When sleep is perceived as wakefulness: an experimental study on state perception during physiological sleep

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Accepted in revised form 22 August 2007; received 8 December 2006

SUMMARY While electrophysiologically measured sleep and perception of sleep generally concur, various studies have shown this is not always the case. The objective of the present study was to assess the perception of actual state during sleep by the technique of planned awakenings and interviewing subjects on the preawakening state. Sixty-eight (43 females, 25 males) young (mean age: 24.1, SD 5.1 years) normal sleeping subjects were deliberately awakened out of consolidated sleep, either stage 2 (S2), or REM sleep, during the first night in a non-clinical sleep laboratory. While the preawakening state was experienced as sleep in 48 cases (70.6%), it was experienced as wakefulness in 20 cases (29.4%). The percentage of awake judgements was somewhat, but not significantly, higher for awakenings out of S2 (38.2%), to REM sleep (20.6%). The proportion of mismatches between electrophysiologically defined sleep and state judgements was time-dependent with more awake judgements for REM sleep in the second half of the sleep period (41.7%) than in the first one (17.4%). Those subjects who made an awake judgement more frequently had a feeling of being aware of the situation and their surroundings than those who made a sleep judgement (80% versus 33%). Awareness during sleep may be a cognitive style, which favours mismatches between state perception and electrophysiologically defined sleep. Sleep periods with concordant or discordant state judgements did not differ in electrophysiologically defined sleep onset latency, sleep efficiency, or sleep state distribution.

KEYWORDS awakening, awareness, cognitive activity, sleep perception

INTRODUCTION

For decades, the electroencephalogram (EEG) has been used as a valid method to discriminate between the two behavioural states of sleep and wakefulness. Based on the fact that electrophysiological patterns correlate quite well with subjective state perception (Lindsley, 1952), it has become common to assume a kind of isomorphism between electrophysiologically measured sleep and subjectively experienced sleep. Any discrepancy between perceived and measured sleep was declared to be sleep state misperception, implying the inability of the subject to correctly perceive a given state. Sleep state misperception even became a diagnostic category. It was termed *sleep state misperception* in the first version of the International Classification of Sleep Disorders (ICSD, 1990) and *paradoxical insomnia* in the revised version (ICSD-2, 2005). As a consequence of the definition of sleep by operationalized electrophysiological criteria, the role of cognitive processes for state perception during sleep has been widely neglected.

Although striking discrepancies between physiological or pharmacologically induced sleep and state perception have been observed occasionally (Fischgold and Schwartz, 1961, p. 214 and p. 366), systematic studies of this phenomenon are quite rare. Various earlier studies (Alster and Lavie, 1989; Anch *et al.*, 1982; Campbell and Webb, 1981; Knab and Engel, 1988; Langford *et al.*, 1972) compared objective and subjective sleep data by assessing the ability of subjects to signal spontaneous awakenings during night sleep by pressing a button. In all of these studies, it was shown that a number of electrophysiologically defined arousals was either not perceived, or at least not signalled by the subjects. This was

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especially true for NREM sleep, while in REM sleep spontaneous arousals were more often perceived and signalled. From these results, it was concluded that sleep perception is more accurate in REM sleep than in other sleep stages. Studies which used the technique of deliberate awakenings to measure sleep perception (Amrhein and Schulz, 2000; Bonnet and Moore, 1982; Foulkes, 1962; Mendelson, 1995a,b, 1998; Mercer *et al.*, 2002; Rotenberg, 1993; Sewitch, 1984a,b) confirmed the dependency of state judgement from the actual sleep state. In normal sleeping subjects the proportion of those who judged the state before an arousing tone signal as awake was in the range of 19% (Amrhein and Schulz, 2000) to 27% (Sewitch, 1984b). This rate was higher for NREM sleep and ranged between 40% (Mercer *et al.*, 2002) and 55% (Sewitch, 1984b). Sewitch (1984b) described sleep/wake perception as a process of discrimination that involves cognitive interpretations of physiological and psychological data. According to this assumption, uncertain decisions occur when inconsistent aspects of experience have to be taken into consideration, or when perceptions are missing that would lead to a certain decision. Mercer *et al.* (2002) extended this approach by comparing sleep/wake perception of normal sleepers and patients with insomnia. The data were analysed by a statistical technique based on signal detection theory. Awake judgements after having been awoken from sleep were consistently higher for insomniac patients than for normal controls, and they differed between sleep states. For control subjects, deliberate awakenings resulted in 39% wake judgements in S2 sleep and 19% in REM sleep. The corresponding values were clearly higher for insomniac patients with 80% for S2 and 62% for REM sleep.

Beside the sleep state, other internal events and cognitive experiences, which may influence the state judgement, were explored. Gibson *et al.* (1982) observed that most subjects used a few criteria to discriminate between states. The perceived depth of sleep was the most frequently used criterion, although it did not differ between correct and incorrect sleep/wake judgements. Three cognitive criteria were associated with correct sleep/wake estimations, namely 'control of thoughts', the 'awareness of surroundings', and a 'time element' (Gibson *et al.*, 1982). The ongoing mental activity before planned awakenings was further evaluated in a study by Foulkes (1962) who showed that thoughts are more image-like just before awakenings from REM sleep compared with NREM sleep. Other studies (Foulkes and Vogel, 1965; Vogel *et al.*, 1966) confirmed that subjects experienced that they were able to control mental activity during NREM sleep, whereas mental activity typically 'just happened' during REM sleep. Additionally, the extent of contact to the external situation differed across sleep stages, with a higher degree of orientation in space and time during NREM than during REM sleep.

The aim of the present study was to further evaluate those factors upon which the state judgement after a deliberate awakening from sleep is dependent. In contrast to earlier studies, the number of planned awakenings was low. While the first 27 subjects were awakened twice, the next 41 subjects were awakened only once. All subjects were awakened in their first laboratory night. The reason for reducing the number of awakenings from two to one was that, in some cases, it was difficult to identify a second segment of uninterrupted sleep, as defined below, to waken subjects a second time and interview them. The data from the two parts of the study were combined to create a large enough sample for statistical analysis. To avoid interaction effects, in cases with two awakenings, only the first one was included in the analysis.

METHODS

Subjects

The sample consisted of 68 young persons (43 females and 25 males; mean age 24.1 years, standard deviation 5.1 years) without sleep complaints, most of whom were psychology students at the Free University of Berlin, recruited by advertisement. These volunteer subjects did not receive payment but were informed about their sleep patterns in the laboratory and were given a printout of their polysomnographic sleep profile as a bonus for participation. Before study participation, all volunteers were interviewed about their sleep habits. Only those subjects who evaluated their sleep subjectively as 'good' or 'very good' and who did not report any difficulties of falling or staying asleep were included. In addition, subjects were informed about the time schedule and technical routine of the laboratory to adapt their sleep rhythm as necessary. Subjects were also asked to avoid stimulants like coffee or tea in the late afternoon and evening hours before the sleep study. During polysomnographic sleep recording on the study night, none of the subjects showed indications of a sleep disorder. Thus, all subjects who participated in the study were able to be included in the data analysis.

Procedures

Subjects arrived at 21:30 hours in the sleep laboratory, where they were instructed about the procedure, in particular that they would be awakened and interviewed once (or twice) during the night. They were made familiar with the 10-item questionnaire of the nocturnal interview (Table 1). Subjects were informed that the tone signal, indicating the beginning of the interview, could occur at any time, independent of whether the subject was asleep or awake. After placing the electrodes, subjects went to bed at about 23:00 hours. Before turning off the light they read the questions of the interview again. Forty-one subjects were awakened once and 27 subjects were awakened twice during the night by a standardized audio signal with an acoustic pressure of 70 dB (at a distance of 1 m from the head) and a frequency of 400 Hz. Immediately, after the awakening signal the experimenter entered from the adjacent recording room and completed the interview, while the subject stayed lying in bed. The room remained darkened, apart for a little light shining through the connecting door. Afterwards subjects could sleep until the next morning (or to

Table 1 Questions of the interview

1. Were you awake or did you sleep before you heard the tone signal?
2. How sure are you about your decision?
a) Absolutely sure
b) Fairly sure
c) Not sure
3a. If 'sleep' was answered to question 1:
Before you heard the tone signal, were you...
a) ...in deep sleep,
b) ...in light sleep, or
c) ...in a transient state between awake and sleep?
3b. If 'awake' was answered to question 1:
Before you heard the tone signal, were you...
a) ...wide awake,
b) ...awake but sleepy, or
c) ...in a transient state between awake and sleep?
4. If 'awake' was answered to question 1:
How long had you been awake before you heard the signal?
5. On which impressions is your judgement of having been awake or asleep based?
6. Was there something on your mind before being awakened?
If yes:
a) Was it rather clear and distinct or rather vague and blurred?
b) Was it rather image-like or rather thought-like?
c) Could you control it yourself or did it just happen?
7. Did you notice a transition from the sleep to wakefulness?
If yes:
Can you describe it further?
8. How quickly did you become awake?
9. Before you heard the signal were you aware of where you were and where the things around you were located?
10. Approximately how much time passed since the light was turned off (or: since the last awakening) until now?

the second awakening). Subjects were awakened and interviewed during their stay on the first night in sleep laboratory. Potential sleep disturbances by the first night effect (Agnew *et al.*, 1966) were tolerated in favour of logistic advantages of single night recordings in a student-run laboratory.

Polysomnography

The polysomnographic data were recorded with a commercial digital measurement system (Sagura-2000 for Windows). The registration with standard filter settings included four EEGs (F3-A2, C3-A2, C4-A1, O2-A1), two horizontal EOGs, chin EMG, and ECG. Respiration was controlled with a chest belt, and oxygen saturation of the blood and pulse were measured with an oximeter, which was placed on a finger of the non-dominant hand. Sleep scoring was performed according to the rules of Rechtschaffen and Kales (1968).

Awakening conditions

Deliberate awakenings were performed in stable S2, and in REM sleep. To guarantee consolidated preawakening sleep phases, awakenings had to be preceded either by a minimum of 7.5 min of uninterrupted REM sleep or 15 min of uninterrupted S2 sleep. The respective number of 30 s epochs before awakening had to be continuously assigned to the same sleep stage, either S2 or REM, and had to be free of arousals, which were detected and rated visually online. Planned awakenings did not take place before the end of the first NREM–REM sleep cycle. The sequence of awakening from S2 or REM sleep was randomized within (in case of two awakenings) and between subjects. All awakenings and interviews were performed by DW and LM.

Nocturnal interview

The subjects had been familiarized with the 10 questions (Q1–Q10) of the interview (Table 1) before the start of the sleep recording in the evening. Any ambiguities were clarified with the experimenter, if necessary. The questions were adapted from an earlier study in our laboratory (Amrhein and Schulz, 2000), with only slight changes of the wording. The perception of the preawakening state was assessed using the first three questions. Q1 requested a state judgement (sleep or awake), Q2 asked about the certainty of the state judgement (absolutely sure – fairly sure – not sure), and Q3 about the quality of the preawakening state (deep sleep – light sleep – transitional state – awake but sleepy – wide awake). Q4 demanded an estimate of the duration of prior wakefulness if the actual state was rated as awake, and Q5–Q9 asked about different cognitive aspects in relation to the state judgement. Q5, an open question, asked about those internal perceptions which led to the sleep/awake judgement. Q6 asked about three aspects of mental activity, namely distinctness, image or thought-likeness, and controllability, while Q7–Q9 assessed formal aspects of the transition from the pre- to the postawakening state. Q7 asked whether a state transition was perceived or not, Q8 about the speed of awakening, in case of a sleep judgement, and Q9 asked about any awareness of the surrounding, or orientation before the awakening. The last question (Q10) asked for a time estimate since lights out (or since the last awakening, in case of two awakenings).

Statistics

Statistical analysis was performed with the chi-square test for nominal data (sleep/awake judgement, items referring to mental content, perceived transition and awareness of the surroundings), and the *t*-test for independent samples for metric data (sleep latencies, duration of awakening, time estimates of the subjects). Two aspects of the *temporal position* of the deliberate awakenings were examined, (a) its position within a given NREM–REM sleep cycle, and (b) its position in the whole sleep phase.

Position within the NREM–REM cycle

For awakenings out of REM sleep, the number of REM sleep epochs before the awakening was counted and compared with the duration of a neighbouring, undisturbed REM sleep phase. This undisturbed REM sleep phase could be located either before or after the cycle with the experimental awakening, depending on whether the deliberate awakening occurred early or late in sleep. In the same way, the duration of NREM sleep before awakenings out of stage 2 were compared with the duration of uninterrupted NREM sleep phases.

Position within the whole sleep phase

The potential influence of the duration of prior sleep on the state judgement was also tested. To this end, the distribution of intervals between lights off and the start of the interview was established separately for S2 and REM sleep awakenings, and the median was determined. Interviews before the median were designated 'early', and those after the median 'late'.

RESULTS

State judgements

Sixty-eight young subjects (43 women and 25 men) with a mean age of 24.1 years (SD: 5.1 years) participated in the study. Half of them (n = 34) were awakened from sleep stage 2, the other half from REM sleep. While for 48 subjects (70.6%) the estimated state before deliberate awakening was concordant with electrophysiologically measured sleep, 20 subjects (29.4%) gave a discrepant state rating. They assumed that they were awake before the arousing signal occurred. Ninety percent of the subjects with a mismatch between perceived and measured preawakening state were either fairly sure (n = 12) or absolutely sure (n = 6) that their state estimate was correct, while only two were unsure. In contrast to this, subjects with a concordant state judgement had fewer 'sure' ratings (64.6% sure versus 35.4% unsure). About half of the subjects with a concordant state judgement had perceived the preawakening state as deep sleep (47.9%), while 29.2% rated the state as light sleep, and 22.9% as a transitional state between sleep and wakefulness. Subjects with discordant state judgement rated the preawakening state either as a transitional state (45%), as awake but sleepy (45%) or, in two cases (10%), as wide awake (Table 2).

Although the proportion of awake judgements was higher for awakenings out of S2 (13/34 = 38.2%) than for REM sleep (7/34 = 20.6%), the difference was not significant. The two sleep states also did not differ significantly in the level of certainty of subjective judgements (Table 2).

Table 2 Characteristics of state judgements as either awake or asleep*

		S2 sleep		*REM sleep*	
Questions	*Response categories*	*Awake*	*Asleep*	*Awake*	*Asleep*
Q 1: Were you awake or did you sleep before you heard the tone signal?		13	21	7	27
Q2: How sure are you about your decision?	Absolutely sure	4	4	2	9
	Fairly sure	8	8	4	10
	Not sure	1	9	1	8
Q3: Before you heard the tone signal, were you ...?	Deep sleep	–	8	–	15
(Depending on the response to Q1, Q 3 was worded differently; see Table 2)	Light sleep	–	10	–	4
	Transient state	7	3	2	8
	Awake but sleepy	4	–	5	–
	Wide awake	2	–	–	–
Q6: Was there something on your mind before being awakened?	Yes	9	13	5	24
	No	4	8	2	3
If yes, Q6a: Was it rather clear and distinct or rather vague and blurred?	Clear	2	6	3	19
	Vague	6	4	2	5
	No response	1	3	–	–
If yes, Q6b: Was it rather image-like or rather thought-like?	Image-like	5	3	4	20
	Thought-like	3	8	1	4
	No response	1	2	–	–
If yes, Q6c: Could you control it yourself or did it just happen?	Control	0	2	3	6
	No control	7	9	2	18
	No response	2	2	–	–
If asleep, Q7: Did you notice a transition from sleep to wakefulness?	Yes	10	4	2	13
	No	10	9	5	13
	No response	1	–	–	1
Q9: Before you heard the signal were you aware of where you were and where the things around you were located?	Yes	10	8	6	8
	No	3	13	1	19

*There were not enough usable answers to question 4 to allow statistical analysis.

Characteristics of state judgements

The additional questions of the interview gave some insight into the processes, which may have led subjects to rate the state immediately prior to hearing the tone signal either as asleep or awake. Two-thirds of the subjects reported that there was something on their mind when they were cued, with a slightly higher proportion in REM than in S2 sleep (85.3% versus 64.7% respectively; $\chi^2 = 3.8$, $P < 0.05$). The rate of mental activity was similar for asleep and awake state judgements (77.0% versus 70.0% respectively).

In those subjects, who had perceived having had any thoughts, the quality of thought differed between conditions. The mental content was more clear, when aroused out of REM sleep, compared with S2 sleep (75.9% versus 44.4% respectively; $\chi^2 = 4.7$, $P < 0.05$), more image-like (REM: 82.8% versus S2: 42.1%; $\chi^2 = 8.5$, $P < 0.05$), but with a similar low level of controllability in both sleep states (REM: 31.0% versus S2: 11.1%). Of these three mental content variables, only clarity co-varied significantly with the state judgement. Clarity of mental content was more frequently reported when the state was perceived as asleep (73.5%) compared with awake (38.5%; $\chi^2 = 5.0$, $P < 0.05$), while there was no difference for the features image-like (65.7% for asleep versus 69.2% for awake), and controllability (22.9% for asleep versus 25.0% for awake).

Awareness of the actual situation, when the tone was sounded (Question 9) differed across judgements with a significantly higher rate of awareness when the state was rated awake than asleep (80.0% versus 33.3% respectively; $\chi^2 = 12.3$, $P < 0.05$). Awareness ratings, on the other hand, did not differ across sleep states S2 and REM (52.9% versus 41.2% respectively).

The temporal position of the interviews

Position within the NREM–REM cycle

The mean duration (±SD) of REM sleep prior to an awakening was 11.8 min (±6.9) and 21.9 min (±10.7) for uninterrupted REM sleep. The respective mean durations for NREM sleep were 25.6 min (±16.9) and 66.2 min (±20.8). The comparison shows that planned awakenings out of REM sleep started about half way through a REM sleep phase, while planned awakenings out of S2 sleep took place mostly before the middle of a NREM sleep phase.

Position within the whole sleep phase

To control for the time of night effect, interviews were separated into 'early' and 'late' ones, according to their position in the sleep phase. Early and late were defined in relation to the median of the time points of all interviews as described above. The medians were computed separately for S2 and REM sleep and were very similar with 239 min (range: 86–430) for S2 and 241 min (range: 136–380) for REM sleep.

Table 3 Distribution of sleep and wake judgements in relation to the temporal position of the interview in the sleep phase

The interview started from:	*Early**		*Late**		χ^2*-test* (P-*value*)
	Awake	*Asleep*	*Awake*	*Asleep*	
S2 sleep	6	11	7	10	0.12 (NS)
REM sleep	1	16	6	11	4.50 (<0.05)

*'Early' and 'late' were defined by the temporal position of the interview relative to the median time point of all interviews. The medians were computed separately for S2 and REM sleep. They were 239 min for S2 and 241 min for REM sleep.

For S2 sleep, the state judgements did not differ significantly between early and late awakenings. Awake judgements were 35.3% for early and 41.1% for late interviews. In contrast, for REM sleep, the proportion of awake judgments was low (5.9%) for early interviews and significantly higher (35.3%) for late interviews ($\chi^2 = 4.50$, $P < 0.05$; Table 3).

Polysomnographic sleep measures

Sleep quality for sleep and wake judgements after deliberate awakening was also analysed. There were no significant differences in sleep latency, sleep efficiency, or in the amount of the different sleep stages (Table 4). Finally, subjects with concordant or discordant state judgements also did not differ in sex or age.

DISCUSSION

The results suggest that an appreciable amount of time asleep is not perceived as sleep but as wakefulness, even by those without a sleep complaint. The absolute number of mismatches between electrophysiologically measured sleep and state judgements may be overestimated in our study, as deliberate awakenings were induced in a first laboratory night

Table 4 Polysomnographic sleep parameters (mean ± SD)

	State judgement	
	Awake	*Sleep*
No. subjects*	18	42
Sleep latency (min)†	24.0 ± 20.2	19.6 ± 13.1
Sleep efficiency (%)‡	88.8 ± 9.1	89.1 ± 8.8
Wake (%)	14.7 ± 9.1	14.4 ± 8.5
NREM stage 1 (%)	4.9 ± 2.6	6.1 ± 3.8
NREM stage 2 (%)	46.6 ± 4.8	46.3 ± 7.2
NREM stage 3 (%)	8.5 ± 5.0	8.6 ± 2.8
NREM stage 4 (%)	9.2 ± 6.2	8.1 ± 5.6
REM sleep (%)	16.7 ± 6.7	15.8 ± 4.1

*Caused by a technical defect 16 sets of digitally stored polysomnographic data were lost.
†Sleep latency was defined as the time interval between lights off and the first epoch of S2 sleep.
‡Sleep efficiency was defined as the ratio of total sleep time (TST), divided by total time in bed (TBT) ×100. Wake time, which was caused by the interview, plus the time to resume sleep after the interview, was eliminated.

without prior adaptation. Thus, a first night effect (FNE) with increased arousal has to be taken into account (Agnew *et al.*, 1966; Lorenzo and Barbanoj, 2002). In spite of this study design limitation, the results concur with those of other studies which had used deliberate awakenings to gain information on state perception in sleep (Amrhein and Schulz, 2000; Mendelson, 1995b; Mercer *et al.*, 2002; Sewitch, 1984a,b). All studies, including the present one, come to the conclusion that state perception deviates in a substantial number of cases from measured sleep, as defined by electrophysiological criteria. While this observation is not new (Borkovec *et al.*, 1981, Coates *et al.*, 1987; Frankel *et al.*, 1976), it has been largely neglected. As a consequence, cognitive processes during sleep and their contribution to state perception are poorly understood.

Although the percentage of awake judgements did not differ significantly between S2 and REM sleep, the tendency of more awake judgements after awakenings out of S2 sleep was in line with the results from earlier studies (Mendelson, 1995b; Mercer *et al.*, 2002; Sewitch, 1984a,b). The more pronounced difference in earlier studies may be due to a higher rate of planned awakenings in these studies. A greater number of awakenings per night may influence the perception of the current sleep state in two ways. First, multiple awakenings result in a fragmentation of sleep, which may increase the general level of arousal and, thus, cause increased frequency of awake judgements, even if electrophysiological recordings indicate sleep. Second, multiple awakenings offer a chance to compare among the different preawakening states and therefore may contribute to discrimination learning. This may strengthen any experiential differences in the perception of S2 and REM sleep.

Major correlates for the mismatches between state judgement and measured sleep were (i) the degree of awareness of the sleeper for the surrounding, and (ii) the distance between sleep onset and the planned awakening.

Awareness of the sleeper for the situation and the surrounding

Those subjects who felt themselves oriented in their surroundings before they were awakened by the acoustic signal had a high probability of perceiving the preawakening state as wakefulness. If the loss of consciousness is a pivotal criterion for sleep (De Manacéïne, 1896; Massimini *et al.*, 2005), it is conceivable that the opposite, namely the inner experience of being aware of one's situation and surroundings favours the perception that the actual state is wakefulness and not sleep. Moreover, in contrast to an outside observer who would use behavioural criteria to make a sleep/wake judgement, the sleeping brain does not have access to such information, and therefore behavioural criteria cannot be used by the sleeper as a basis for critical control and contingent correction of the subjective state perception. But, why is there a dissociation between state judgement and electroencephalographic (EEG) criteria of sleep?

The present data show that the same EEG state, which was perceived as sleep in 70–80% of subjects studied, was perceived 20–30% as wakefulness in interviews. The relationship between EEG patterns and state perception seems to be asymmetric. While it would be highly improbable to judge a given state as sleep when the EEG indicates wakefulness (cf. Mercer *et al.*, 2002, their Tab. 2), a dissociation between EEG-defined states and state judgement is not rare in sleep, as the data show. One main reason for such a discrepancy may be that state perception is more closely related to mental activity than to the EEG. The answers to question 6 of the interview show that mental activity is abundant during sleep. Preawakening mental activity was reported by 65% of subjects who were awakened out of S2 sleep, and even higher, namely 85%, after REM sleep awakenings.

Beside the quantity, also the quality of mental activity may contribute to state judgement. Mental activity in REM sleep was rated as more image-like and clearer than in S2 sleep. Mental activity in REM sleep, which is generally more dream-like (Hobson *et al.*, 2000), contrasts sharply to cognitive processes when awake and, thus, induces a sleep judgement. The case is different for cognitive activity in S2 sleep, which was rated more frequently as thought-like, and thus is closer to wakeful cognitive activity. The similarity in structure and content of mental activity between wakefulness and some states of sleep, in combination with the loss of behavioural control, may produce the perception of being awake, even when the EEG indicates sleep. It would be of interest whether high-density EEG mapping or brain imaging techniques would show any difference between sleep states which are concordant or discordant with state judgement. Balkin *et al.* (2002) have studied local brain blood flow changes during the process of reorientation after awakening. Whether such changes would differ systematically also in respect to subjective state judgement is still an open question.

The time of the planned awakening

A descriptive analysis of the positions of the deliberate awakenings out of REM and S2 sleep in a given NREM–REM cycle showed that they most often occurred in the middle of the respective sleep phase, or earlier. Thus, state ratings during the interviews were probably not much influenced by approaching sleep phase transitions.

While time of night did not have much effect on state judgement when subjects were aroused from S2 sleep, there was a significant effect for REM sleep interviews. The proportion of awake judgements in this sleep state was low, when subjects were awakened early in the sleep phase, but high when this occurred late in the sleep phase. The observed interaction between REM sleep and time of night replicates the same finding by Mendelson (1998). In addition, Mendelson (1998) found a significant interaction for S2 sleep with a high rate of awake judgements early in sleep, and a low rate late in sleep. That this interaction was not observed for S2 in this study is probably due to the different timing of the awakenings. While the early awakenings in Mendelson's study were placed in the first NREM sleep phase ('10 min after first spindle'), S2 awakenings in the present study spared the first NREM sleep phase. This assumption is also compatible with a study by Rotenberg (1993) who found a decrease in awake judgements from the first to the second NREM–REM sleep cycle.

Semantics of sleep–wake discrimination

From the nocturnal interviews it appeared that subjects frequently had difficulties describing the preawakening state, especially when awakened from S2 sleep. The internal experience of this state appears to be vague and diffuse in many cases. In the present study, it was also observed that subjects rethought their answers and requested that they be allowed to revise an answer to a given question more frequently after awakenings from S2 than from REM sleep. This suggests that giving a state description, or making a discrimination, may be more difficult than the semantic categories of the interview would suggest.

One way to overcome this problem would be to use a fuzzy response format instead of a point estimate (Gehrman *et al*., 2002) to document cognitive activity and state perception. From the present data set, it became clear that in an appreciable number of awakenings out of electrophysiologically defined sleep, the subjects experienced the state as transient, something between sleep and awake (cf. Tab. 2). Thus, different response formats for sleep questionnaires or interviews should be applied in future studies.

The technique of deliberate awakenings

The technique of deliberate awakenings has a few shortcomings, which may have influenced the results. First, if the subjects are informed about the procedure before going to bed, expectancy of the awakening(s) may increase arousal during sleep. Second, memory for sleep-related cognitive activity is notoriously poor. This may be related to a general difficulty transferring material from one mental state into another one, as in Koukkou and Lehmann's (1983) suggestion that forgetting dreams is a function of the magnitude of the difference between states during storage and recall. Third, sleep inertia after a deliberate awakening (Åkerstedt *et al*., 2002) may likewise contribute to the difficulty in giving a coherent report of the preawakening cognitive activity. Finally, one may assume that the different methodological peculiarities are not fixed but vary, depending on the state or stage where the awakening occurs, and the duration of prior sleep. This makes systematic control of the methodologically induced error variance even more difficult.

In summary, there appears to be an asymmetrical relationship between objectively measured sleep/wake states, on the one hand, and state judgement on the other. While the correlation between electrophysiologically defined wakefulness and state perception is perfect in normal subjects, the correlation is less perfect for the sleep state. Depending on cognitive activity, the actual sleep stage, and the duration of prior sleep, portions of electrophysiologically defined sleep are perceived as wakefulness. Even if this discrepancy can be reduced by positive feedback (Downey *et al*., 1989; Sewitch, 1984b), its existence should remind us that electrophysiological criteria to define sleep are valid descriptors of the physiological state, but do not consider cognitive activity, which largely contributes to state perception. A final point to discuss is the proper design for studying state perception in sleep.

Between versus within subjects designs

If there are stable individual differences in state perception, a within subjects design would be probably more appropriate than a between subjects design, as we have applied in the present study. A within subjects study could be performed either with multiple awakening within a single night, or over a series of nights with a single or only few awakenings per night. Another alternative would be to determine one or more factors, which may be correlated with state perception, and to compare groups of subjects who score either high or low on those factors. Our group is just developing a questionnaire to assess one such candidate factor, namely orientation or awareness during sleep (Rothkirch *et al*., 2006).

ACKNOWLEDGEMENT

We thank Catherine N. Oliver for linguistic support.

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