The basic ultradian rhythm of daytime sleepiness was investigated in eight male students using principal component analysis (PCA). After 8 h of sleep, daytime sleepiness was evaluated for every 30 min from 0800 to 1900 by five measures: MSLT, Kwansei-Gakuin Sleepiness Scale (KSS), EEG delta, theta and alpha activities. These measures were applied to the PCA for each subject. The first three eigenvalues accounted for about 80% of the variance, PC scores were then computed. The time series analysis showed several predominant ultradian peaks in the PC scores for all subjects. These peaks included 8-10, 15 and 22 cycles/day, corresponding to 140-180, 96 and 66 min/cycle. The data suggest that the temporal structure of daytime sleepiness may consist of some ultradian components other than Kleitman’s (1963) BRAC frequencies.

Key words: daytime sleepiness, ultradian rhythm, sleepiness scale, multiple sleep latency test (MSLT), electroencephalography, principal component analysis.

Since Kleitman (1963) proposed the concept of the Basic-Rest Activity Cycle (BRAC), a number of studies have shown the evidence supporting the existence of ultradian rhythms in various physiological and behavioral functions, with a period of about 90 min (Lavie, 1982). Significant ultradian fluctuations in daytime vigilance level have been also observed (Okawa, Matousek, & Petersén, 1984). These results suggest that daytime sleepiness may occur periodically. However, only a few studies have been published regarding ultradian rhythms in daytime sleepiness.

Which measures are useful to investigate the temporal structure of daytime sleepiness? Multiple Sleep Latency Test (MSLT: Carskadon & Dement, 1979), Stanford Sleepiness Scale (SSS: Hoddes, Dement, & Zarcone, 1972), EEG spectra (Gevins, Zeitlin, Ancoli, & Yeager, 1977), and so forth have been frequently used to evaluate sleepiness. These are helpful and reliable measures for evaluating sleepiness. However, the results differed somewhat among the measures, although sleepiness was tested for the same subjects (e.g. Carskadon & Dement, 1981; Horne & Wilkinson, 1985). This discrepancy may be explained by the reason that the results obtained from these measures are expressed as the complex of components both common to all measures and unique to each of the measure, which are influenced by the various methodological manipulations.

If daytime sleepiness occurs periodically according to ultradian rhythm, about 90 min cycle should be observed for all sleepiness measures. If only one measure is used, however, it is difficult to determine whether observed periodicities are attributed to the basic structure of sleepiness or to unique components in the measures. Hence, in order to examine the temporal fluctuations of daytime sleepiness, it is necessary to exclude the unique components included in the measures and to extract the common components among them. It is also necessary to use several sleepiness measures simultaneously.

1 The authors wish to gratefully acknowledge Dr. Paul Naitoh, Naval Health Research Center, San Diego for his critical reading and valuable suggestions.
The aim of this study is to assess the possible existence of the basic ultradian components of daytime sleepiness. In the study, we used principal component analysis (PCA) based on the structure of correlation between the sleepiness measures to extract the common components. Using the obtained principal components (PCs), the characteristics of temporal fluctuations of daytime sleepiness were investigated.

Method

Subjects

Eight male students, aged 19–22 yrs, participated in the study. They reported habitual sleep time of 7–8 h nightly and daily naps less than twice weekly. They were also drug free, and had EEG alpha waves with more than 10% of their waking records (Johnson, Lubin, Naitoh, Nute, & Austin, 1969).

Sleepiness Measures

In the present study we used three measures: MSLT, Kwansei-Gakuin Sleepiness Scale (KSS: Ishihara, Saito, & Miyata, 1982), and EEG spectra.

MSLT. MSLT is a method to measure the latency to stage 1 sleep in a quiet, darkened room. The shorter the latency is, the sleepier the subject is. According to the standard procedure (Carskadon & Dement, 1979), the sleep latency on the MSLT was defined as the time elapsed from the light off to the onset of stage 1. In the present study, our procedure was different in two ways from the standard one (Carskadon & Dement, 1979). First, sleep latencies were measured at 30 min intervals instead of 2 h since we wanted to detect ultradian fluctuations of daytime sleepiness, not circadian fluctuations. Second, the time in bed was restricted to 15 min, that is 5 min shorter than the standard procedure, since we wanted to decrease the bed rest effect of MSLT on the next sleep latency tests. Each MSLT score (min) was calculated as 15 min minus the sleep latency (min). So the high MSLT score shows increased sleepiness in the present study.

KSS. KSS is a self-rating scale conducted in Japanese developed after the SSS (Hoddes et al., 1972) using Thurstone's scale (Ishihara et al., 1982). The scale consists of 22 statements, where subjects selected all of the statements which described their current state of sleepiness. The score ranged from 0 to 7. The higher the score is, the sleepier the subject is.

EEG spectra. The power spectra of EEG from rest recording with the eyes closed, just prior to sleep stage 1 onset on MSLT, was computed. The EEG patterns during wakefulness are influenced by sleepiness. It is known that the EEG alpha (8–13 Hz) activity attenuates and EEG delta (1–3 Hz) and theta (4–7 Hz) activities develop during transient period from awake to sleep (Hori, 1979, 1985). This suggests that decreased alpha band power and increased delta and theta band power in the waking EEG may reflect the increased sleepiness. So the spectral intensity was computed for delta, theta and alpha bands.

When the light was out during MSLT, Cz EEG during relaxed wakefulness with the eyes closed was analyzed using a Sanei Signal Processor, type 7T07A. The power spectra were computed for consecutive 10.24 s epochs with a sampling rate of 100/s (1024 samples/epoch) using a Fast Fourier Transformation (FFT). The 61.44 s long spectra were then computed by averaging 6 consecutive 10.24 s epochs for smoothing power spectra. The spectral values were fed to a NEC PC9801m3 micro computer, and saved on floppy disks. The disk-saved data was integrated for delta (0.5–3.5 Hz), theta (3.5–7.5 Hz), alpha (7.5–12.5 Hz) bands, and transformed into magnitude values in microvolts (μV: square root of power).

Procedure

On the first day of the experiment, sub-
jects were asked to come to the laboratory at 2100. Electrodes were attached to monitor EEGs (Cz, P3, P4, Oz), horizontal EOGs and a submental EMG.

Subjects went to bed in a sound-attenuated, temperature-controlled room (3 100 x 2 680 x 2 300 mm) at 2300. The background noise level in the room was less than 35 dB, and room temperature was maintained at 22.5 ± 1°C. Subjects were wakened at 0700, and only then were the electrodes for EMG removed. After washing and having breakfast, daytime sleepiness was measured at 30 min intervals 22 times from 0800 to 1900. At 1200, subjects had lunch, so daytime sleepiness was not evaluated at that time.

Polygraphical recordings of EEG, EOG and EMG were obtained with a 14-channel Sanei electroencephalograph, type 1A57, at a paper speed of 1.0 cm/s. The EEG, EOG and EMG signals were also recorded on a 10-channel TEAC FM tape recorder, type SR-10, at a tape speed of 1.2 cm/s.

The procedure for each sleepiness measure taken every 30 min was as follows: Subjects completed KSS and lay in bed. They were instructed to close their eyes and to fall asleep after the light was turned off. The sleep latency test started after the bedroom door closed and the lights were put out. The sleep latency tests ended within 3 min after stage 1 sleep had appeared. When stage 1 sleep did not appear, sleep latency tests lasted up to 15 min. Moreover, at the same time when the lights were out, the Cz EEG spectra were computed on-line for a duration of about 1 min.

In this study, the experiment was designed to minimize the influence of sensory deprivation or social isolation. So the experimental situation was arranged similar to daily life. After each sleep latency test ended, the leads of electrodes were removed from the electrode box and the bedroom door was opened. During these non-test periods, subjects were allowed to engage in daily activities such as reading, watching TV or having light meals and drinks, except taking physical exercise and resting with eyes closed.

### Data Analysis

**Sleep stages.** All night sleep recordings were scored in 1 min epochs and daytime (i.e. MSLT) in 30 s using the criteria of Rechtschaffen and Kales (1968).

**Time series analysis.** The lost samples at lunch time (1200) were replaced with values linearly interpolated. To estimate the ultradian periodicities, the power spectral analysis was then performed on time series by the maximum entropy method (MEM). The advantage of this method is that power spectra density with greater frequency resolution can be obtained than the Fourier Transformation (Tsuji & Kobayashi, 1988). Using the MEM, power spectra in each time series were computed for 41 spectral frequencies from 4 to 24 cycles/day with 0.5 cycles/day resolution. Spectral peaks were then identified as follows: three adjacent frequency bands on each side of the peak were monotonic decreasing function (Johnson et al., 1969), and the amplitude of the peak frequency was greater than the mean amplitude of the spectra.

**Principal component analysis.** An application of PCA for time series data was tried by Tsuji and Kobayashi (1988). They extracted ultradian components of waking EEG activities by PCA. In the present study the aim of PCA was to extract the common components among the sleepiness measures. The correlation coefficients between the measures show the ratio of the variance of common components to the total variance. And the remainders obtained after subtracting the variance of common components from the total variance show the sum of variance of unique components included in the measures. Therefore, the components correlated with each sleepiness measure are extracted as the common components, and the com-
Ultradian components of daytime sleepiness

Table 1

<table>
<thead>
<tr>
<th>Subject</th>
<th>Stage 1</th>
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<tr>
<td>8</td>
<td>26</td>
<td>272</td>
<td>114</td>
<td>41</td>
<td>453</td>
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<td>227.1</td>
<td>90.4</td>
<td>82.5</td>
<td>436.8</td>
</tr>
<tr>
<td>SD</td>
<td>12.9</td>
<td>27.3</td>
<td>23.3</td>
<td>23.7</td>
<td>30.6</td>
</tr>
</tbody>
</table>

Components not correlated are identified as the unique components. The PCA provides the composite variables which have maximum correlation with any variables on the data set. The obtained composite variables can be considered the common components among the measures.

In this study the five time series, that is, MSLT scores, KSS scores, EEG delta, theta and alpha band activities, were submitted to a PCA performed on the 5×5 correlation matrix for each subject. Principal component (PC) scores were then computed, and plotted across time of day.

Results

All Night Sleep

Table 1 presents the amounts of sleep of each stage obtained during the night sleep for each subject. The total sleep times were about 7.5 h for 6 of eight subjects. Although the total sleep time for Sub. 6 was 362 min, it might be considered within the limits of a normal night sleep. This data suggests that the effects of extreme sleep reduction or sleep loss was negligible on daytime sleepiness in this study.

Sleepiness Fluctuations

Figure 1 illustrates an example of time series constructed from raw data of each sleepiness score (Sub. 7). Daytime fluctuations are clear in all sleepiness indexes. Figure 2 illustrates the power spectra in Fig. 1 data. Several peaks are presented for all sleepiness indexes. The spectra in the MSLT panel peaked at 10.5, 15 and 22 cycles/day. Similarly, the spectra in the KSS panel peaked at 18 cycles/day, 10 and 18.5 cycles/day in the EEG delta, 9 and 14 cycles/day in the EEG theta, and 9 and 18 cycles/day in the EEG alpha panel. Thus about two kinds of perio-

![Fig. 1. An example of the time series constructed from raw data of each sleepiness measure. Data from subject 7.](image-url)
dicities were observed: 14–18 cycles/day (80–100 min) which were similar to Kleitman's BRAC (1963), and 9–10 cycles/day (150–160 min) which were longer than BRAC. Other subjects also showed similar pattern. Figure 3 illustrates the histograms of peak frequencies identified from all sleepiness measures for all subjects. Dominant frequency components are observed in all measures panels of this figure. In MSLT and KSS scores the most dominant peaks were in the BRAC frequency range (14–15 cycles/day). And the slower frequency (9 cycles/day) was the most prominent in EEG theta and alpha activities. The bottom of Fig. 3 illustrates the histogram of the peaks from the five sleepiness measures. The predominant peaks were observed in the 9 cycles/day (160 min/cycle) frequency band. This data shows the presence of ultradian rhythms in daytime sleepiness. In spite of using sleepiness measures simultaneously, however, the peak frequencies differed among the measures. Moreover, several kinds of peak frequencies were observed in the same time series. It is not clear whether these periodicities are attributed to basic temporal fluctuations of daytime sleepiness or to unique components in the measures. This suggests that it is necessary to filter out the unique components and to extract the common components.

**Extraction of Common Sleepiness Components by PCA**

Factor loadings of PCs refer to the correlation between the PCs and the sleepiness measures. Although the structure of correlation for each PC was different among the subjects, the first three components accounted for about 80% (77.5–88.4%, mean 83.5%) of the total variance.
for all subjects. PC scores of these three components were then computed.

Figure 4 illustrates an example of PC scores based on the data in Fig. 1 (Sub. 7). Figure 5 presents the power spectra in Fig. 4 data. The first principal component (PC-1) peaked at 10.5, 15 and 22 cycles/day. Peak frequencies of 6.5 and 17.5 cycle/day were observed in PC-2, and 10 and 20 cycles/day in PC-3. In other subjects several peaks were also observed in all PCs. Figure 6 illustrates the histogram of the peaks identified from each of the three PCs for all subjects. Several dominant frequency components were observed in the PC scores. The bottom of Fig. 6 illustrates the histogram of all peaks from the three PC scores. In contrast to the sleepiness measures (Fig. 3), the most dominant peak was observed in the 15 cycles/day frequency band, corresponding to the Kleitman’s BRAC. And the subdominant frequency bands were observed in the much slower 8 and 10 cycles/day (180 and 144 min/cycle), and much faster 22 cycles/day (65 min/cycle).

Discussion

Two factors have been discussed on daytime sleepiness in normal individuals: the amount and quality of prior sleep, and the phase of the circadian rhythm (Dement & Carskadon, 1982). Concerning the amount of night sleep, several studies have investigated the effects of sleep deprivation (Carskadon & Dement, 1979; Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) and sleep reduction (Carskadon & Dement, 1981; Horne & Wilkinson, 1985) for normal subjects.
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on daytime sleepiness. As for the quality of night sleep, the effects of sleep disruption (Bonnet, 1986; Stepanski, Lamphere, Badia, Zorick, & Roth, 1984) have been studied. Lumley, Roehrs, Zorick, Lamphere, and Roth (1986) showed that sleep variables which might be especially associated with increased daytime sleepiness were the amount of slow wave sleep and the continuity of sleep. Bonnet (1986) also suggested that the sleep continuity was more important. Concerning the rhythmic aspects of daytime sleepiness, circadian rhythm has been studied. It has been shown that daytime sleepiness follows a circadian variation with a midday peak around 1400 to 1600, so called “post lunch dip” (Åkerstedt & Gillberg, 1982; Richardson, Carskadon, Orav, & Dement, 1982). However, only a few studies (e.g., Lavie & Scherson, 1981; Lavie & Zomer, 1984) have discussed ultradian components as second rhythmic aspects of daytime sleepiness.

Okawa et al. (1984) reported that daytime vigilance levels fluctuated with ultradian cycles. Lavie and Scherson (1981) and Lavie and Zomer (1984) observed the daytime ultradian cycle in sleep ability. This data suggests that daytime sleepiness may also fluctuate with ultradian cycles. In the present study the sleepiness measures dominantly peaked at about two ultradian periodicities: 14–15 cycles/day, corresponding to Kleitman’s BRAC, and the slower 9 cycles/day, corresponding to 160 min/cycle. These results demonstrate the presence of ultradian rhythms in daytime sleepiness. It is not clear, however, whether the detected periodicities are attributed to the basic temporal structure of sleepiness or to the unique characteristics of the measures.

Using the PCA, three common components could be extracted from five sleepiness measures. These three PCs are considered to be basic components of daytime sleepiness. The obtained PC scores were dominantly peaked at 15 cycles/day (96 min/cycle). These results suggest that the 90 min cycles/day periodicities might be the most basic ultradian component of daytime sleepiness. However, several prominent spectral peaks other than 15 cycles/day (Fig. 6) were observed in PC scores. These results show that the ultradian nature of daytime sleepiness is not always simple. On the other hand, the prominent 9 cycles/day fluctuations in the sleepiness measures (Fig. 3) were not observed in PC scores. This frequency band may represent a unique component in the measures.

Several reports have shown long and short ultradian periodicities. Okawa et al. (1984) observed that daytime vigilance fluctuations occur with periodicities widely ranging from 60 to 110 min. Lavie and Zomer (1984) also reported that daytime vigilance levels are regulated by circadian and at least two ultradian components. Tsuji and Kobayashi (1988) reported ultradian rhythms in EEG activities with periods of 100 min and 3–8 h. Manseau and Broughton (1984) observed 3 h/cycle fluctuations in the theta EEG bandwidth. These data suggest the existence of the multi-oscillatory system in ultradian rhythms (Lavie, 1982). Our results revealed several rhythmic fluctuations in daytime sleepiness other than 90 min period. Although Manseau and Broughton (1984) argued that the 3–4 h/cycle may be a subharmonic of 90 min/cycle, the observed periodicities in the present PC scores are not considered harmonics or subharmonics of one another. Present data supports Lavie’s (1982) multi-oscillator hypothesis.

It may now be important to point out the possibilities that the present procedures could effect as an experimental bias. First, daytime sleepiness was tested at 30 min intervals in the present study. Since this sampling time is too short to detect cycles less than 60 min, it is not clear whether there are basic ultradian components of daytime sleepiness with periods of less than
60 min. Therefore, in order to detect the ultradian periodicities of daytime sleepiness, it may be useful in future to use the sampling times of less than 30 min. Second, this sampling time might also provide certain time cues. The extent to which the harmonics of a 30 min cycle could influence the present results is not clear. In order to exclude this effect, it may be useful to evaluate sleepiness at irregular intervals. However, since it requires at least 15 min for evaluating sleepiness using MSLT, there were methodological limits on the use of shorter sampling times at irregular intervals in the present study. Therefore, in future it might be necessary to improve these sleepiness measures regarding the time of measurement, as well as changing the sampling times of 30 min.

However, the present findings revealed the possible existence of the several basic ultradian components in daytime sleepiness. In order to investigate the extent to which these components will influence human behavior, further studies will be needed.

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