, and increased SWS. These patterns revealed that SWS was unchanged after exercise only in subject A, and this was thought to be attributable to the fact that SWS was highest in subject A, even on non-exercise days. One also noted that there were significant individual differences in both objective and subjective sleep parameters. Iguchi *et al.* [23] reported a similar conclusion: that there are two patterns of SWS responses to daytime activities depending on the individual. The subjects in their reports were college students who engaged in physical and mental activities, and their SWS sleep parameters were counted by using EEG power. SWS changes in some subjects were more sensitive to physical activities while other changes were more sensitive to mental activities.

In this study, subjects were measured for three to seven nights of exercise and non-exercise days to examine objective and subjective sleep parameters separately. This is the first study of its kind. Such studies are important to evaluating the effects of experimental rooms and habituation. According to Lester *et al.* [47], the effects of the experimental room were reflected in sleep stage 4, while habituation commonly occurred after three or four days, and in some cases, after seven or eight days. Kimura *et al.* [48] examined daily and individual variations in sleep parameters and concluded that daily variations are smaller than individual variations, and that habituation occurred after the fifth day. They suggested that a follow up of each subject is important if the subject group is small.

In this study, the laboratory situation was made to resemble real life in an urban area in that all of the subjects were exposed to intermittent transportation noise in the form of a passing truck. Based on the author's measurements of traffic volume in a residential area of M city, a representative mid-sized city in Japan, an average of 4·4 trucks pass per hour from 23:00–07:00. It was also found that, if the residence faces a road, the indoor peak sound level when a truck passes is around 60 dB(A).

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