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Discrimination of Early Sleep Stages: Behavioral Indicators

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Summary: Six subjects participated in a one-night sleep-onset experiment. They were aroused from stage 1 and stage 2 as defined by standard electroencephalographic criteria. Subjects pressed a button upon arousal to indicate which of two subjective states they were in just before awakening. Performance accuracy from stage 1 awakenings appeared to remain relatively constant at approximately 83%; performance from stage 2 awakenings showed increasing accuracy. Response latencies increased between stage 1 and stage 2 awakenings. **Key Words:** Discrimination—Sleep onset—Sleep—Stages 1 and 2—Behavioral responding.

Sleep-related subjective experiences are not as well understood as objective changes that occur during sleep. Nevertheless, investigation of subjective experiences may aid in understanding the nature of sleep. A successful illustration of this is the discovery of rapid eye movements (REMs) (Aserinsky and Kleitman, 1954). The changes in eye motility were interesting in their own right, but it was not until they were closely associated with subjective reports of a peculiar form of mental activity—dreaming—that their importance emerged (Dement and Kleitman 1957*a,b;* Dement and Wolpert, 1958).

Defining of the exact moment of sleep onset has had less success. An early attempt to compare changes in subjective experiences to objectively defined physiological activity was made by Loomis et al. (1937). A large percentage of subjects who were awakened at the first appearance of sleep spindle (later defined as stage 2 sleep onset) and asked to judge whether or not they had been asleep reported that they were still awake. In a study by Kamiya (1961), an awakening bell was rung at the first appearance of sleep spindles; subjects almost always reported being awake in stage 1 and almost half of time when in stage 2. Similar results have been described by Walker (1972) (Agnew and Webb, 1972; Webb, 1976). These results are in line with the concept of a psychophysical threshold (Baird and Noma, 1978) for sleep between stages 1 and 2.

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Interesting patterns of subjective experience have been associated with sleep onset. The psychological organization of the sleep-onset period has been outlined, although an ideal psychophysiological parallel has not been established (Vogel et al., 1966). The fourth stage of sleep onset [descending stage 2 electroencephalogram (EEG), characterized by 12–14 Hz "sleep spindles"—Vogel et al., 1966] is often considered to be the beginning of "true sleep" (Agnew and Webb, 1972).

Until the present time, no direct attempt has been made to ascertain if subjects can discriminate between objectively defined "falling asleep" and "being asleep." Vogel et al. (1966) mentioned that subjects reported awareness of differences in the four sleep-onset stages during postexperimental interviews. Thus, asking "Were you awake?" or "Were you asleep?" may not be the correct phrasing of the question. Instead, asking subjects "What is the difference between *this* stage [descending stage 1 with slow eye movements (SEMs)] and *that* stage (stage 2)?" may provide more information as to the significance of the objective indicator—sleep spindles. Just as a particular form of "dreaming" is associated with REMs, an analogous form of subjective experience may be associated with the beginning of sleep.

The first step in establishing the differences between stage 1 with SEMs and stage 2 sleep onset would be to assess the discriminability of these two stages. Then the question of what criteria subjects use to discriminate between the two sleep-onset stages could be addressed. Brown and Cartwright (1978) reported that their subjects' behavioral responses were more accurate predictors of obtaining verbal reports of imagery during sleep than were EEG patterns. It has also been established that subjects can learn to discriminate between stage 1 REM and stage 2 NREM (not sleep onset) (Antrobus and Fisher, 1965; Antrobus and Antrobus, 1967). In those studies, subjects used combinations of several internal cues. This process is likened to a concept-formation task.

This study uses behavioral responding to examine the accuracy with which subjects can discriminate two sleep-onset stages subjectively.

METHODS

Subjects

The subjects were 7 unpaid volunteers (3 males, 4 females) ages 25–31 years (mean age, 29). All were in good health and did not report any significant sleep problems. The subjects were asked to abstain from central nervous system stimulants and depressants 24 hr prior to the start of the experiment, and they were asked to get a normal amount of sleep the night before the experiment.

Procedure

Subjects were given instructions while the electrodes were being attached. They were told that they were going to be aroused from two different EEG stages of sleep onset and that they were to press the button (of a small hand-held press button switch taped to their preferred hand) once or twice according to their perceived arousal stage. Subjects were then placed in bed inside the sleep chamber. At the end of the experimental session the subjects were briefly interviewed. They were then told that they could sleep without interruption for the rest of the night.

Electrode Placement

EEG bipolar electrodes were placed between C_3-O_1 or C_4-O_2. The side of electrode placement was determined by the subjects' preferred sleeping side independent of handedness. EOG electrodes were placed on the same side as the EEG placement (Connolly and Kleinman, 1978).

Apparatus

Recordings were made on a Beckman-Offner Type R dynograph of (1) EEG activity, (2) electro-oculographic (EOG) activity; and (3) subject's behavioral button pressing. Chart speed was constant at 10 mm/sec throughout the experiment.

Awakenings

Subjects were awakened from one of two early sleep-onset stages: stage 1 or stage 2 as defined by standard criteria (Rechtschaffen and Kales, 1968). The targeted awakening stage was selected by entry into a balanced random binary table. Stage 1 awakenings were determined by a decrease in alpha EEG amplitudes and the presence of SEMs for an epoch of 30 sec. Stage 2 awakenings were determined by the presence of 14 Hz, sleep-spindle waveforms lasting at least 500 msec within a total epoch of 30 sec. Subjects were aroused when the target stage was reached; the awakening stimulus was a loud 1.5 sec (440 Hz) tone. Subjects indicated as soon as possible after awakening which of two states they thought they were in by depressing the hand-held switch (i.e., once for state 1 and twice for state 2). Response latency was defined as the elapsed time between the awakening stimulus and the subject's behavioral response as recorded on the polygraph. The first eight awakenings for each subject were not followed by any feedback in order to establish a base line; after this they were given verbal feedback over an intercom as to the accuracy of their response ("Yes that was . . ."; "No that was . . ."). Subjects were then asked to compute the answer to a mathematical problem (e.g., square root of 16) or other similar questions to reestablish a waking base-line state. This waking state was confirmed with their polygraphic recordings. At the end of this brief verbal interchange they were instructed to try and go to sleep. This procedure was repeated approximately 32 times with each subject.

Results from one subject were eliminated from the analysis because postexperimental interviewing revealed that she had misinterpreted the instructions and had been attempting to identify two different levels of the same awakening stimulus.

Later analysis of the EEG/EOG records revealed that for 29 different trials, the sleep stage at awakening differed from the scheduled awakening: 21 of these were scheduled stage 2 and revised to stage 1; 8 were revised in the opposite fashion. The revised classifications were used for all data analysis.

Statistical Method

A 2×2 contingency table was constructed, with the columns representing the subjects' behavioral responses for stage 1 or stage 2 and the rows representing the objectively (EEG/EOG) defined sleep stage. Agreement between subjective response and objective assessment is represented by the cells along the negatively sloped diagonal. This table allows us to generate χ^2 values.

The χ^2 statistic tests association. It is a good technique for indicating if the obtained results differ from random observations, but it does not indicate the degree of agreement among categories (e.g., accurate assessment of sleep state). The κ coefficient has been suggested as a measure of such agreement (Fleiss, 1973). If agreement is only that expected by chance alone, then $\kappa = 0$. Positive values indicate more than chance agreement, and $\kappa = 1$ indicates perfect agreement.

RESULTS

A total of 173 awakenings were collected from 6 subjects. From these, 130 correct subjective identifications of sleep stage were recorded ($\chi^2 = 40.65$; $p < 0.001$, $df = 1$; see Table 1). As a group, our subjects correctly identified 86% of stage 1 awakenings in the control period, and this rate remained relatively constant throughout the experiment. For stage 2 awakenings, the percentage of correct responses started at a base-line level of 55% in the control period and exhibited a positive increase to 71% correct in "run" 4.

Table 2 summarizes the results of the χ^2 analysis. All computed χ^2's were found to be significant ($p < 0.01$; $df = 1$). Additionally, a significant χ^2 was obtained by computing individual subject's χ^2 and summing these across subjects (Cochran, 1954). The κ coefficients were also calculated and found to be significant ($p < 0.01$).

In addition to measuring the accuracy of the subjective evaluation and objective criteria, there are other behavioral indices of depth of sleep. Mean response latencies for stage 1 and stage 2 were 3.13 sec (SD = 2.04 sec) and 3.92 sec (SD = 3.07 sec), respectively. Mean time between awakenings was 3.28 min for stage

TABLE 1. *2 × 2 Contingency response tables*

	Behavioral			Behavioral			Behavioral			Behavioral		
	1	2		1	2		1	2		1	2	
Stage 1	24	4	28	22	6	28	25	4	29	12	3	15
Stage 2	9	11	20	7	13	20	6	13	19	4	10	14
	33	15	48	29	19	48	33	15	48	16	13	29
	Run 1: 1st 8 arousals			Run 2: 2nd 8 arousals			Run 3: 3rd 8 arousals			Run 4: 4th 8 arousals		

TABLE 2. *The χ^2 and κ coefficients*

	χ^2		κ coefficient	
Run 1	9.0	$p < 0.01$	0.42 ± 0.14	Z = 3.00
Run 2	9.28	$p < 0.01$	0.42 ± 0.14	Z = 3.04
Run 3	14.97	$p < 0.001$	0.55 ± 0.14	Z = 3.87
Run 4	7.75	$p < 0.01$	0.52 ± 0.18	Z = 2.78
Overall	40.65	$p < 0.001$	0.48 ± 0.07	Z = 6.38

1 and 8.34 min for stage 2. Mean intervals between stage 1 and stage 2 progressively decreased during the experiment (7.25, 6.4, 5.0, and 2.4 min for runs 1, 2, 3, and 4, respectively).

DISCUSSION

The results obtained from experimental awakenings during one evening for each subject indicate that the individuals were initially able to discriminate differences between stages 1 and 2, as evaluated by the significant χ^2 value for run 1 (control run). The positive κ's further support the reliability of this finding and indicate an increase in "recognition" of stage 2, which may be interpreted as a "recognition of sleep." Subjects appear to be able to maintain this ability, as supported by significant χ^2's for runs 2–4.

The performance of these subjects may have been the result of at least three types of cues: the time interval required to get to the objectively defined sleep-onset stage; the time taken to arouse from an objectively defined stage; and experiential differences between the two stages.

With respect to the EEG/EOG-defined stage, the average time intervals between stages 1 and 2 decreased by 67%, even though their ratios (time to Stage 1/time to Stage 2) remained relatively constant. Thus, if the mean time to a sleep stage was used as a discriminative cue, more errors might be expected later in the experiment. This was not found to be the case. The second class of possible cues mentioned above that might facilitate the discrimination between stages 1 and 2 may be related to response latencies. As objective measures, response latencies were found to be associated with sleep stage. Stage 2 awakening latencies were longer than those from Stage 1. Thus, the transition from stage 2 to wakefulness, in comparison to the transition from stage 1, may have aided subjects in their discriminations. As noted, the third class of possible cues that might facilitate discrimination of these two sleep-onset stages may be experiential differences between them. However, the influence of this class of cues cannot be assessed within the scope of the present experiment.

All subjects found multiple awakenings noxious—increasingly so during the course of the experiment. This, however, did not appear to affect performance adversely. In conclusion, it is apparent that the objectively defined stages of sleep onset correlate with some aspects of subjective experience and allow subjects to make discriminations. The nature of these subjective experiences has been partially explored from a slightly different perspective (Foulkes, 1962; Foulkes and

Vogel, 1965; Foulkes and Rechtschaffen, 1966; Vogel et al., 1966; Foulkes and Fleisher, 1975). By examining the sleep-onset transition, and the changes in subjective experience associated with that process, it might be possible to delineate explicitly the steps that take place during a successful transition to sleep. This, in turn, might lead to a clearer understanding of the intriguing psychological phenomena associated with the objective events of sleep onset.

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