PART 1. ENVIRONMENTAL FACTORS AND STATES OF SLEEP

Abstract

Five healthy male subjects, selected from the Japanese wintering group, were studied to obtain the information about not only the long-term changes in sleep patterns but also the relationship between sleep patterns and prominent environmental factors, presumably affecting sleep patterns.

Sleep polygraphic recordings were performed together with other measurements such as time activity study of daily life, body weight, flicker test, CMI test etc. The six measurements were carried out at Syowa Station, Antarctica and a comparative measurement was done at Tokyo before departure for Antarctica and after return to Tokyo.

No significant difference in total sleep time, sleep onset latency and REM onset latency was found during the periods of experiments. The proportion of SWS tended to decrease gradually in Antarctica, and to recover to the base-line data after the subjects returned to Japan. The changes in SWS showed a positive correlation with those of atmospheric temperature. On the other hand, REM sleep tended to decrease in mid-term and to increase in early- and late-term in Antarctica. The changes in REM sleep showed a positive correlation with those of the energy expenditure calculated from time activity study of daily life. On the contrary, the changes in average REM cycle length, average REM interval length and REM onset latency showed a negative correlation with those of the energy expenditure.

These results indicate that the two kinds of sleep, namely, SWS and REM sleep, adapted individually to the two different external factors.

1. Introduction

Life within the Antarctic region carries with it exposure to the extremely cold environment and marked changes of light-dark pattern during the course of the year, as compared with the temperate zone. In addition to these factors, there are the enforced heavy exercise during summer and the enforced society consisting of a small number of persons isolated from the home land. However there is very little quantitative information to what degree humans are affected.

While numerous complaints are heard among the people about the disturbance of sleep both in the Arctic (KLEITMAN and KLEITMAN, 1953) and in the Antarctic (HACHISUKA, 1972; LEWIS, 1960; TAYLOR, 1960) during the dark period (polar night), there are few literatures on the observations of the long-term changes in sleep patterns in such an extreme environment (NATANI *et al.*, 1970; PATERSON, 1975; WEITZMAN *et al.*, 1975).

The present work was designed to investigate not only seasonal changes in sleep patterns but also the relationship between sleep patterns and prominent environmental factors, presumably affecting sleep patterns at Syowa Station (69°00′S, 39°35′E), Antarctica in the 16th Japanese Antarctic Research Expedition 1974–1976 (JARE–16*).

* The members of JARE-16 left Tokyo on board icebreaker FUJI in November 1974, and arrived at Syowa Station in the beginning of January 1975. After a one-year stay they left Antarctica for Japan in February 1976.

2. Materials and Methods

The investigation were carried out 8 times. The first measurement was done in October at Tokyo in 1974 prior to departure from Japan. The second to seventh were performed (bimonthly, February to December) at Syowa Station in 1975, and the last study in July 1976 at Tokyo, 6 months after the returning to Japan (Table 1). The investigations are designated by the abbreviations TZ-1, AT-1, AT-2, AT-3, AT-4, AT-5, AT-6 and TZ-2 as shown Table 1.

Table 1. Data acquisition design.

Data period	Modal dates	Code designation	Location/Season
1	Oct. 1974	TZ–1	Tokyo, Japan/Autumn
2	Feb. 1975	AT–1	Syowa Station
3	Apr. 1975	AT–2	Syowa Station
4	June 1975	AT–3	Syowa Station/Polar night
5	Aug. 1975	AT–4	Syowa Station
6	Oct. 1975	AT–5	Syowa Station
7	Dec. 1975	AT–6	Syowa Station/Midnight sun
8	July 1976	TZ–2	Tokyo, Japan/Summer

TZ=Temperate zone, AT=Antarctica.

Meteorological conditions and the light-dark patterns during experiments are illustrated in Figs. 1 and 2, respectively.

2.1. Sleep laboratory and equipment for recording

Syowa Station is located on East Ongul Island, which is only 29 m above sea level and about 4 km apart from the Antarctic Continent. The sleep laboratory was made in a part of the building called "Kansoku-to", about 150 m apart from main buildings. The good electric conditions were kept. Another merit was to have no disturbance of the all-night sleep, because of hardly anybody being around during the night (Fig. 3).

The sleep laboratory was semi-sound proofed, and darkened by black curtains.

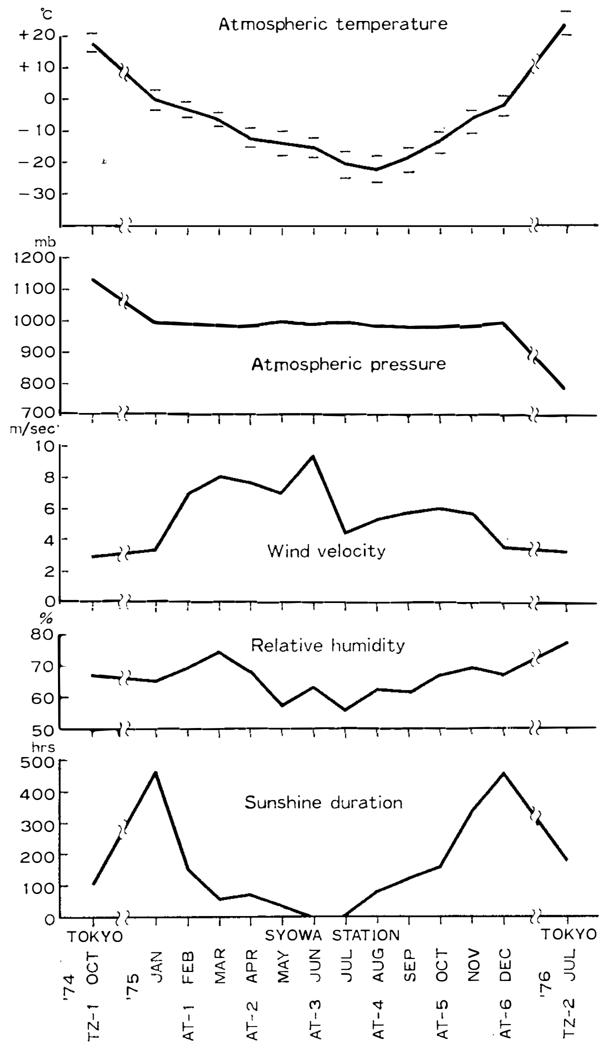


Fig. 1. Environmental conditions during experiments.

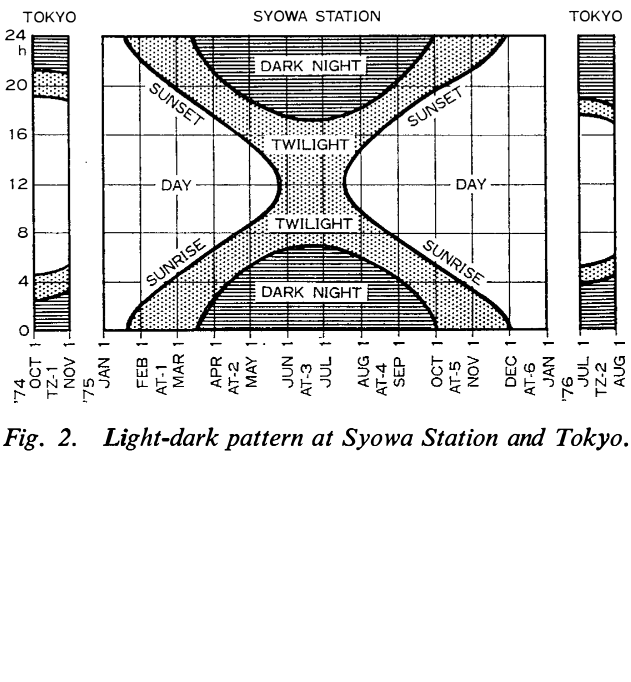


Fig. 2. Light-dark pattern at Syowa Station and Tokyo.

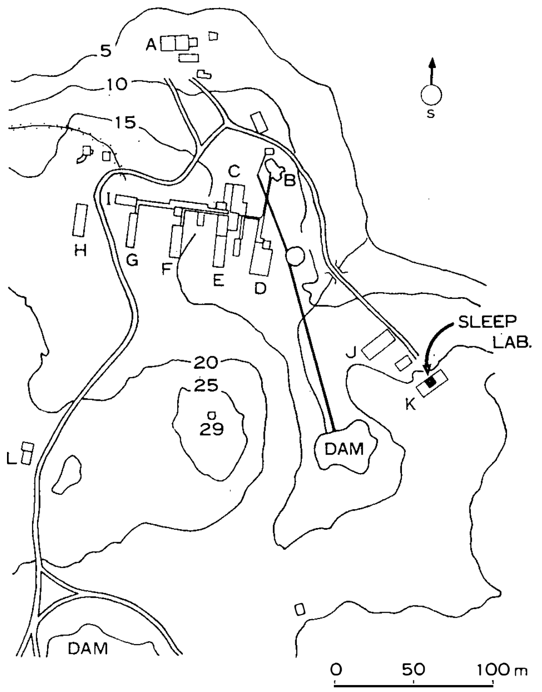


Fig. 3. Main facilities of Syowa Station. Alphabet letters represent the following: A; garage and metal workshop, B and D; generator hut, C; mess hall, E, F and G; sleeping quaters, H; meteorological station, I; telecommunication hut, J; environmental science laboratory, K; upper atmosphere physics laboratory (kansoku-to), L; ionosphere laboratory.

Room temperature was kept between 17° and 19°C at the height of 1.5 m above the floor.

A 45 kVA diesel-powered electric generator supplied electricity through the autovoltage regulator. This generator was used for scientific equipments only, so that constant AC 100 V potentials and frequency of 50 Hz (ranged from 49.85 to 50.00 Hz) were obtained. Elimination of electric noise was realized without any difficulties, by protecting the wall outlet current in the laboratory, and using ground earth and the 50 Hz artifact eliminator supplemented to EEG machine, so that it was not necessary to make an electric shielded room.

2.2. Subjects

Five healthy male subjects were selected from 30 Japanese wintering members. None of them had experience of the wintering in Antarctica. As summarized in Table 2, age of these subjects ranged from 24 to 31, with a mean value of 27.8, and their physical states were similar to each other. Each subject lived in Syowa Station according to the daily schedule as shown in Table 3. Naps were not allowed and alcohol, coffee and drugs were inhibited, but usual work was not limited in each of the experimental periods. The subjects slept wearing sleeping suit and blankets as usual.

Table 2. Physical and occupational characteristics of subjects.

No.	Subject	Age (years)	Height (cm)	Weight (kg)	Surface area (m^2)	Occupation
1	Y.E.	27	166	57.0	1.59	Cook
2	H.W.	24	160	59.0	1.57	Cook
3	Y.I.	27	166	64.5	1.68	Physician
4	Y.S.	31	158	54.0	1.50	Logistics
5	S.I.	30	161	57.5	1.56	Radio operator
Mean		27.8	162.2	58.4	1.58	

Table 3. Daily schedule during one year stay at Syowa Station in 1975.

	Weekday		Sunday	Mon. : —
	Summer	Winter		
Rising	07:00	08:00		Tues. : Bath
Breakfast	07:30–08:00	08:30–09:00	07:30–08:30	Wed. : Movie
Tea time	10:00	10:30	10:00	Thur. : —
Lunch	12:00–13:00	12:30–13:30	11:00–12:00	Fri. : —
Tea time	15:00	15:00	15:00	Sat. : Bath
Supper	18:00–19:00	18:00–19:00	18:00–19:00	Sun. : Movie

Number indicates local time in Syowa Station. Winter signifies May to July.

2.3. Recording technique

All-night sleep recordings were performed by using a Nihon Koden 9 channel multipurpose EEG machine (type 4109), with a paper speed of 1.5 cm per second. The sleep polygraphic pattern is shown in Table 4. Silver cup electrodes were used

Table 4. Data acquisition array.

Channel	Designation	Derivation	Time constant
1	EOG	L outer canthus (E_1)–L ear (A_1)	0.3
2	EOG	R outer canthus (E_2)–L ear (A_1)	0.3
3	EMG	Mental-submental	0.03
4	EEG	L central (C_3)–R ear (A_2)	0.3
5	EEG	R central (C_4)–L ear (A_1)	0.3
6	ECG	L ear (A_1)–R upper arm	0.1
7	PLG	Tip of R index finger	0.6
8	RG	Abdomen	D C
9	SPR	R palm–R forearm	0.3

EOG: electrooculogram, EMG: electromyogram, EEG: electroencephalogram, ECG: heart rate, PLG: plethysmogram, RG: respirogram and SPR: skin potential reflex.

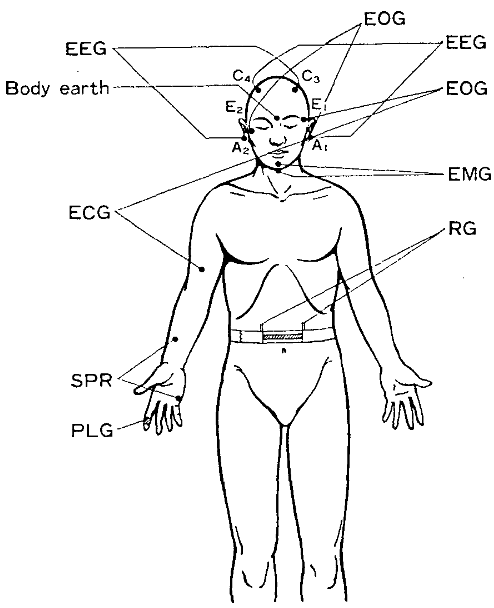


Fig. 4a. A signal acquisition montage used during experiments.

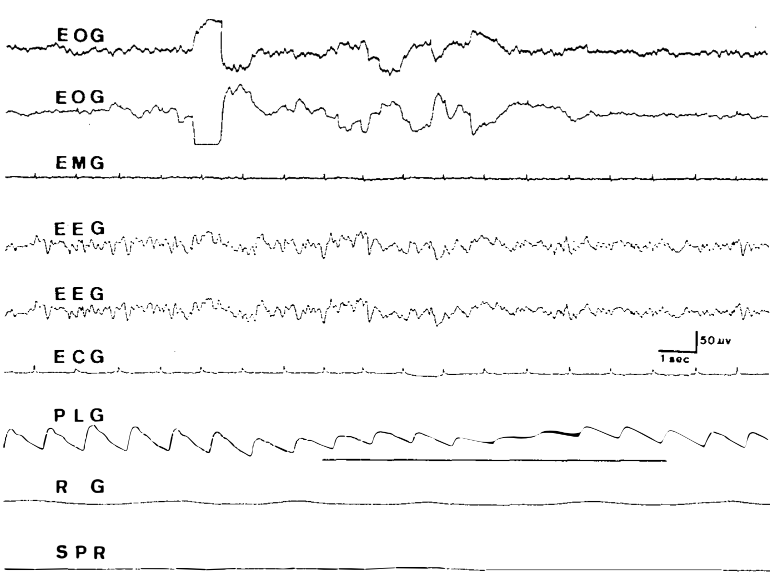


Fig. 4b. One epoch of stage REM of all-night sleep polygraphic record of the subject Y.I. A vasoconstriction response (underlined) on plethysmogram is visible following a volley of rapid eye movements. Skin potential reflex was seldom seen in this case during experiments.

for the electroencephalogram (EEG). Beckman biopotential skin electrodes for the electrooculogram (EOG) and electromyogram (EMG). Acetone was used for the skin preparation. Each electrode was fixed by 14% Celloidin in EEG, and by Blenderm surgical tape (3M company surgical tape NO 1525) in EOG and EMG. Other parameters, *i.e.*, electrocardiogram (ECG), plethysmogram (PLG), respirogram (RG) and skin potential reflex (SPR) were recorded simultaneously as illustrated in Figs. 4a and b.

2.4. Measurements

2.4.1. Sleep polygraphic records: Three consecutive nights of sleep polygraphic recordings were performed in each of the 8 experimental periods, and a total of 114 all-night sleep records were obtained. The recording started at 11 p.m., local time, and lasted until usual awaking time, about 7 a.m., the next day. The first and second nights were treated as habituation nights and the third night's record was used for the sleep stage classification (AGNEW *et al.*, 1966). The records for the sleep stage classification were divided into 20-second epochs, and scored by standardized criteria (RECHTSCHAFFEN and KALES, 1968). The results obtained were compared with the base-line data (TZ-1).

2.4.2. Other measurements: Together with this polygraphic recording, time activity study of daily life was done in order to know the activity pattern and to evaluate the energy expenditure during 3 days for each subject in each of the experimental periods. The results were shown by the mean value of 3 days for each subject. In accordance with the manner of HIROSE (1972) and NORMAN (1965), the activity patterns were classified into 11 categories as shown in Table 11 and the daily energy expenditure (kcal/day) of each subject was calculated from the following formula:

$$A = BMR \times t_1 + BMR \times \Sigma\ (1.2 + RMR) \times t_2$$

where,

A : Energy expenditure of the day (kcal),
BMR : Basal metabolic rate of the subject (kcal/min),
RMR : Relative metabolic rate for each category of activity,
t_1 : Time spent lying (min),
t_2 : Time spent for each category of activity (min).

According to the results of measurements of relative metabolic rate for various activities of Japanese (NUMAJIRI, 1974), the following figures have been taken as the value of *RMR* of each category of activity.

Lying: 0.0, Sitting: 0.3, Standing: 0.5, Walking: 2.0, Light work: 1.0, Medium work: 3.0, Heavy work: 5.0.

The basal metabolic rate for each subject was also determined from sex, age, body weight and height from the published standard value of basal metabolic rate for a Japanese (NUMAJIRI, 1974). Although this method is not a direct measurement of the energy expenditure, it is reasonably permissible to use the mean values obtained from literature (LEWIS *et al.*, 1961).

Fatigue was measured both by flicker test and by individual self-reports on the subjective symptom of fatigue. The measurements were carried out three times a day during 3 days in each of the experimental periods. The results obtained from the measurements at supper (the third of three a day) were presented by the mean value of 3 days.

Body weight was also measured in each of the experimental periods.

CMI (The Cornell Medical Index-Health Questionnaire) test used in Psychiatric Department, Hiroshima University School of Medicine, with 94 questions, was examined on the first day of each the experimental period for each subject to know the degree of the psychiatric and somatic conditions. The results were shown in a manner of CMI-profile described by ISHIKAWA *et al.* (1966).

2.5. Statistical analysis

The results obtained in each observation were represented by mean$\pm$SD (standard deviation) and compared with the base-line data (TZ-1). T-test was used as a statistical method, and the significance level at $P<0.05$ was chosen.

3. Results

3.1. Sleep patterns

No significant difference was seen in the total sleep time (TST) in any experimental periods (Table 5). Sleep latency to each sleep stage is shown in Table 6. No significant difference was seen in sleep onset latency, and REM onset latency, but REM onset latency tended to increase during the dark period (AT-3). Number of stage changes, number of movement arousals and number of awakings are summarized in Table 7. Number of stage changes tended to decrease in Antarctica, particularly during the second half of the wintering over period. Number of movement arousals tended to decrease in early- and late-term in Antarctica. On the other hand, number of awakings tended to increase in mid-term in Antarctica. Sleep stage percent of TST is shown in Table 8. Percent stage W (%SW) as well as number of awakings tended to increase in mid-term in Antarctica. The change in percent stage 1 (%S1) resembled to that of REM onset latency. Percent slow wave sleep (SWS; S3+4) tended to decrease progressively until mid-term (AT-4), the period of which showed the lowest atmospheric temperature, and thereafter tended to increase constantly toward the base-line value in Antarctica. Finally, it

Table 5. Total sleep time (min).

Code \ Subject	Y.E.	H.W.	Y.I.	Y.S.	S.I.	Mean±SD	Significant difference
TZ-1	425.00	452.33	510.67	496.33	499.33	476.73±36.46	
AT-1	385.00	494.00	397.00	483.67	429.66	437.87±49.45	NS
AT-2	446.67	412.33	496.67	527.67	515.67	479.80±48.77	NS
AT-3	437.00	480.00	534.00	521.33	438.00	482.07±45.32	NS
AT-4	433.33	463.67	476.33	488.67	433.00	459.00±25.19	NS
AT-5	377.33	463.00	482.67	462.33	499.67	457.00±47.15	NS
AT-6	415.67	429.67	483.00	489.33	546.00	472.73±52.10	NS
TZ-2	—	497.33	—	471.00	535.33	501.22±32.34	NS

NS indicates no significant difference from TZ-1. The definitions of the terms: Total sleep time; time from sleep onset to the final awaking in the morning.

Table 6. Sleep latency (min).

	TZ–1 (N=5)	AT–1 (N=5)	AT–2 (N=5)	AT–3 (N=5)	AT–4 (N=5)	AT–5 (N=5)	AT–6 (N=5)	TZ–2 (N=3)
Stage 1	2.07 ±2.64	1.73 ±0.64	1.87 ±1.02	1.47 ±1.82	2.00 ±1.62	1.33 ±1.05	2.20 ±1.92	1.78 ±1.07
Stage 2	18.40 ±13.48	5.40 ±2.66	9.40 ±6.53	38.93 ±49.27	16.73 ±9.45	7.73 ±6.84	6.66* ±3.27	9.11 ±3.17
Stage 3	30.93 ±13.29	16.87 ±2.59	19.53* ±9.62	50.93 ±54.66	28.40 ±14.25	17.53 ±8.95	16.40* ±5.17	15.22 ±3.97
Stage 4	42.40 ±12.94	41.93 ±7.28	38.07 ±13.36	71.34 ±55.04	47.07 ±20.79	58.75 ±54.53	28.67 ±6.13	28.11 ±5.84
Stage REM	79.53 ±21.69	74.93 ±15.40	77.46 ±14.58	101.33 ±39.80	76.00 ±10.99	67.40 ±12.50	78.60 ±14.52	68.56 ±7.03

Asterisks indicate significant differences ($p<0.05$) from TZ–1. The definitions of the terms: Sleep onset latency; the time from lights out until the appearance of first stage 1. Latency of other each stage; the time from sleep onset to the first appearance of each stage.

Table 7. Number of stage changes, number of movement arousals and number of awakings.

	TZ–1 (N=5)	AT–1 (N=5)	AT–2 (N=5)	AT–3 (N=5)	AT–4 (N=5)	AT–5 (N=5)	AT–6 (N=5)	TZ–2 (N=3)
Number of stage changes	274.60 ±56.58	234.80 ±35.29	264.00 ±64.44	239.80 ±49.85	206.00* ±40.03	216.60* ±50.90	242.60* ±52.94	290.33 ±57.35
Number of movement arousals	124.60 ±72.82	97.00* ±25.23	125.60 ±41.80	118.80 ±20.02	123.40 ±49.33	105.20* ±42.90	113.60* ±36.90	159.67 ±74.01
Number of awakings	6.20 ±6.06	9.00 ±9.87	9.40 ±9.15	21.40 ±20.84	25.20 ±20.18	11.20 ±9.98	8.80 ±3.27	14.00 ±11.79

Asterisks indicate significant differences ($p<0.05$) from TZ–1.

Table 8. Sleep stage percent of total sleep time.

	TZ–1 (N=5)	AT–1 (N=5)	AT–2 (N=5)	AT–3 (N=5)	AT–4 (N=5)	AT–5 (N=5)	AT–6 (N=5)	TZ–2 (N=3)
% stage W	0.45 ±0.47	0.69 ±0.77	0.69 ±0.73	1.55 ±1.63	1.89 ±1.59	0.81 ±0.66	0.62 ±0.22	0.90 ±0.71
% stage 1	17.58 ±5.90	11.52 ±3.44	15.05 ±2.72	18.72 ±6.97	15.93 ±4.22	12.48 ±3.12	13.55 ±2.86	19.27 ±6.91
% stage 2	48.51 ±4.42	55.49 ±4.21	52.45 ±3.44	51.64 ±8.42	54.04* ±4.73	52.26 ±2.78	54.58* ±3.58	44.56 ±5.02
% stage 3	9.36 ±2.02	9.35 ±2.63	8.00 ±2.02	7.51 ±1.91	6.34 ±3.59	8.45 ±2.81	8.72 ±1.86	9.65 ±0.58
% stage 4	1.93 ±1.23	0.52* ±0.33	0.59* ±0.39	0.90 ±1.03	0.60* ±0.70	0.26* ±0.27	0.53* ±0.64	1.64 ±0.73
% SWS (S3+4)	11.29 ±2.43	9.89 ±2.97	8.59 ±2.39	8.40 ±2.77	6.95 ±4.17	8.72 ±3.01	9.25 ±2.46	11.30 ±0.29
% stage REM	19.99 ±3.65	21.22 ±4.37	21.36 ±2.23	18.41 ±3.43	20.01 ±3.69	24.00* ±3.23	20.26 ±2.33	22.69 ±2.36
% movement times	2.18 ±0.99	1.18* ±0.87	1.85 ±1.02	1.27* ±0.95	1.24* ±0.69	1.75 ±0.94	1.74 ±0.63	1.28 ±1.15

Asterisks indicate significant differences ($p<0.05$) from TZ–1.

returned completely to the base-line value after six months residence in Japan (TZ-2). On the contrary percent stage 2 (%S2) tended to increase in Antarctica, and the increase in %S2 matched the reduction in %SWS. Percent stage 4 (%S4) decreased significantly, except dark period in Antarctica (Table 9). Percent stage REM (%SREM) tended to decrease in mid-term (dark period), and to increase in early- and late-term in Antarctica, though the changes in %SREM were very small except AT-5. No significant correlation was seen between %SWS and %SREM. Percent movement times (%MT) tended to decrease mainly in mid-term in Antarctica. The results of REM parameters are shown in Table 10. No significant difference was seen in number of REM periods and average REM period length. Average REM cycle length and REM interval length showed movements almost parallel to each other, and tended to increase in mid-term in Antarctica. A series of histogram of all-night sleep patterns of one subject in overall sessions is illustrated in

Table 9. Percent stage 4 of total sleep time.

Code \ Subject	Y.E.	H.W.	Y.I.	Y.S.	S.I.	Mean±SD	Significant difference
TZ–1	0.55	3.68	2.48	1.88	1.07	1.93±1.23	
AT–1	0.26	0.67	1.01	0.21	0.47	0.52±0.33	p<0.05
AT–2	0.30	0.40	1.28	0.51	0.45	0.59±0.39	p<0.05
AT–3	0.38	0.35	2.62	0.13	0.99	0.90±1.03	NS
AT–4	0.08	0.93	1.68	0.07	0.23	0.60±0.70	p<0.05
AT–5	0.00	0.36	0.69	0.07	0.20	0.26±0.27	p<0.05
AT–6	0.08	0.39	1.59	0.00	0.61	0.53±0.64	p<0.05
TZ–2	—	2.48	—	1.27	1.18	1.64±0.73	NS

NS indicates no significant difference from TZ–1.

Table 10. REM parameters.

	TZ–1 (N=5)	AT–1 (N=5)	AT–2 (N=5)	AT–3 (N=5)	AT–4 (N=5)	AT–5 (N=5)	AT–6 (N=5)	TZ–2 (N=3)
Number of REM periods	4.80 ±0.45	4.40 ±0.55	4.60 ±0.55	4.40 ±0.55	4.20 ±0.45	5.00 ±0.00	4.80 ±0.45	5.00 ±0.00
Average REM period length (min)	25.09 ±3.68	24.02 ±3.45	26.60 ±2.92	24.15 ±5.23	25.35 ±6.33	25.28 ±3.69	23.52 ±4.06	26.89 ±3.64
Average REM interval length (min)	64.86 ±6.31	67.68 ±5.60	71.28* ±4.80	75.75 ±14.35	80.49* ±11.16	65.73 ±10.24	72.62 ±10.57	68.72 ±4.09
Average REM cycle length (min)	87.02 ±6.44	92.41 ±6.87	100.34* ±6.94	99.50 ±13.48	103.09* ±9.73	92.25 ±11.12	96.11 ±12.00	95.67 ±6.90

Asterisks indicate significant differences (p<0.05) from TZ–1. The definitions of the terms: REM period length; the duration of one REM period. REM interval length; the time between the ending of one REM period and the beginning of the next. REM cycle length; the time between the beginning of one REM period and the beginning of the next.

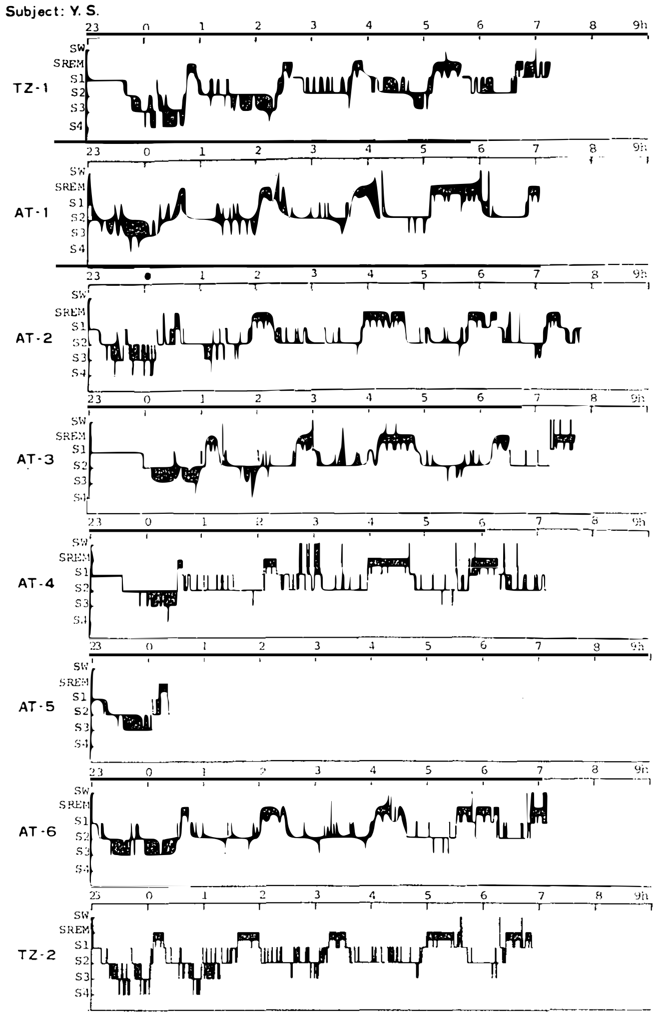


Fig. 5. Histograms of all-night sleep polygraphic records of the subject Y.S. in the eight observations.

Fig. 5.

3.2. Activity patterns

The mean values of the percent time spent in the various activities during 3 days in each of the experimental periods are shown in Table 11. The proportion of time spent outdoors and in medium and heavy work tended to be shorter during the dark period (AT-3) than during any other sessions, whereas the proportion of time spent indoors and in lying and sitting, tended to be longer. On the contrary, when the sunshine duration was longer, their proportion showed the inverse relationship. It seems that activity patterns depend on either usual obligatory work or solar rhythm rather than on atmospheric temperature.

Table 11. Seasonal values of time spent in various activities (in %).

Activities	TZ–1 (N=5)	AT–1 (N=5)	AT–2 (N=5)	AT–3 (N=5)	AT–4 (N=5)	AT–5 (N=5)	AT–6 (N=5)	Mean* ±SD
Lying	44.24 ±3.42	35.10 ±5.17	43.20 ±3.26	45.12 ±5.85	42.86 ±3.84	38.56 ±4.99	41.58 ±6.86	41.07 ±3.64
Sitting	18.02 ±10.14	19.86 ±6.28	19.06 ±8.66	29.68 ±9.35	23.42 ±10.35	19.72 ±6.82	15.28 ±3.34	21.17 ±4.91
Standing	3.08 ±2.85	0.52 ±0.31	0.10 ±0.22	0.66 ±0.92	0.18 ±0.30	3.06 ±5.69	0.96 ±1.36	0.91 ±1.10
Walking indoors	6.86 ±5.89	4.42 ±4.26	0.76 ±1.34	1.30 ±2.21	1.78 ±1.89	0.98 ±1.36	2.06 ±2.08	1.88 ±1.33
Light work indoors	18.18 ±10.95	22.56 ±11.04	16.72 ±12.96	19.30 ±11.27	18.18 ±11.78	20.44 ±17.00	22.62 ±20.79	19.97 ±2.37
Medium work indoors	0.00 ±0.00	5.28 ±11.81	13.48 ±15.28	0.00 ±0.00	4.98 ±8.97	5.24 ±4.65	6.56 ±9.88	5.92 ±4.34
Heavy work indoors	1.46 ±2.04	0.00 ±0.00	0.00 ±0.00	0.00 ±0.00	0.38 ±0.61	0.42 ±0.94	0.00 ±0.00	0.13 ±0.21
Walking outdoors	4.88 ±4.01	2.60 ±1.85	0.76 ±0.42	2.18 ±2.06	2.02 ±2.08	3.00 ±3.76	1.14 ±1.28	1.95 ±0.86
Light work outdoors	1.34 ±3.00	4.10 ±4.37	1.72 ±2.36	1.06 ±1.70	0.44 ±0.98	1.60 ±3.41	1.62 ±1.72	1.76 ±1.25
Medium work outdoors	0.28 ±0.63	5.50 ±6.46	4.20 ±5.36	0.28 ±0.63	3.54 ±6.37	4.58 ±5.40	5.84 ±9.22	3.99 ±2.00
Heavy work outdoors	1.66 ±3.71	0.00 ±0.00	0.00 ±0.00	0.42 ±0.94	2.36 ±4.90	2.38 ±5.32	2.36 ±3.90	1.25 ±1.23
Lying and sitting	62.26 ±11.76	55.02 ±6.55	62.26 ±10.47	74.80 ±7.33	66.28 ±9.43	58.28 ±11.49	56.86 ±8.05	62.25 ±7.36
Time spent indoors	91.84 ±6.24	87.80 ±10.21	93.32 ±5.80	96.06 ±2.61	91.64 ±5.44	88.44 ±6.77	89.06 ±8.56	91.05 ±3.22
Time spent outdoors	8.16 ±6.24	12.20 ±10.21	6.68 ±5.80	3.94 ±2.61	8.36 ±5.44	11.56 ±6.77	10.94 ±8.56	8.94 ±3.22
Medium and heavy work both in- and outdoors	3.40 ±3.17	10.78 ±12.01	17.68 ±13.50	0.70 ±0.99	11.26 ±9.27	12.62 ±10.57	14.76 ±18.63	11.30 ±5.78

Asterisk indicates the mean value from AT–1 to AT–6.

3.3. Energy expenditure, body weight and fatigue

The calculated energy expenditure is shown in Table 12. The energy expenditure tended to increase in early- and late-term in Antarctica when there was longer sunshine duration, and it was minimum during the dark period (AT-3). The mean values of the energy expenditure in each of the experimental periods in Antarctica did not exceed about 2800 kcal per day, although they varied considerably with individual subject. According to NUMAJIRI (1974), the energy expenditure of 2800 kcal/day corresponds to that for workers engaged in medium class physical work in Japanese. The results of the changes in body weight and fatigue are illustrated in Fig. 6. Body weight tended to increase gradually until the end of the wintering

Table 12. Energy expenditure (kcal/day).

Code \ Subject	Y.E.	H.W.	Y.I.	Y.S.	S.I.	Mean±SD
TZ-1	2306	3002	2633	2145	2340	2485.2±338.3
AT-1	3241	2332	3022	2622	2299	2703.2±417.9
AT-2	3484	2071	2745	2719	2423	2688.4±521.7
AT-3	2230	2054	2166	2009	2128	2117.4± 87.9
AT-4	3012	2806	2474	2156	2499	2589.4±329.7
AT-5	3311	2498	2787	2860	2252	2741.6±399.8
AT-6	3693	2449	2612	2775	2501	2806.0±511.3

Energy expenditure was calculated from the activity pattern obtained from the mean value of 3 days in each of the experimental periods.

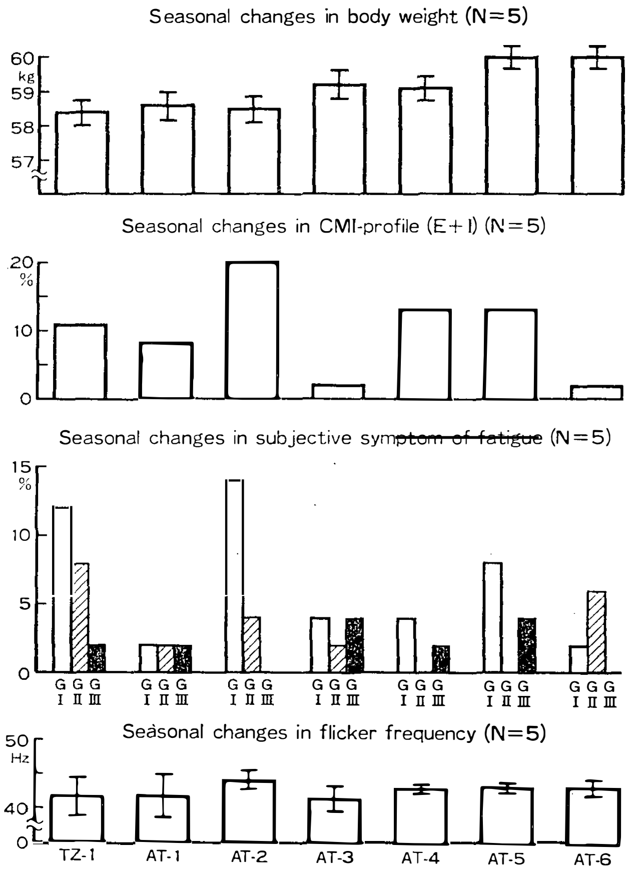
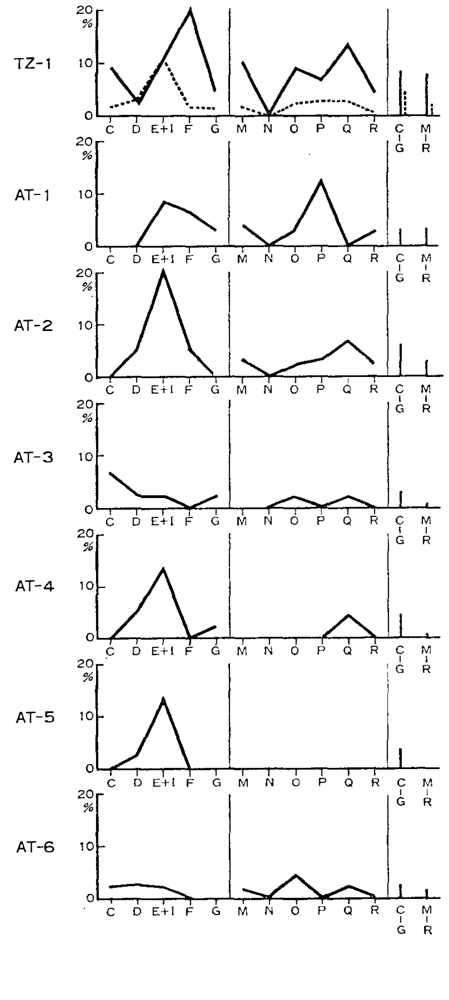


Fig. 6. The mean values of body weight and flicker frequency with standard deviation in each observation.

over period. However, its increase was very small and no significant difference was seen from the base-line data (TZ-1). Measurements concerning fatigue were made by flicker test, self-reported subjective symptom of fatigue and CMI-profile E+I (described later). Flicker test usually matches Group I (GI) of subjective symptoms, which represents the drowsiness and the dullness (OGI, 1970). But the changes in GI were rather similar to those of CMI-profile E+I.

3.4. CMI-profile

The results are illustrated in Fig. 7. In the proportion of somatic complaints (C ~ G), the changes in E+I were prominent. Minimum in the dark period (AT-3) was consistent with minimum of the energy expenditure in the same period. On the other hand, in the proportion of psychiatric complaints (M ~ R), many kinds of complaints tended to decrease progressively in the course of the wintering over period. No depression or any other pathological status was seen in overall sessions. The noticeable feature was absence of psychiatric complaints in AT-5.



C: Cardiovascular system (9)
D: Digestive tract (8)
E+I: Musculoskeletal system and fatigability (9)
F: Skin (4)
G: Nervous system (9)
M: Inadequacy (12)
N: Depression (6)
O: Anxiety (9)
P: Sensitivity (6)
Q: Anger (9)
R: Tension (9)
Note: Number of questions is indicated in the bracket. Dotted line shows mean value in Antarctica.

Fig. 7. CMI-profile C–G signify somatic conditions, and M–R psychiatric conditions.

3.5. Correlations between sleep patterns and environmental factors

It was found that the changes in %SWS had a positive correlation with those

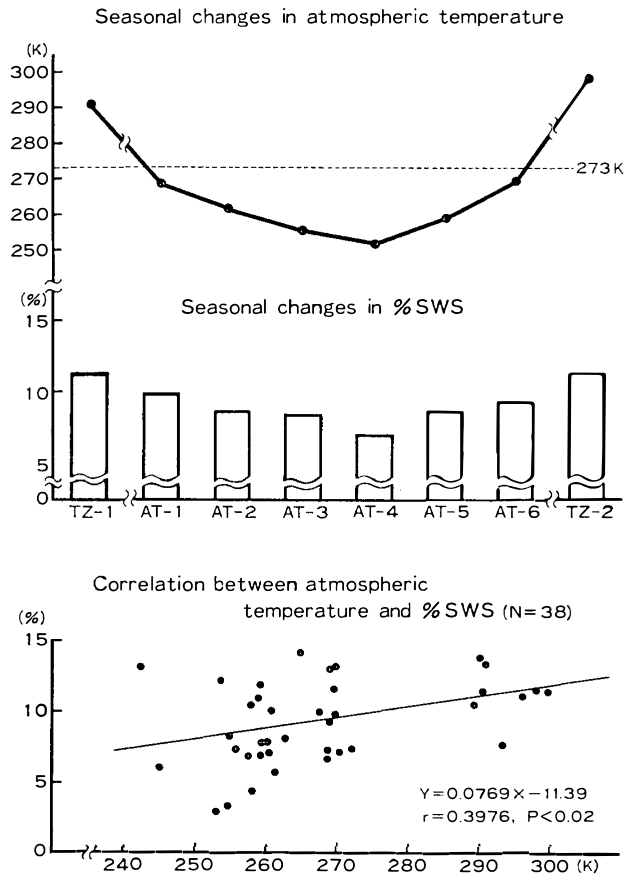


Fig. 8. Correlation between SWS and atmospheric temperature.

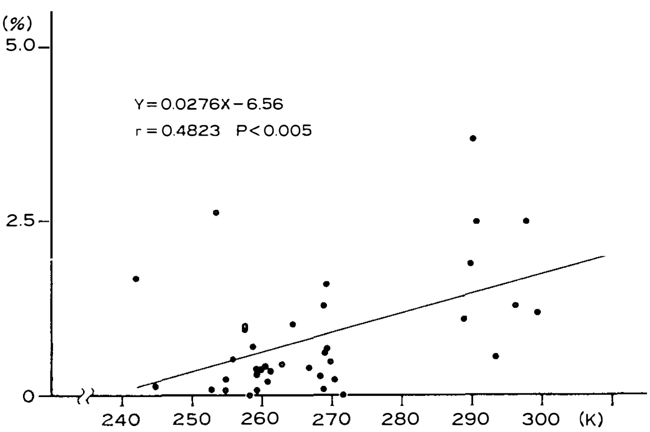


Fig. 9. Correlation between %S4 (N=38) and atmospheric temperature is shown. Percent stage 4 showed the higher positive correlation with atmospheric temperature than %SWS.

of atmospheric temperature ($r=0.3976$, $P<0.02$) as illustrated in Fig. 8. So far as %S4 is concerned, a positive correlation was higher ($r=0.4823$, $P<0.005$) as illustrated in Fig. 9. On the contrary, the changes in %S2 showed a negative correlation with those of atmospheric temperature ($r=-0.3843$, $P<0.02$). No significant

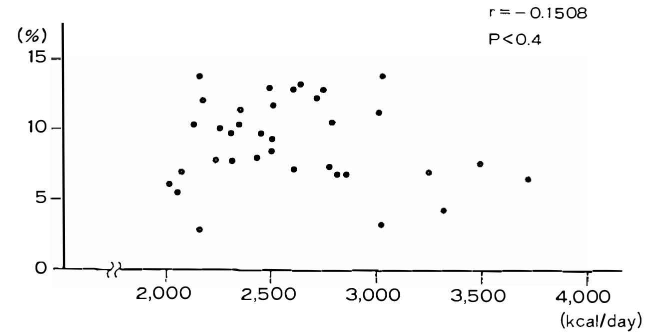


Fig. 10. Correlation between %SWS (N=35) and the energy expenditure.

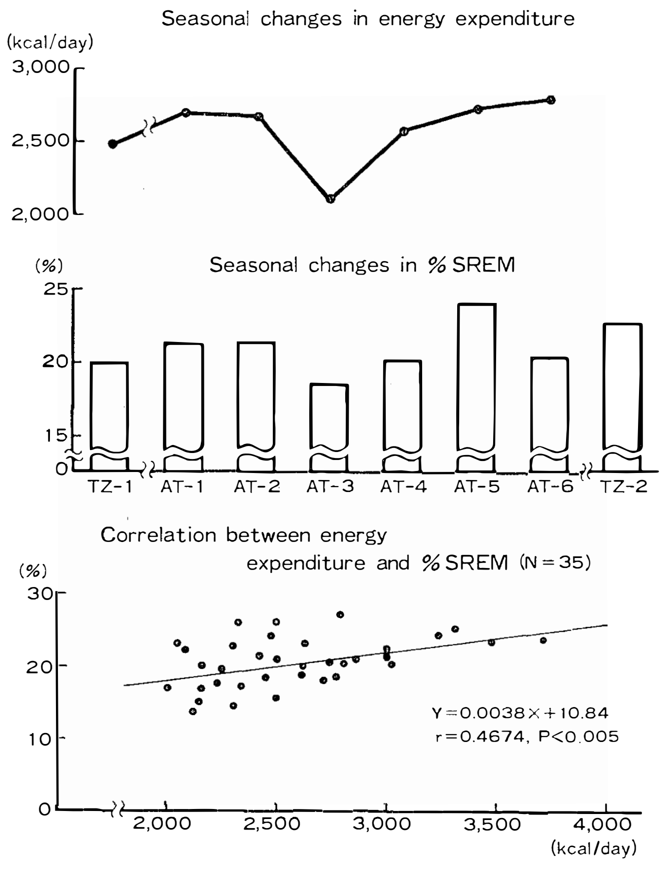


Fig. 11. Correlation between REM sleep and the energy expenditure.

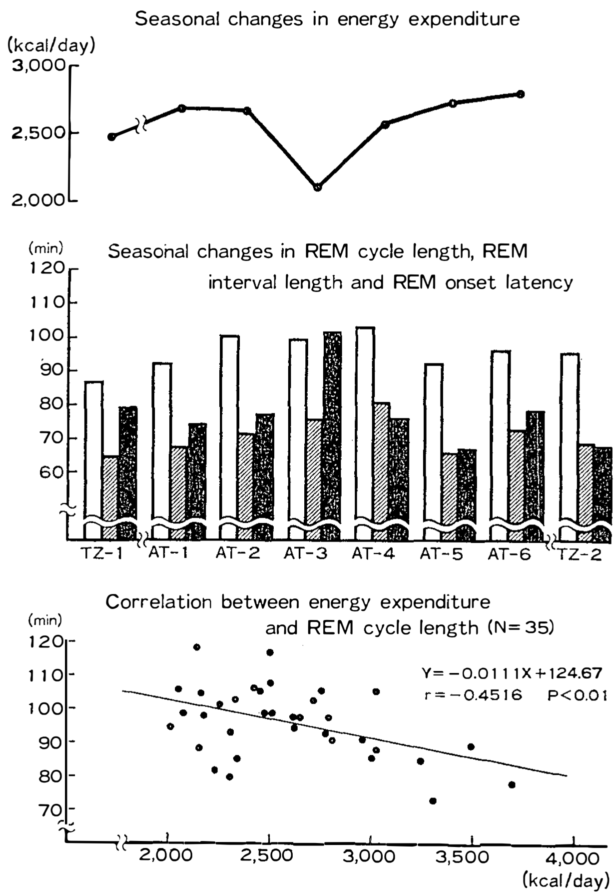


Fig. 12. Correlation between REM parameters and the energy expenditure. In the middle portion of the figure, white rectangles signify average REM cycle length, hatched rectangles average REM interval length and black rectangles REM onset latency.

correlation was seen between %SWS and the energy expenditure as illustrated in Fig. 10. Also it was found that the changes in %SREM had a positive correlation with those of the energy expenditure ($r=0.4674$, $P<0.005$) as illustrated in Fig. 11. On the contrary, the changes in average REM cycle length, in average REM interval length and in REM onset latency showed a negative correlation with those of the energy expenditure ($r=-0.4516$, $P<0.01$; $r=-0.4945$, $P<0.005$; $r=-0.4347$, $P<0.01$) as illustrated in Fig. 12. In addition, a negative correlation was seen between the number of movement arousals and the energy expenditure ($r=-0.4354$, $P<0.01$). The changes in number of stage changes showed a positive correlation with those of atmospheric temperature ($r=0.3704$, $P<0.05$) and a negative with those of the energy expenditure ($r=-0.3880$, $P<0.05$).

It was impossible to find a direct correlation between these sleep parameters and other factors such as light-dark pattern, psychiatric stress, fatigue and body weight change.

4. Discussion

It is of considerable interest how the sleep patterns are influenced by polar extreme environments, when the subjects living in the temperate zone stay in the polar region for one year. However, literature is scanty on concerning the observation of the long-term change in sleep pattern investigated by EEG polygraphic method in the polar region.

In the Antarctic region, NATANI *et al.* (1970) reported the first polar EEG study of sleep. This was undertaken at the high altitude (2804 m) Amundsen-Scott American Station at the South Pole (5 months without the sun). In their results, TST varied little but sleep onset latency increased and %SREM decreased in Antarctica, while SWS decreased progressively until their subjects returned to USA. NATANI and SHURLEY (1973) thought that this reduction in SWS could largely be attributed to the high altitude and suggested that it was mediated by a possible depletion of serotonin (5-HT). PATERSON (1975) reported the study carried out at the British Antarctic Survey Base at Halley Bay (75°31′S, 26°43′W), which was only 30 m above sea level and buried below the snow surface. He found that SWS reduced significantly in the second half of the wintering over period, whereas TST and absolute amounts of SREM increased in summer (midnight sun). He speculated that extremes of daylight in the polar region might be primarily responsible for the quantitative change in SWS. In the Arctic, WEITZMAN *et al.* (1975) reported a study carried out at Tromsø (69°39′N, 18°58′E), Norway. Most of their subjects were born in northern Norway and have been adapted to the polar environment. They did not find any difference in TST and sleep stage percents during the overall seasons.

In the present work, %SWS tended to decrease gradually until AT-4, the period of which showed the lowest atmospheric temperature, thereafter it tended to increase gradually in Antarctica. Furthermore, it recovered to the base-line data at TZ-2, the period being six months after the subjects returned to Japan. Concomitant increase in %S2 matched the reduction in %SWS. On the other hand, %SREM tended to increase in early- and late-term and to decrease in mid-term (dark period), in which the energy expenditure showed the lowest level, in Antarctica. Although it is difficult to compare the present results with those of the previous works in literature because of their differences among environmental conditions, species and methods, these results in the present work partly agreed with the studies reported by NATANI *et al.* (1970) and PATERSON (1975).

It is known that presleep states such as daytime stress decrease %S4 and do not affect %SREM (LESTER *et al.*, 1967), and depressive states decrease both SWS and REM sleep (GRESHAM *et al.*, 1965; LOWY *et al.*, 1971; MENDELS *et al.*, 1967). However, the present subjects did not show any symptoms of depressive illness in overall sessions, and psychiatric stress was seen more in TZ-1 than in Antarctica. Thus, there was no correlation between sleep patterns and psychiatric complaints. There is another possibility of decreasing SWS due to low energy expenditure, since heavy daytime exercise increases SWS (BAEKELAND and LASKY, 1966). However no correlation was seen between %SWS and the energy expenditure in the present work. Hyper- and hypothyroidism change the proportion of SWS (DUNLEAVY *et al.*, 1974; KALES *et al.*, 1967; PASSOUANT *et al.*, 1966), but no evidence was found in the plasma level of thyroxin at Syowa Station (TSUBOI *et al.*, 1976). It is reported that starvation was accompanied by a significant rise in SWS and a significant fall in REM sleep (MACFADYEN *et al.*, 1973), and a high carbohydrate diet is associated with an increase in REM sleep in normal people (PHILLIPS *et al.*, 1975). In the present work, however, the subjects had the steady food intake in overall sessions. It is reported that there was a significant increase in REM sleep when patients with anorexia nervosa gained weight (LACEY *et al.*, 1975). Also it is reported that there was a strong positive correlation between an adult's body weight and the usual amount of REM sleep (ADAM, 1977a), and the percentage deviation from ideal body weight was significantly correlated with the mean NREM-REM cycle length (ADAM, 1977b). The present results showed a gradual but small increase in body weight in the course of the wintering over period, and neither REM sleep nor REM cycle length showed a correlation with body weight.

It was found, however, that the changes in %SWS had a positive correlation with those of atmospheric temperature experienced for each subject during daytime in the experimental observations. The changes in %SREM showed a positive correlation with those in the energy expenditure calculated from daily activity patterns during experiments, whereas the changes in average REM cycle length, average REM interval length and REM onset latency, showed a negative correlation with those in the energy expenditure.

Then it is stressed here that low environmental temperature is also a possible factor of reducing SWS. It is reported, in fact, that low environmental temperature is an important external factor changing sleep patterns in animal studies (PARMEGGIANI and RABINI, 1970; SCHMIDEK *et al.*, 1972). Furthermore, it is suggested that these changes in sleep patterns were probably due to the interaction between thermoregulatory and sleep processes (PARMEGGIANI and RABINI, 1970). The mean value of time spent outdoors in Antarctica is very small (8.94% per day) and does not differ the temperate zone value (8.16% per day). However, the subjects were constantly exposed to intense cold for a short time during their one-year stay at Syowa Station. Therefore, the change in SWS may be a result of adaptation to the cold environment.

From the standpoints of starvation (MacFadyen *et al.*, 1973), nutrition (Lacey *et al.*, 1975), body weight (Adam, 1977a, b) and the metabolic rate (Hartmann, 1968), it has been suggested that REM sleep and REM cycle length are closely linked to general body metabolism. The present results support this suggestion, and furthermore give the more clear evidence of a connection among REM sleep, REM cycle length and metabolism.

Although there is abundant evidence that the extreme shifts in the ratio of light to darkness during the year affect plants and animals, it was impossible to find the direct influence on sleep patterns in the present work.

However, as Lewis *et al.* (1961) pointed out, the present results showed that the seasonal changes of light and darkness determined the activities to a much greater extent than the cold in the polar region. Therefore, the fact that the energy expenditure calculated from activity patterns was correlated to REM sleep, indicates that the extremes of light-dark pattern had indirectly influenced REM sleep.

Finally, the present work showed that SWS was influenced by the cold but REM sleep by the energy expenditure. Despite the extraordinary research effort expended on sleep in the fields of electrophysiology, pharmacology and biochemistry, we still know very little about the biological significance of sleep. In this respect, it is worth noting that the two kinds of sleep, namely SWS and REM sleep made simultaneous adaptation to the two different external factors in the present work. It is well known that biogenic amines are closely linked with the states of sleep, *i.e.*, the brain stem systems of 5-Hydroxytryptamine (5-HT) neurons are responsible for SWS and for the priming mechanism of REM sleep, whereas noradrenaline (NA) and acetylcholine (ACH) systems are involved in the executive mechanisms of REM sleep (Jouvet, 1972). On the other hand, the brain NA level did not change significantly in mice during prolonged exposure to cold, whereas the activity of brain 5-HT neurons decreased for some days in cold, though it returned gradually to the control level after the mice had acclimatized themselves to cold (Harri and Tirri, 1969). The individual changes in SWS and REM sleep may be explained on this basis.

5. Conclusion

The following facts have been confirmed from the long-term trial of all-night sleep polygraphic recordings and many other measurements performed simultaneously in five healthy male subjects, the members of JARE-16.

1) Total sleep time or sleep onset latency varied little even when the subjects have lived in such an extreme environment.

2) The proportion of SWS reduced according to the lowering of atmospheric temperature.

3) This reduction in SWS was compensated mainly by the increase in S2.

4) The proportion of REM sleep and REM cycle length varied according to the changes in the energy expenditure.

5) The extremes in light-dark pattern influenced indirectly the proportion of REM sleep, mediated via the changes in activities of daily life.

6) The two kinds of sleep, namely, SWS and REM sleep showed adaptation to the two different external factors separately.

Acknowledgments

The author acknowledges the assistance received from many sources in performing this work.

The author is indebted to Prof. T. UOZUMI, Department of Neurosurgery, Prof. H. EZAKI, Department of Surgery, Prof. H. OKUDA, Department of Hygiene, and Assist. Prof. H. KODAMA, Department of Psychiatry, Hiroshima University School of Medicine, and to Prof. S. TORII, Department of Physiology, Toho University School of Medicine and to Prof. K. ASAHINA, Chukyo University, for suggesting and criticizing this work. The author also expresses his sincerest gratitude to Prof. T. HOSHIAI, National Institute of Polar Research, leader of JARE-16, and to all the members of the expedition for their kind cooperation in the investigation.

Finally, thanks are also expressed to Mr. E. TODA, President of Mazda Unyu Hiroshima Co., for providing the instruments used in this work.

Parts of this article were reported at the 7th Annual Meeting of the Japan

Society of Electroencephalography and Electromyography on November 16, 1977 at Sendai City, at the 2nd Annual Meeting of Japanese Society of Sleep Research on May 27, 1978 at Osaka City, and at the 3rd International Congress of Sleep Research on July 28, 1979 at Tokyo.

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(*Manuscript received December 20, 1979*)