

EEG activities during elicited sleep onset REM and NREM periods reflect different mechanisms of dream generation

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Abstract

Objective: To be the first to compare EEG power spectra during sleep onset REM periods (SOREMP) and sleep onset NREM periods (NREMP) in normal individuals and relate this to dream appearance processes underlying these different types of sleep periods.

Methods: Eight healthy undergraduates spent 7 consecutive nights in the sleep lab including 4 nights for SOREMP elicitation using the Sleep Interruption Technique. This enabled us to control preceding sleep processes between SOREMP and NREMP. EEG power spectra when participants did and did not report 'dreams' were compared between both types of sleep. Sleep stages, subjective measurements including dream property scores, sleepiness, mood, and tiredness after awakenings were also examined to determine their consistency with EEG findings.

Results: Increased alpha EEG activities (11.72–13.67 Hz) observed mainly in the central area were related to the absence of SOREMP dreams and appearance of NREMP dreams. Analyses of sleep stages combining two studies (16 participants) also supported the Fast Fourier Transform findings, showing that when dreams were reported there were decreased amounts of stage 2 and increased stage REM in SOREMP and increased stage W in NREMP. SOREMP dreams were more bizarre than NREMP dreams. Participants felt more tired after SOREMP with dreams than without dreams, while the opposite was observed after NREMP episodes.

Conclusions: EEG power spectra patterns reflected different physiological mechanisms underlying generation of SOREMP and NREMP dreams. The same relationships were also reflected by sleep stage analyses as well as subjective measurements including dream properties and tiredness obtained after awakenings. This study not only supports the hypothesized relationships between REM mechanisms and REM dreams as well as arousal processes and NREM dreams, it also provides a new perspective to dream research due to its unique techniques to awaken participants and collect REM dreams during experimentally induced SOREMP.

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1. Introduction

1.1. Physiological and functional aspects specific to REM sleep

Rapid eye movement (REM) sleep seems to have a significant role in specific neurocognitive functions. This has been supported by evidence showing a relationship between increased REM activities and intensive learning before school exams (Smith and Lapp, 1991), intensive learning

of a second language (De Koninck et al., 1989, 1990), learning of Morse code (Mandai et al., 1989), enhancement of procedural (Smith, 1995; Plihal and Born, 1997) and associative memory (Stickgold et al., 1999), and improvement on a basic visual discrimination task (Karni et al., 1994; Stickgold et al., 2000).

Specific activation in particular brain regions during REM sleep has been found using positron emission tomography (Maquet et al., 1996; Braun et al., 1998). Gamma-frequency EEG activities (30–70 Hz) have been reported to be related to cognitive activities both specifically in wakefulness and REM sleep (Llinas and Ribary, 1993; for review, see Gottesmann, 1999, pp. 473–477; Hobson et al., 2000b, p. 1345). Also, in ERP studies, the P300 compo-

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ment (Cote and Campbell, 1999) as well as N1 and P2 have been reported to show specific morphology during REM sleep (for review, see Campbell et al., 1992). These findings allow us to speculate that some cognitive processes during REM sleep are similar to those during wakefulness.

On the other hand, NREM sleep is characterized by decreased cerebral activation due to the ongoing deactivation of the reticular activation system (Hobson et al., 2000b; for review, see Gottesmann, 1999). Spindle wave activity observed in stage 2 of NREM sleep has been reported to reflect hyperpolarization of the thalamocortical relay cells which strongly reduce the transmission of sensory information through the thalamus (Halasz, 1993).

1.2. Controversy over the mechanisms of dream generation

In spite of the extensive evidence indicating specific activated physiological and functional states during REM sleep when compared to NREM sleep described above, the hypothesized specific relationship between REM physiological mechanisms and dreams has been criticized by many researchers (Antrobus, 1983; Foulkes and Schmidt, 1983; Cavallero et al., 1990, 1992; Cicogna et al., 1991; Foulkes, 1993; Rosenlicht et al., 1994; Antrobus et al., 1995). Since dreamlike mentation reports are obtained not only after awakening from REM sleep, but also from NREM sleep, sleep onset, or relaxed awakening, it has been claimed that dreaming can take place even without REM sleep mechanisms (for review, see Foulkes, 1996).

A central claim is that the differences observed in verbal reports obtained from REM and NREM sleep are not due to the qualitative differences of REM and NREM sleep mechanisms, but rather due to the different levels of cortical activation (Antrobus, 1983; Foulkes and Schmidt, 1983; Cavallero et al., 1990, 1992; Foulkes, 1993, 1996; Rosenlicht et al., 1994; Bosinelli, 1995; Feinberg and March, 1995). Antrobus et al. (1995) found significant effects for both the REM–NREM cycle and the diurnal rhythm on the intensity of subjects' visual images and concluded that a cortical activation pattern, which is common to both the REM–NREM cycle and the diurnal rhythm, determines the intensity of visual imagery and cognitive activity during sleep.

However, comparing dream recall obtained from sleep onset, stage 2, and stage REM, Casagrande et al. (1996) found that there were still inter-stage differences in bizarreness in the global measure and visual imagery in the psycholinguistic measure even after controlling for narrative length, which supported the hypothesis that different neural states specific to REM sleep contribute to the differences in mentation among sleep stages.

Other researchers have proposed alternative models for dream production, such as the functional state-shift hypotheses (Koukkou and Lehmann, 1983) where dreaming is thought to depend on the proximity of EEG activities between pre-awakening and post-awakening or the 'covert

REM hypotheses' (Nielsen, 2000a,b) theorizing the existence of covert REM sleep processes during NREM sleep or sleep onset which produce the dreamlike activity occurring in NREM sleep.

1.3. Methodological difficulties of experimental awakenings from sleep

In most dream studies, mentation reports are collected by awakening participants from their natural sleep. However, because of the rigidity and regularity of the NREM–REM sleep cycle, it has been almost impossible to compare NREM and REM mentation without the potential contaminating effects of the previous NREM or REM periods (Herman et al., 1978). That is, in any experimental setting where REM and NREM periods are defined as independent variables, prior sleep stage changes and accumulated sleep length and/or depth could be confounding factors. Thus, it is questionable whether REM mentation obtained from REM awakenings was truly generated only from REM periods and uninfluenced by prior NREM periods and awakenings.

Considering these confounds, Takeuchi et al. (2001a) tested the hypothesis that different physiological mechanisms underlie dreaming during REM and NREM sleep using the Sleep Interruption Technique (SIT; Takeuchi et al., in press; Miyasita et al., 1989a; see Section 2). This technique allowed Takeuchi et al. (2001a) to elicit sleep onset REM periods (SOREMP) and sleep onset NREM periods (NREMP), thus controlling preceding sleep length and sleep stage. Their study demonstrated that the appearance of SOREMP dreams was strongly related to the amount of stage REM, while NREM sleep onset dreams were related to the amount of stage W (wakefulness and/or arousals).

Thus, different physiological processes seem to underlie dream generation in SOREMP and NREMP episodes.

1.4. EEG activity and sleep stages

Supposing that EEG activity patterns reflect activation in the specific anatomical pathways related to dream generation, we would expect that more specific EEG activities quantified using Fast Fourier Transform (FFT) analyses during dreaming would give us more precise information about the sleep processes related to dream generation. Previous findings examining the relationship between dream and EEG activities seem to be diverse depending on the protocol or time frame of EEG analysis. For instance, Williamson et al. (1986) reported a relationship between beta power and dream recall from stage 2 mentation. Morel et al. (1991) did not find a relationship between successful recall and EEG activity during 30 s of pre-stage 2 awakening but found a significant relationship between successful recall and reduced levels of sigma activity (12–16 Hz) in post-stage 2 awakening. Rochlen et al. (1998) found an interaction in which a greater shift from sleep to wakefulness in beta and delta (0.5–4 Hz) activities was related to recall failure in control participants but was

related to recall success in participants with depression although they analyzed REM and NREM mentation together.

1.5. Objective

This study is the first to employ FFT analyses to compare EEG activities underlying SOREMP and NREMP dreaming using healthy participants. Using the SIT allows us to compare EEG spectral power between elicited SOREMP and NREMP without the confounds of preceding sleep processes.

Our hypotheses are: (1) EEG power spectra patterns will reflect different physiological mechanisms underlying generation of SOREMP and NREMP dreams; (2) regression analyses using sleep stage results merged from previous and current studies will support the findings from the EEG-FFT analyses; (3) subjective measurements, including dream content and subjective tiredness after awakening, will reflect the above physiological differences.

2. Methods

2.1. Participants

Eight healthy undergraduates (19–22 years old, 5 females) without any psychiatric history or sleep disorders participated in our study. They were carefully screened to avoid participants with potential narcolepsy-related symptoms such as cataplexy and sleep attacks. Informed consent was obtained after an explanation of the entire process of our study. Participants were asked to maintain their regular sleep cycle as much as possible beginning 1 week before the study. During this time, they kept note of their sleep pattern and general health. None of them consumed any alcohol or medication that would influence their sleep for the duration of the study. Data from 7 participants were used for the present analyses since one (male) participant showed two episodes of SOREMP at the initial sleep onset during the adaptation and baseline nights (see Section 2.2), which might be potentially regarded as meeting the diagnostic criteria for narcolepsy (American Sleep Disorders Association, 1990).

2.2. Sleep interruption procedures

The SIT was developed to elicit SOREMP from normal individuals by manipulating the NREM–REM sleep cycles (see Takeuchi et al., in press) and has enabled examination of mentation during SOREMP such as sleep paralysis (Takeuchi et al., 1992, 2002a), hypnagogic hallucinations (Takeuchi et al., 1994), and dreaming (Takeuchi et al., 2001a,b) in addition to the mechanisms of thermoregulation during sleep (Sasaki et al., 1993).

The SIT utilizes the findings that SOREMP will appear in normal sleepers when circadian and/or ultradian rhythms

are disrupted (Weitzman et al., 1970; Carskadon and Dement, 1975, 1980; Schulz and Tetzlaff, 1982; Fukuda et al., 1987; Foret et al., 1990; Bishop et al., 1996). It enables the systematic elicitation of SOREMP from normal individuals yielding the following findings: (1) there is a positive linear relationship between NREM duration prior to the sleep interruption (SI) and the probability of SOREMP occurrence (Miyasita et al., 1989b); and (2) the probability of SOREMP was greater in the NREM–REM cycle in the later part of the night (Sasaki et al., 2000). Another benefit of using SOREMP is its reliability as an analysis window of physiological concomitants of dreaming due to its briefness and proximity to the corresponding retrospective reports.

Participants spent 7 consecutive nights in our sleep lab (the 1st and the 2nd nights, adaptation nights; the 3rd night, baseline night; and the 4th to 7th nights, experimental nights). During the experimental nights, the SIT was applied to elicit SOREMP for comparison with NREMP in terms of EEG activities, dream recall rate, dream properties, and subjective measurements after awakenings. Each participant's sleep was interrupted for 1 h after 50 min of NREM sleep had elapsed since the termination of the 3rd REM period in the NREM–REM sleep cycle (Fig. 1).

As seen in Fig. 1, during the interruption, participants were assigned the following tasks to maintain minimal arousal: (1) a 6 min Alpha Attenuation Test (AAT; Michimori et al., 1994); (2) a 30 min auditory vigilance task (VT); and (3) a 6 min AAT. They were then allowed to return to sleep and were awakened again after 5 min had elapsed from either the first appearance of REMs (SOREMP episode) or a sleep spindle/K-complex indicative of stage 2 sleep (NREMP episode). In the event that the 1st REMs were observed after a spindle/K-complex, the participant was awakened 5 min after these REMs and this was considered a SOREMP episode. Immediately following the awakening, participants filled out a brief questionnaire concerning their present sleepiness (Visual Analogue Sleepiness Scale; VASS), mood, tiredness, and mental states prior to awakening (see Section 2.4). This procedure (tasks – returning to sleep – awakening at 5 min after SOREMP/NREMP – mentation and subjec-

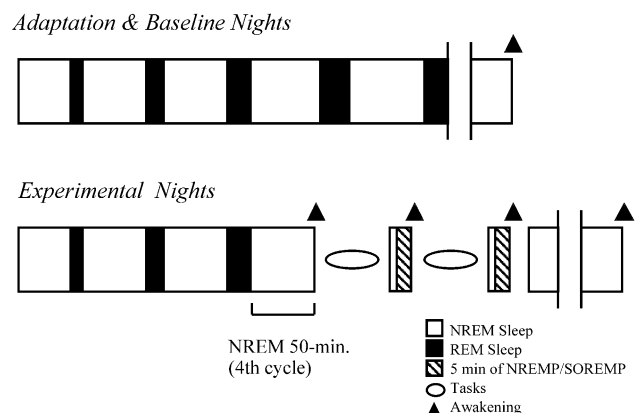


Fig. 1. Experimental design.

tive data collection – return to sleep – awakening 5 min after REMs/K/spindle – dream data collection) was repeated once more. After completion of these procedures, participants slept until their net sleep reached its usual sleep length.

2.3. Collection of mentation reports

Participants were awakened by tone bursts (1000 Hz, duration 5 s, ISI 10 s) through earphones. The tones were presented in 5 dB steps, beginning from 10 dB below their alert waking thresholds. The participants were instructed to squeeze and hold a ball attached to their dominant hand for 3–5 s when they heard the tone. They were then asked to fill out a questionnaire that included the VASS, rating scales on their mood, tiredness, and their mental states just prior to the tone stimulus. To avoid contamination of arousal effects in their mentation reports, questions for these subjective states were minimal and brief. If they reported having any kind of mental activities, they were asked to complete the rating scales assessing the properties of their mental activities (English version of the Dream Property Scale, DPS-E; Takeuchi et al., 2001b; see Section 2.3.2).

2.3.1. Definition of mentation reports

The definition of dream seems to be diverse among studies (Nielsen, 2000a). It is common for any mentation reports to be categorized as dreaming based on each experimenter's own criteria. However, Herman et al. (1978) suggested in their review on the problems in dream research that there is a high potential risk of experimenters' expectations intruding into the data. Therefore, in order to avoid the possible biases caused by the experimenter's judgments, we left the definition of the mentation to each participant's own criteria expecting that the error variance caused by participants' judgments would be more randomly distributed than the experimenter's judgment. Thus, their mental activities were classified strictly based on the participants' free marking on the questionnaire just after awakening. In the questionnaires, we inquired about their mentation as follows, 'Just before squeezing the ball, did you have some experience?'. Responses available to this question were 'dreaming' (either 'I can recall its content' or 'I cannot recall its contents'), 'thinking' (either 'I can recall its content' or 'I cannot recall its contents'), 'other' ('Please describe concretely'), and 'none'. To make a clear comparison among independent variables, only episodes where 'dreaming' ('I can recall its content') (dream), and 'none' (nothing) were used in EEG-FFT analyses.

2.3.2. DPS-E

The DPS-E gives us normed scores for 4 basic properties based on 15 polar adjectives with 7 point Likert scales (standardized): emotionality (relaxed–tense, pleasant–unpleasant, unconcerned–worried, calm–twitchy), rationality (risky–cautious, unfamiliar–familiar, strange–ordinary,

chaotic–orderly), activity (drowsy–alert, vague–vivid, quiet–noisy, discontinuous–continuous), and impression (fuzzy–clear, unfocused–focused, foggy–clarity). After completing the DPS-E, participants were asked to verbally report their mental experiences, which were recorded for later transcription.

2.4. Subjective states after awakenings

VASS scores were calculated based on the absolute distance from the edge of a line (sleepy to alert) to the point which participants marked as indicative of their current sleepiness. The scores of tiredness and mood were computed based on the participants' assessing their subjective states using 5 point Likert scales: tiredness ('extremely' to 'not at all') and mood ('bad' to 'good').

2.5. Tasks during the SI

2.5.1. AAT

The AAT is an objective measure of sleepiness, expressed by the ratio of eyes closed to eyes open alpha power, and has been shown to be correlated with the Multiple Sleep Latency Test (MSLT) (Michimori et al., 1994). During the AAT, participants were asked to alternately open and close their eyes every 30 s for a total of 6 min.

2.5.2. VT

The VT is also an objective measure of sleepiness, indicated by the participant's performance. It also serves to keep the participant's arousal at a minimal level. Two types of tones (1000 Hz) with slightly different durations (target: 700 ms, $P = 0.2$; non-target: 500 ms) were presented through headphones in a pseudo-randomized fashion with a variable ISI (mean 2 s). Each block contained 300 trials (60 targets), lasted 10 min, and was repeated 4 times. The participants were required to detect the longer tone and press a button as quickly as possible.

2.6. Recordings

Eighteen channels from standard EEG sites (Fp1, Fp2, F3, Fz, F4, F7, F8, C3, Cz, C4, T4, T5, T6, P3, Pz, P4, O1, O2) with EOG (outer canthus) referred to A2 (later re-referenced offline to averaged mastoid using A1) and bipolar submental EMG were digitized and stored with a sampling rate of 200 Hz using Harmonie™ (Stellate Systems Inc., Montreal, Canada).

2.7. Physiological measurements

2.7.1. EEG power spectra

EEG power spectra were computed using a FFT routine with 5.12 s FFT length every 5 s using Hanning tapered windows with a 50% overlap. We chose to use 5 s epochs to facilitate comparisons with 30 s epochs for the sleep stage scoring. Epochs with artifacts were discarded from further analyses. Finally, EEG spectra with a resolution of 0.39 Hz

were summed to obtain the mean power spectra of 10 bandwidths (delta (d), 1.95–3.91 Hz; theta1 (t1), 3.91–5.86 Hz; theta2 (t2), 5.86–7.81 Hz; alpha1 (a1), 7.81–9.77 Hz; alpha2 (a2), 9.77–11.72 Hz; alpha3 (a3), 11.72–13.67 Hz; sigma1 (s1), 13.67–15.62 Hz; sigma2 (s2), 15.62–17.58 Hz; beta1 (b1), 17.58–23.82 Hz; beta2 (b2), 23.82–29.69 Hz). To minimize the effect that this may have had on the statistical analyses, specifically considering individual differences observed in EEG amplitudes, standardized (*z*) scores of power spectra were calculated based on the mean and SD for each participant of all episodes in the experimental nights in each bandwidth. To examine fluctuation of EEG activities, coefficient of variation (CV) values were also calculated based on the absolute mean and SD of power for each participant during each episode.

2.7.2. Sleep stages

Each 30 s epoch was scored based on standard criteria (Rechtschaffen and Kales, 1968) but using Cz. Sleep onset was defined as the beginning point of the first 30 s epoch of continuous stage 1, 2, or REM. The definition of SOREMP in clinical settings is usually REM latency of 15 min or less. However, this operational definition is based on the protocol of the MSLT itself, which requires that patients be awakened after 15 min has elapsed after their sleep onset. However, there is still a possibility that REM sleep might appear if participants were allowed to sleep longer than 15 min. Therefore, in this paper, SOREMP was defined as REM sleep appearing within 25 min after sleep onset based on the bimodal distribution of SOREMPs observed after SI in normal participants (Bes et al., 1996; Miyasita et al., 1989a; Sasaki et al., 2000). Whether each episode was SOREMP or NREMP depended on whether the episode contained stage REMs (SOREMP) or not (NREMP).

2.8. Statistical tests

SPSS 9.0 for Windows (SPSS Inc., Chicago, IL) was used for statistical analyses.

To test the effect of sleep episodes (SOREMP/NREMP) and dream appearance (dream/nothing) on EEG power spectra, 2 × 2 ANOVAs were performed. Taking into account the potential Type I error caused by the number of independent treatments for the sample size, (1) the effects were considered significant only when the alpha probability exceeded the 0.025 level, and (2) we only considered effects which were observed at the same frequency across several proximal sites or across several contiguous frequency bands at the same site.

Hierarchical regression analyses were performed to test the effect of the amount of each sleep stage on dream appearance to examine consistency with FFT analyses. We performed overall analyses by merging data obtained from the current study with that of Takeuchi et al. (2001a) (32 SOREMP dreams, 8 NREMP dreams, 8 SOREMP nothing, 47 NREMP nothing), hypothesizing that these two data

sets will show the same effects as Takeuchi et al. (2001a). To compensate for the different locations (Japan and Canada) where data were collected and the variance of sleep length after SI to SOREMP/NREMP awakenings, both variables (location, sleep length) were partialled out on the 1st and 2nd steps. Then, time in each sleep stage was entered in the 3rd step. Partialling out in the 1st and 2nd steps was to remove the effect of total sleep length and different condition in each experiment (Japanese and Canadian) from the effect of each sleep stage if any. This method is known to produce a statistically cleaner measure by eliminating effects caused by the 3rd factors while retaining information about the origins of the useful variance (Cohen and Cohen, 1983).

Considering the small sample size, *U* tests were used to compare DPS-E scores for the 4 properties reported in NREMP and SOREMP dreams.

Three univariate ANOVAs were performed to test the effect of sleep episodes (SOREMP/NREMP) and dream appearances on subjective states (VASS, tiredness, mood).

3. Results

3.1. Mental activities obtained from SOREMP and NREMP in experimental nights

A total of 56 sleep episodes were obtained after interruptions during the 4 experimental nights from 7 participants. Four episodes were discarded due to technical difficulties. Out of the remaining 52 episodes, there were 29 SOREMP and 19 NREMP episodes as indicated in Table 1. Four episodes did not meet the standard criteria (Rechtschaffen and Kales, 1968) of either stage REM or stage 2 and were classified as ‘unidentified’ (Table 1). As indicated in Table 1, participants were more likely to regard their mental activities as *dream* when they were awakened from SOREMP episodes.

3.2. Dream occurrences and EEG activities

There were no main effects of either sleep episodes or dream occurrences on mean *z* score or CV except for a marginal trend towards an increased *z* score for Cz-delta during SOREMP (<0.027). Interestingly, however, as summarized in Table 2, there were consistent and significant interactions on the mean power spectra for the central and

Table 1
Mental activities obtained from NREMP and SOREMP episodes

	NREMP (%)	SOREMP (%)	Unidentified
Dream	3 (16)	15 (52)	0
Thought	2 (11)	0 (0)	2
Recall failure	9 (47)	5 (17)	1
Nothing	5 (26)	9 (31)	1
Total	19 (100)	29 (100)	4

Table 2
Interactions between sleep episodes and dream occurrences on mean FFT power spectra^a

Sites/band	d	t1	t2	a1	a2	a3	s1	s2	b1	b2
F3	–	–	–	–	–	–	–	–	–	–
Fz	–	–	–	0.070	0.030 ⁺	0.042 ⁺	0.012*	0.060	–	–
F4	0.021*	0.092	–	0.032 ⁺	0.027 ⁺	0.040 ⁺	0.032 ⁺	–	–	–
C3	–	0.064	–	0.096	0.054	0.051	0.048 ⁺	–	–	–
Cz	–	–	–	0.011*	0.042 ⁺	0.017*	0.034 ⁺	–	–	–
C4	0.096	0.020*	0.039 ⁺	0.017*	0.007**	0.009**	0.007**	0.100	–	–
P3	–	0.051	–	–	0.083	0.018*	0.028 ⁺	–	–	–
Pz	–	–	–	0.047 ⁺	0.123	0.042 ⁺	0.056	–	–	–
P4	–	–	–	0.063	0.066	0.040 ⁺	0.032 ⁺	–	–	–
O1	–	–	–	–	–	0.094	–	–	–	–
O2	0.096	–	–	0.086	0.064	0.017*	0.021*	0.061	–	–

^a P values less than or equal to 0.10 are indicated (d.f. = 1, 28, **P < 0.01, *P < 0.025, ⁺P < 0.05, – NS). d, delta (1.95–3.91 Hz); t1, theta1 (3.91–5.86 Hz); t2, theta2 (5.86–7.81 Hz); a1, alpha1 (7.81–9.77 Hz); a2, alpha2 (9.77–11.72 Hz); a3, alpha3 (11.72–13.67 Hz); s1, sigma1 (13.67–15.62 Hz); s2, sigma2 (15.62–17.58 Hz); b1, beta1 (17.58–23.82 Hz); b2, beta2 (23.82–29.69 Hz).

parietal sites in the alpha and sigma bands (7.81–15.62 Hz) although there was no interaction in CV.

Fig. 2 enables us to visualize these interactions between sleep episodes and dream occurrences on alpha and sigma EEG activities. The central area (Cz) showed the most marked effects, that is, SOREMP without dream showed increased alpha and sigma EEG activities compared to SOREMP with dream, whereas the opposite relationship was observed in NREMP. This pattern seems to be spread out to proximal frontal and parietal sites, although the left

frontal hemisphere (F3) did not show this pattern. Moreover, the interaction was observed in a slightly broader bandwidth (alpha and sigma1) in the central area compared to the frontal, parietal, occipital area (mainly alpha3 and sigma1; Table 2). In the occipital area, only the right hemisphere (O2) showed this interaction.

3.3. Dream occurrences and sleep stages

The data from Takeuchi et al. (2001a), combined with the

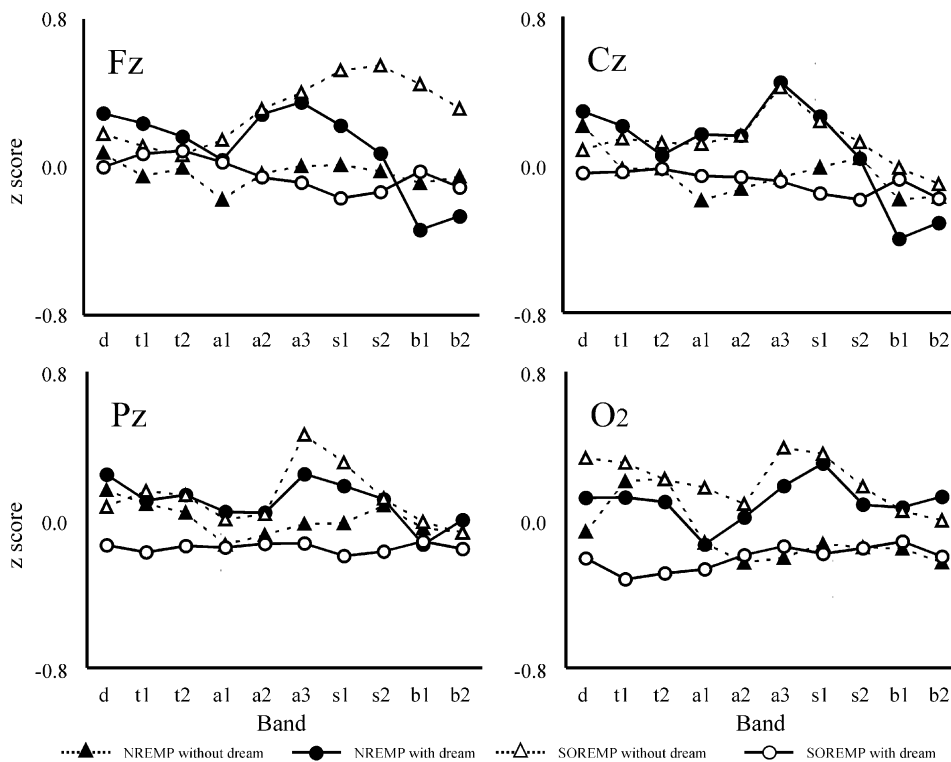


Fig. 2. Mean power spectra for SOREMP and NREMP with/without dream at Fz, Cz, Pz, and O2. d, delta (1.95–3.91 Hz); t1, theta1 (3.91–5.86 Hz); t2, theta2 (5.86–7.81 Hz); a1, alpha1 (7.81–9.77 Hz); a2, alpha2 (9.77–11.72 Hz); a3, alpha3 (11.72–13.67 Hz); s1, sigma1 (13.67–15.62 Hz); s2, sigma2 (15.62–17.92 Hz); b1, beta1 (17.92–23.82 Hz); b2, beta2 (23.82–29.69 Hz).

Table 3

Semipartial correlations (sr) obtained by multiple regression analyses using the time spent in each sleep stage to predict dream recall from two studies

		Stage W	Stage 1	Stage 2	Stage REM
NREMP episodes	sr	+0.414	+0.109	-0.160	-
	(P value)	(0.000)	(NS)	(NS)	-
SOREMP episodes	sr	-0.062	-0.047	-0.300	0.317
	(P value)	(NS)	(NS)	(0.016)	(0.010)

current data set, yielded a total of 47 SOREMP dreams, 11 NREMP dreams, 17 SOREMP nothing, and 52 NREMP nothing. Dream occurrences were regressed on time spent in sleep stage (W, 1, 2, REM) for each SOREMP episode and sleep stage (W, 1, 2) for each NREMP episode. The location and sleep length accounted for 3.7% ($R = 0.192$, $P = 0.129$) and 5% ($R = 0.294$, $P = 0.077$), respectively, in predicting SOREMP, while in NREMP episodes each accounted for 4.1% ($R = 0.201$, $P = 0.114$) and 5.6% ($R = 0.310$, $P = 0.059$), respectively. As indicated in Table 3, dreams were related to an increase in the amount of stage REM and decreased stage 2 during SOREMP, while dreams were related to the appearance of stage W in NREM episodes.

3.4. Dream properties between SOREMP and NREMP episodes

Fifteen dreams from SOREMP episodes and 3 dreams from NREMP episodes in the current study were obtained based on participants' responses on the DPS-E (Takeuchi et al., 2001b).

Due to the sample size and a lack of homogeneity of variances, Mann–Whitney U tests were used based on median scores. The U tests showed that SOREMP and NREMP dreams differed significantly on the rationality scale ($U = 5.50$, $z' = -2.023$, $P < 0.05$). Although the

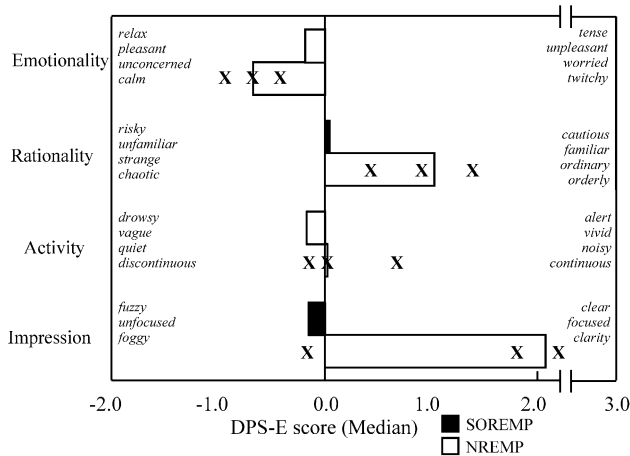


Fig. 3. Comparison of dream property scores in SOREMP and NREMP. Each bar indicates median score and 'x' indicates each DPS-E score of NREMP dream.

sample size was small, at least none of the NREMP dreams were regarded as 'bizarre' in nature (Fig. 3).

3.5. Subjective states after awakening

There were no main effects for sleep episodes and dream occurrences on mood or sleepiness assessed by the VASS. However, a significant interaction on participants' tiredness ($F(1, 28) = 4.506$, $P < 0.05$) was observed as seen in Fig. 4. After awakening from SOREMP with dreams, participants felt more tired than after SOREMP without dreams. Conversely, they felt more tired after NREMP without dreams than after NREMP with dreams.

4. Discussion

4.1. EEG activities underlying dream appearance processes in SOREMP and NREMP

This is the first study to examine EEG activities during SOREMP and NREMP dreaming. As we hypothesized, EEG power spectra analyses indicated different processes related to dream occurrences in SOREMP and NREMP. Interactions were observed in the EEG-FFT power spectra analyses mainly in central sites in a2, a3, and s1 (9.77–13.67 Hz). We observed decreased spectral power in these frequencies during SOREMP episodes with dreaming and

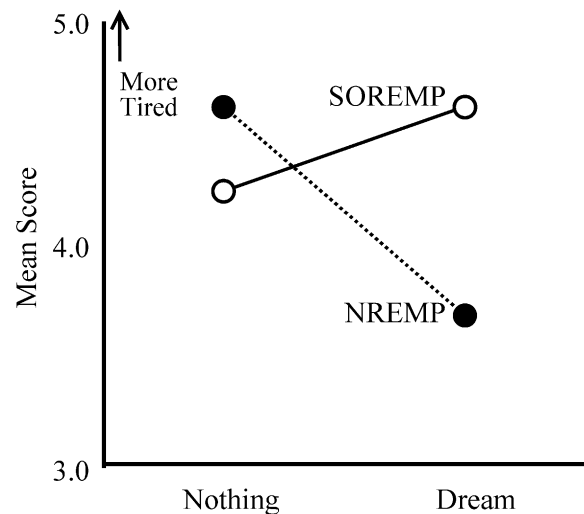


Fig. 4. Comparison of tiredness scores after awakenings from SOREMP and NREMP with/without dreams.

NREMP episodes without dreaming but increased spectral power during NREMP episodes with dreaming and SOREMP episodes without dreaming.

The previous findings of a relationship between dream and EEG seem to be quite varied depending on the protocol or method of analysis, e.g. dream recall and beta activity in stage 2 (Williamson et al., 1986), dream recall and decreased sigma activity only in post-stage 2 awakening (12–16 Hz; Morel et al., 1991), a greater shift from sleep to wakefulness in beta and delta (0.5–4 Hz) activities and recall failure in control participants but recall success in depressed participants when REM and NREM mentation were analyzed together (Rochlen et al., 1998). However, in general, the consensus appears to be that there is a relationship between some beta activity and dream recall. For example, studies examining high frequency (beta-gamma) EEG during sleep seem to indicate that these EEG frequencies are possible markers of activated REM processes (Gross and Gotman, 1999; Uchida et al., 1994; Ferri et al., 2000; for review of the studies, see pp. 473–477 in Gottesmann, 1999).

However, we did not find any specific interactions in beta activities. One possibility may be attributed to the specific nature of SOREMP without a (or with a very short) preceding NREM period. Some physiological activities suggestive of REM mechanisms are reported to be activated up to 15 min prior to explicitly observed REM sleep, such as heart rate variability (Scholz et al., 1997), suppression of sweating effector activity (Dewasmes et al., 1997), and N300 attenuation (Niiyama et al., 1998). Therefore, it is suspected that SOREMP may be ‘immature’ REM sleep that appears before typical REM-related components are fully activated. In other words, during SOREMP some REM-related mechanisms underlying beta EEG activities might not have been activated enough to be reflected in the EEG.

Werth et al. (1997) reported that the distribution of the peak frequencies of sleep spindles across participants and derivations showed a bimodal pattern at 11–12 Hz in broader sites and 13 Hz in C3, P3, and O1. Hence, one might wonder if alpha-sigma activities observed in the current study could be regarded as spindle activities. However, sleep stage analyses clearly showed increased stage W in NREMP dream and increased stage REM and decreased stage 2 in SOREMP. In addition, given that spindle activities were related to dream appearances, more dreams should have been reported from NREMP. Therefore, it seems logical to interpret increased alpha-sigma activities as related to arousal processes (primarily alpha) rather than spindle-related activities (primarily sigma).

Moreover, the previous findings examining arousals during sleep seem to support our hypothesis that NREM dreaming is related to the intrusion of arousal processes. For instance, external stimuli have been shown to influence mentation during NREM sleep but not REM sleep (Castaldo and Shevrin, 1970; Conduit et al., 1997). Participants are often unaware of micro-arousals even though their EEG

clearly shows arousal during sleep (Ogilvie et al., 1989; Ogilvie, 2001). The micro-arousals during sleep are reported to occur as often as 4–26/h depending on the definition of arousal (Mathur and Douglas, 1995). Furthermore, NREM dreaming is likely to increase among people whose sleep is generally disturbed (Zimmerman, 1970).

That is, during NREM sleep, people may incorporate some information from external surroundings into their memory during brief arousals and later they amend or reconstruct these mental activities as ‘dream’ as if they had been experienced during sleep. This possibility may also be supported by the finding that misperception or uncertainty during the last states before awakening is likely to happen in NREM awakenings more than REM awakenings (Antrobus and Saul, 1980; Sewitch, 1984a,b).

The inverse relationship between SOREMP dream and alpha-sigma frequencies can be construed to be that dream processes are more activated when REM sleep is not interrupted by these arousal-related EEG activities. This can be supported by many findings suggesting a relationship between REM sleep and some type of cognitive function (De Koninck et al., 1989, 1990; Plihal and Born, 1997; Karni et al., 1994; Smith, 1995; Stickgold et al., 1999, 2000), specific neuroanatomical findings (Maquet et al., 1996; Braun et al., 1998; Madsen et al., 1991) and neurophysiological patterns (Llinas and Ribary, 1993; Cote and Campbell, 1999).

Taking previous findings, our current FFT results, and the sleep stage analyses of the two merged data sets together, arousal components suggested by EEG activities seem to reflect different processes in NREMP and SOREMP dream occurrences. It seems logical to regard NREM dreams as a by-product of arousal processes and SOREMP dreams as a by-product of REM mechanisms.

4.2. Subjective measurements

In the current study, we also examined subjective measurements including dream properties, sleepiness, tiredness, and mood right after awakenings to determine whether these would be consistent with our EEG findings. The small sample size may limit our ability to confidently demonstrate differences between NREMP and SOREMP dreams. However, we did find significant differences in the distribution of ‘bizarreness’ scores, suggesting that SOREMP dreams are likely to entail more bizarre properties compared to NREMP dreams. This is in accordance with previous findings that REM dreams are visually intensive, emotional, bizarre and related to specific physiological activities (for a review of dreams and their relationship with REM sleep, see Stickgold et al., 2001).

The interaction on the tiredness measurement showed that participants felt more tired after SOREMP with dreams and after NREMP without dreams. In our current EEG analysis, increased dream occurrences appeared to be related to continuous REM sleep during SOREMP episodes,

and intrusions of arousal during NREMP episodes. Considering potential carry-over effects (Bertini and Violani, 1992) from the preceding sleep state, increased tiredness could be regarded as reflecting the preceding states – persistent sleep process during SOREMP with dreams and those during NREMP without dreams. On the other hand, less tiredness may reflect a readiness for awakening (higher arousal) during SOREMP without dreams and NREM with dreams.

Therefore, taking the EEG and subjective results together, different levels of tiredness observed as an interaction between sleep episodes and dream occurrences seem to support our hypothesis of different mechanisms for SOREMP and NREMP dreams.

Thus, our subjective measurements also support the current EEG findings suggesting that dream generation is related to REM mechanisms during SOREMP, but arousal-related mechanisms during NREMP.

In terms of phenomenological aspects, SOREMP shows the same physiological characteristics as REM sleep except for its preceding sleep length. Therefore, to generalize the current findings from SOREMP to typical REM sleep we will need to compare EEG activities as well as dream properties between SOREMP and typical REM sleep. At least within the current study and considering previous findings specific to REM sleep as described above, SOREMP dreams appear to share not only common characteristics and probably generating mechanisms as dreams from typical REM sleep but also similar differences from NREMP dreams.

5. Conclusion

EEG power spectra patterns reflected different physiological mechanisms underlying the generation of SOREMP and NREMP dreams. This result was also supported by sleep stage analyses. Subjective measurements including dream properties and tiredness also reflected these physiological findings. Our findings support the hypothesis of a close (perhaps exclusive) relationship between dream generation and REM mechanisms that previous researchers (Hobson et al., 2000a; Nielsen, 2000a,b) have outlined. Further examination will be needed to determine if the current findings can be generalized to typical REM sleep.

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References

- American Sleep Disorders Association. ICSD – international classification of sleep disorders: diagnostic and coding manual, Rochester, MN: Diagnostic Classification Steering Committee, Thorpy MJ, Chairman, 1990.
- Antrobus JS. REM and NREM reports: comparison of word frequencies by cognitive classes. *Psychophysiology* 1983;20:562–568.
- Antrobus H, Saul H. Sleep onset: subjective, behavioral and electroencephalographic comparisons. *Waking Sleeping* 1980;4:259–270.
- Antrobus J, Kondo T, Reinsel R. Dreaming in the late morning: summation of REM and diurnal cortical activation. *Conscious Cogn* 1995;4:275–299.
- Bertini M, Violani C. The postawakening testing technique in the investigation of cognitive asymmetries during sleep. In: Antrobus JS, Bertini M, editors. *The neuropsychology of sleep and dreaming*, Hillsdale, NJ: Lawrence Erlbaum Associates, 1992. pp. 47–62.
- Bes FW, Jobert M, Cordula ML, Schulz H. The diurnal distribution of sleep propensity: experimental data about the interaction of the propensities for slow-wave sleep and REM sleep. *J Sleep Res* 1996;5:90–98.
- Bishop C, Rosenthal L, Helmus T, Roehrs T, Roth T. The frequency of multiple sleep onset REM periods among subjects with no excessive daytime sleepiness. *Sleep* 1996;19:727–730.
- Bosinelli M. Mind and consciousness during sleep. *Behav Brain Res* 1995;69:195–201.
- Braun AR, Balkin TJ, Wesensten NJ, Gwadry F, Carson RE, Varga M, Baldwin P, Belenky G, Herscovitch P. Dissociated pattern of activity in visual cortices and their projections during human rapid eye movement sleep. *Science* 1998;279:91–95.
- Campbell K, Bell I, Bastien C. Evoked potential measures of information processing during sleep. In: Broughton RJ, Ogilvie RD, editors. *Sleep, arousal, and performance*, Boston, MA: Birkhauser, 1992. pp. 88–116.
- Carskadon MA, Dement WC. Sleep studies on a 90 minute day. *Electroenceph clin Neurophysiol* 1975;39:145–155.
- Carskadon MA, Dement WC. Distribution of REM sleep on a 90 minute sleep-wake schedule. *Sleep* 1980;2:309–317.
- Casagrande M, Violani C, Lucidi F, Buttinelli E, Betrini M. Variations in sleep mentation as a function of time of night. *Int J Neurosci* 1996;85:19–30.
- Castaldo V, Shevrin H. Different effect of an auditory stimulus as a function of rapid eye movement and non-rapid eye movement sleep. *J Nerv Ment Dis* 1970;150:195–200.
- Cavallero C, Foulkes D, Hollifield M, Terry R. Memory sources of REM and NREM dreams. *Sleep* 1990;13:449–455.
- Cavallero C, Cicogna P, Natale V, Occhionero M, Zito A. Slow wave sleep dreaming. *Sleep* 1992;15:562–566.
- Cicogna P, Cavallero C, Bosinelli M. Cognitive aspects of mental activity during sleep. *Am J Psychol* 1991;104:413–425.
- Cohen J, Cohen P. *Applied multiple regression/correlation analysis for the behavioral sciences*, Hillsdale, NJ: Lawrence Erlbaum Associates, 1983.
- Conduit R, Bruck D, Coleman G. Induction of visual imagery during NREM sleep. *Sleep* 1997;20:948–956.
- Cote KA, Campbell KB. P300 to high intensity stimuli during REM sleep. *Clin Neurophysiol* 1999;110:1345–1350.
- De Koninck J, Lorrain D, Christ G, Proulx G, Coulombe D. Intensive language learning and increases in rapid eye movement sleep: evidence of a performance factor. *Int J Psychophysiol* 1989;8:43–47.
- De Koninck J, Christ G, Hebert G, Rinfret N. Language learning efficiency, dreams and REM sleep. *Psychiatr J Univ Ottawa* 1990;15:91–92.
- Dewasmes G, Bothorel B, Candas V, Libert JP. A short-term poikilothermic period occurs just after paradoxical sleep onset in humans: char-

- acterization changes in sweating effector activity. *J Sleep Res* 1997;6:252–258.
- Feinberg I, March JD. Observations on delta homeostasis, the one-stimulus model of NREM-REM alternation and the neurobiologic implications of experimental dream studies. *Behav Brain Res* 1995;69:97–98.
- Ferri R, Elia M, Musumeci A, Pettinato S. The time course of high-frequency bands (15–45Hz) in all-night spectral analysis of sleep EEG. *Clin Neurophysiol* 2000;111:1258–1265.
- Foret J, Touron M, Benoit CO, Bouard G. Modifications of sleep structure by brief forced awakenings at different times of the night. *Electroenceph clin Neurophysiol* 1990;75:141–147.
- Foulkes D. Dreaming and REM sleep. *J Sleep Res* 1993;2:199–202.
- Foulkes D. Dream research: 1953–1993. *Sleep* 1996;19:609–624.
- Foulkes D, Schmidt M. Temporal sequence and unit composition in dream reports from different stages of sleep. *Sleep* 1983;6:265–280.
- Fukuda K, Miyasita A, Inugami M. Sleep onset REM periods observed after sleep interruption in normal short and normal long sleeping subjects. *Electroenceph clin Neurophysiol* 1987;67:508–513.
- Gottesmann C. Neurophysiological support of consciousness during waking and sleep. *Prog Neurobiol* 1999;59:469–508.
- Gross DW, Gotman J. Correlation of high-frequency oscillations with the sleep-wake cycle and cognitive activity in humans. *Neuroscience* 1999;94:1005–1018.
- Halasz P. Arousals without awakening – dynamic aspect of sleep. *Physiol Behav* 1993;54:795–802.
- Herman JH, Ellman SJ, Roffwarg HP. The problem of NREM dream recall re-examined. In: Arkin AM, Antrobus JS, Ellman SJ, editors. *The mind in sleep*, Hillsdale, NJ: Lawrence Erlbaum Associates, 1978. pp. 59–92.
- Hobson JA, Pace-Schott E, Stickgold R. Dreaming and the brain: towards a cognitive neuroscience of conscious states. *Behav Brain Sci* 2000a;23:793–842.
- Hobson JA, Pace-Schott E, Stickgold R. Consciousness: its vicissitudes in waking and sleep. In: Gazzaniga MS, editor. *The new cognitive neurosciences*, 2nd ed. Cambridge: A Bradford Book, 2000b. pp. 1341–1354.
- Karni A, Tanne D, Rubenstein BS, Askenasy JJM, Sagi D. Dependence on REM sleep of overnight improvement of a perceptual skill. *Science* 1994;265:679–682.
- Koukkou M, Lehmann D. Dreaming: the functional state-shift hypothesis. A neuropsychophysiological model. *Br J Psychiatry* 1983;142:221–231.
- Llinas R, Ribary U. Coherent 40-Hz oscillation characterizes dream state in humans. *Proc Natl Acad Sci USA* 1993;90:2078–2081.
- Madsen PL, Holm S, Vorstrup S, Friberg L, Lassen NA, Wildschiodts G. Human regional cerebral blood flow during rapid-eye-movement sleep. *J Cereb Blood Flow Metab* 1991;11:502–507.
- Mandai O, Guerrien A, Sockeel P, Dujardin K, Leconte P. REM sleep modifications following a Morse code learning session in humans. *Physiol Behav* 1989;46:639–642.
- Maquet P, Peters JM, Aerts J, Delfiore G, Degueldre C, Luxen A, Franck G. Functional neuroanatomy of human rapid-eye-movement sleep and dreaming. *Nature* 1996;383:163–166.
- Mathur R, Douglas NJ. Frequency of EEG arousals from nocturnal sleep in normal subjects. *Sleep* 1995;18:330–333.
- Michimori A, Stone P, Aguirre A, Stampi C. Analysis of the alpha attenuation test. *Sleep Res* 1994;23:454.
- Miyasita A, Fukuda K, Inugami M. Effects of sleep interruption on REM-NREM cycle in nocturnal human sleep. *Electroenceph clin Neurophysiol* 1989a;173:107–116.
- Miyasita A, Fukuda K, Inugami M, Ishihara K. Appearance rate of sleep onset REM period and pre-awakening NREM duration. *Sleep Res* 1989b;18:141.
- Morel CR, Hoffman RG, Moffitt AR. The electrophysiological correlates of dream recall and nonrecall from stage 2 sleep. *Can J Psychol* 1991;45:140–147.
- Nielsen TA. A review of mentation in REM and NREM sleep: ‘covert’ REM sleep as a possible reconciliation of two opposing models. *Behav Brain Sci* 2000a;23:851–866.
- Nielsen TA. Covert REM sleep effects on NREM mentation: further methodological considerations and supporting evidence. *Behav Brain Sci* 2000b;23:1040–1057.
- Niiyama Y, Sekine A, Fushimi M, Hishikawa Y. Cortical activity of REM sleep often earlier than other physiological phenomena. *Psychiatr Clin Neurosci* 1998;52:152–154.
- Ogilvie RD. The process of falling sleep. *Sleep Med Rev* 2001;5:247–270.
- Ogilvie RD, Wilkinson RT, Allison S. The detection of sleep onset: behavioral, physiological, and subjective convergence. *Sleep* 1989;12:458–474.
- Plihal W, Born J. Effects of early and late nocturnal sleep on declarative and procedural memory. *J Cogn Neurosci* 1997;9:534–547.
- Rechtschaffen A, Kales A. *A manual of standard terminology, techniques, and scoring system for sleep stages of human subjects*, Washington, DC: Public Health Service, U.S. Government Printing Office, 1968.
- Rochlen A, Hoffmann R, Armitage R. EEG correlates of dream recall in depressed outpatients and healthy controls. *Dreaming* 1998;8:109–123.
- Rosenlicht N, Maloney T, Feinberg I. Dream report length is more dependent on arousal level than prior REM duration. *Brain Res Bull* 1994;34:99–101.
- Sasaki Y, Miyasita A, Takeuchi T, Inugami M, Fukuda K, Ishihara K. Effects of sleep interruption on body temperature in human subjects. *Sleep* 1993;16:478–483.
- Sasaki Y, Fukuda K, Takeuchi T, Inugami M, Miyasita A. Sleep onset REM period appearance rate is affected by REM propensity in circadian rhythm in normal nocturnal sleep. *Clin Neurophysiol* 2000;111:428–433.
- Scholz UJ, Bianchi AM, Cerutti S, Kubicki S. Vegetative background of sleep-spectral analysis of the heart rate variability. *Physiol Behav* 1997;62:1037–1043.
- Schulz H, Tetzlaff W. Distribution of REM latencies after sleep interruption in depressive patients and control subjects. *Biol Psychiatry* 1982;12:1367–1376.
- Sewitch DE. The perceptual uncertainty of having slept: the inability to discriminate electroencephalographic sleep from wakefulness. *Psychophysiology* 1984a;21:243–259.
- Sewitch DE. NREM sleep continuity and sense of having slept in normal sleepers. *Sleep* 1984b;7:147–154.
- Smith C. Sleep states and memory processes. *Behav Brain Res* 1995;69:137–145.
- Smith C, Lapp L. Increases in number of REMs and REM density in humans following an intensive learning period. *Sleep* 1991;14:325–330.
- Stickgold R, Scott L, Rittenhouse C, Hobson JA. Sleep-induced changes in associative memory. *J Cogn Neurosci* 1999;11:182–193.
- Stickgold R, Whidbee D, Schirmer B, Patel V, Hobson JA. Visual discrimination task improvement: a multi-step process occurring during sleep. *J Cogn Neurosci* 2000;12:246–254.
- Stickgold R, Hobson JA, Fosse R, Fosse M. Sleep, learning, and dreams: off-line memory reprocessing. *Science* 2001;294:1052–1057.
- Takeuchi T, Miyasita A, Sasaki Y, Inugami M, Fukuda K. Isolated sleep paralysis elicited by sleep interruption. *Sleep* 1992;15:217–225.
- Takeuchi T, Miyasita A, Inugami M, Sasaki Y, Fukuda K. Laboratory-documented hallucination during sleep-onset REM period in a normal subject. *Percept Mot Skills* 1994;78:979–985.
- Takeuchi T, Miyasita A, Inugami M, Yamamoto Y. Intrinsic dreams are not produced without REM sleep mechanisms: evidence through elicitation of sleep onset REM periods. *J Sleep Res* 2001a;10:43–52.
- Takeuchi T, Ogilvie RD, Ferrelli AV, Murphy TI, Belicki K. The Dream Property Scale: an exploratory English version. *Conscious Cogn* 2001b;10:341–355.
- Takeuchi T, Fukuda K, Sasaki Y, Inugami M, Murphy TI. Factors related to the occurrence of isolated sleep paralysis elicited during a multi-phasic sleep-wake schedule. *Sleep* 2002a;25:89–96.
- Takeuchi T, Fukuda K, Murphy T. Elicitation of sleep onset REM periods in normal individuals using the Sleep Interruption Technique (SIT). *Sleep Med* 2002b;3:479–488.

- Uchida S, Maloney T, Feinberg I. Sigma (12-16Hz) and beta (20-28Hz) EEG discriminate NREM and REM sleep. *Brain Res* 1994;659:243–248.
- Weitzman ED, Kripke DF, Goldmacher D. Acute reversal of the sleep-waking cycle in man. *Arch Neurol* 1970;22:483–489.
- Werth E, Achermann P, Dijk D, Borberly AA. Spindle frequency activity in the sleep EEG: individual differences and topographic distribution. *Electroenceph clin Neurophysiol* 1997;103:535–542.
- Williamson PC, Csima A, Galin H, Mamelak M. Spectral EEG correlates of dream recall. *Biol Psychiatry* 1986;21:717–723.
- Zimmerman WB. Sleep mentation and auditory awakening thresholds. *Psychophysiology* 1970;6:540–549.