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Cognitive Activity in Sleep and Responsiveness to External Stimuli

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Summary: The relationship between responsiveness to auditory stimuli presented during sleep and cognitive activity during sleep was assessed. Sixteen college-aged women were instructed while awake to turn off a tone by taking a deep breath. The tone was then presented during Stage 2 and REM sleep. Subjects were awakened after select trials to assess the relationship between responding and reports of ongoing cognitive activity. Consistent with the view that cognitive activity reduces responsiveness, significantly fewer responses were found on report (cognitive activity) trials relative to no-report (no cognitive activity) trials in analyses involving all trials and Stage 2 trials alone. Trained judges then rated the subjects' reports of cognitive activity as indicating incorporation or not indicating incorporation of the tone and/or the breathing response. Incorporation was associated with a reduced likelihood of responding relative to no incorporation in analyses involving all trials. No difference in responding was found between no-incorporation trials and no-report trials, suggesting that reduced responsiveness is associated with cognitive activity only when incorporation occurs. These findings support hypotheses that the reduced responsiveness to external stimulation during sleep is at least in part due to ongoing cognitive activity. **Key Words:** Performance—Instrumental responding—Dreaming—External stimuli—Incorporation.

With appropriate instructions and/or training, sleeping subjects respond to both external stimuli presented by an experimenter (1,2) and naturally occurring internal stimuli, e.g., rapid eye movement (REM) sleep onset (3,4). Many of the factors related to the level of control by external stimuli have been identified (5,6). Relative to wakefulness, however, responsiveness during sleep is considerably reduced. One factor that may be related to reduced responsiveness is sleep mentation. For example, Foulkes (7) suggested that reduced responsiveness to external stimuli during sleep is in part due to the preoccupation of the sleeping subject with ongoing cognitive activity. He hypothesized that the vivid mental activity of REM sleep results in exclusion of other sources of stimulation, which explains why REM sleep in terms of EEG and subjective reports appears to be light sleep while in terms of behavioral responsivity appears to be deep sleep. A second possibility is that responsiveness is reduced by incorporation of ex-

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ternal events into ongoing cognitive activity. The possibility that information presented during sleep may be incorporated into a dream was noted by Freud (8). Freud theorized that one function of dreaming is to protect sleep from the intrusion of external stimuli and that it does this by disguising the meaningfulness of stimuli which might otherwise produce arousal (e.g., a passing train, an alarm clock).

Currently, there are little or no data concerning Foulkes' notion that preoccupation with sleep mentation interferes with responsiveness to stimuli presented during sleep. Thus, it is not known whether a sleeping subject is less likely to respond to a stimulus in the presence as opposed to the absence of cognitive activity. Nor is it known if cognitive activity (dreams) during REM sleep is more "preoccupying" than the thought-like activity frequently associated with non-REM sleep.

Freud's theory has received more experimental attention. The data from several studies have indicated that stimulus events may be incorporated into ongoing dreams (9,10) and a report by Bradley and Meddis (11) provided evidence that stimulus incorporation reduces responsiveness. Under the procedure used by Bradley and Meddis, a stimulus was presented during REM sleep which gradually increased in loudness until subjects closed a handheld switch. The subjects were then asked to report their dreams. It was found that longer response latencies were associated with dream reports that evidenced stimulus incorporation. Not all studies, however, have provided evidence of this effect. For example, in a study comparing arousal threshold during Stage 2 and REM sleep, Rechtschaffen et al. (12) found little evidence that nonresponding was associated with stimulus incorporation. That is, subjects were awakened when no response occurred to the experimental stimulus, and "obvious" stimulus incorporation was found on only about 6% of the trials. It should be noted, however, that one possible explanation of the low level of incorporation is that the investigators purposefully selected a stimulus presentation procedure (method of constant stimuli) that they believed would minimize incorporation.

The purpose of the current study was to provide further information about the relation between cognitive activity during sleep and responsiveness to external stimulation. One goal of the study was to evaluate Foulkes' suggestion (7) that ongoing cognitive activity during sleep will reduce responsiveness to external stimuli. Toward this end, signal tones were presented to sleeping subjects, and comparisons were made of the probability of a prearranged response (taking a deep breath) on trials with and without subject reports of ongoing cognitive activity. The cognitive activity–behavioral response relation was examined during both Stage 2 and REM sleep.

A second related goal of the study was to replicate and extend the findings of Bradley and Meddis (11) that stimulus incorporation during REM sleep reduces responsiveness. A stimulus presentation procedure similar to that of Bradley and Meddis was used, i.e., the stimulus was presented at a low level and, in the absence of a response, the dB level was increased. Judges rated subject reports for evidence of incorporation. Stage 2 presentations, in addition to the REM presentations, permitted determining whether stimulus incorporation would be related to reduced responsiveness in both Stage 2 and REM.

MATERIALS AND METHODS

Subjects

Subjects were 16 female volunteers who ranged from 18 to 25 years old, with no significant health-related or sleep problems and no sleep laboratory history. Twelve of the subjects spent two nights in the sleep laboratory. Due to equipment problems, two subjects were tested a third night. Two subjects withdrew from the study after the first night. Subjects were paid $5 per night and a $5 bonus if they completed the experiment.

Apparatus

Subjects slept on a twin-sized bed in an 8′ by 8′ sleep chamber; all experimental equipment was located in an adjacent room. A Grass Model 78 polygraph was used for recording sleep variables. Solid-state modular control equipment, a Cyborg model 91A analogue/digital (A/D) computer interface, and an Apple IIe microprocessor were used for the control of stimuli and the recording of breathing responses. The signal stimulus was a 1,000-Hz beeping tone (0.5 sec on/off) presented via a speaker mounted approximately 3 feet above the subject's head. Polysomnographic variables were recorded following standard procedures (13). Respiration (chest expansion) was measured by a Grass Model PRTB pneumatic respiration transducer secured around the subject's chest. The respiration signal was recorded using a Model 7PF preamplifier and the A/D computer interface during and 60 s prior to tone trials. During the 60-s pretone interval, a baseline was calculated by averaging the change in the respiratory signal associated with each inspiratory effort. A 50% increase over the baseline was established as the criterion response for the trial (5). All baseline and criterion response determinations were controlled by the microprocessor system.

Procedure

The subjects were requested not to ingest alcohol or nonprescription drugs during the 24-h period preceding each test night. Test nights were separated by at least three nontest nights. Lights-out for each subject was 2300 and lights-on was at 0700. Prior to lights-out, subjects were given 10 practice trials. The procedure for presenting stimulus trials and obtaining nocturnal reports was adapted from Hoelscher et al. (14). The stimulus trials were presented on a variable-interval 45-min schedule, which ranged from 30 to 90 min, and began 2.5 h after lights-out. Ten minutes prior to each scheduled awakening, the polygraph was turned on and the stage of sleep was determined using a standard sleep staging procedure (13). Trials were initiated only if the subject was in unambiguous Stage 2 or REM sleep.

Prior to sleep, each subject was instructed to take a deep breath (a minimum 50% increase from inspiratory baseline) in response to a tone, which would be presented during the night. The tone began at 40 dB (the decibel level was measured at the pillow) and increased 10 dB in intensity if there was no breathing response within 8 s. After 16 s (at a maximum intensity of 50 dB) the tone automatically terminated if a subject failed to respond. Selection of the parameters for this stimulus presentation procedure was based on a pilot study investigating procedures that would result in responding on approximately 50% of the trial presentations. The microprocessor system provided the experimenter with instantaneous feedback regarding the initiation of a trial and either the subject's successful completion of the behavioral response or failure to respond. Ten practice trials were given prior to lights-out. During sleep, the subjects were awakened to obtain verbal reports 30 s after signal onset for both response and no-response trials. These reports were recorded on audiotape and later transcribed for scoring.

All subjects were briefed on the importance of limiting their remarks to the cognitions occurring before the experimental awakening. They were also informed that they might have periods in which they were not thinking or dreaming. Each night resulted in a minimum of four and a maximum of seven experimental awakenings. Verbal reports were obtained from four trial conditions: trials on which a breathing response occurred and those on which no breathing response occurred, during REM and during Stage 2 sleep. To minimize time-of-night effects, data were collected from alternating response and nonresponse trials when possible. On 21.8% of the tone trials, it was not possible to collect data from trials alternating in this fashion. Data were never collected, however, from more than two consecutive response or nonresponse trials. The subjects were awakened by the principal investigator entering their sleep chamber and calling their name. Subjects were then prompted with the statement, "Tell me what was on your mind." Following completion of the subject's reply, a second prompt was issued, "Can you tell me anymore?" Each subject was then allowed to return to sleep.

Scoring

A cognitive report was defined as any verbal response to the experimenter's prompt that was indicative of sleep mentation (e.g., dreaming, thinking, imaging). Two judges, aware of the experimental hypotheses but blind as to the trial conditions, rated the verbal reports for evidence of incorporation. Evidence included (a) a report involving the actual tone and/or response; (b) a report involving any discrete signal stimulus and/or respiratory act; or (c) a report in which unusual noise or breathing was described or could be inferred. Only those reports indicating sleep mentation were included, i.e., reports limited to such comments as "I was awakened by the tone" or "I heard that tone again" were excluded. There was 100% agreement between the judges on which reports to exclude. The judges were trained in the use of the scoring criteria via group training sessions using verbal reports from a pilot study as training exercises. All of the reports were independently scored by each judge to determine the percentage of agreement among the judges. Training continued until the percentage of agreement among the judges reached 90% for incorporation.

RESULTS

Fourteen subjects completed the experiment. A total of 208 tone trials were administered, and subjects were awakened following 151 of these trials to obtain reports on cognitive activity. Approximately the same number of awakenings occurred during Stage 2 (mean = 5.3) and REM (mean = 5.0). The percentage responding to the tone during Stage 2 and REM (68.8% and 68.4%, respectively) was also approximately equal. Reports of cognitive activity were more frequent in REM (80.6%) than in Stage 2 (55.9%). This difference was statistically significant: $t(12) = 4.26$; $p < 0.001$.

Cognitive reports and instrumental responses

Trials on which subjects reported cognitive activity (report trials) were associated with lower responsivity than trials on which subjects reported no cognitive activity (no-report trials). Figure 1 presents Tukey box graphs (15) describing the distribution of the percentage responding observed on report and no-report trials for Stage 2 and REM sleep together (based on 14 subjects) and for Stage 2 (based on 13 subjects) and REM sleep (based on 9 subjects) separately. The differences in the number of subjects for these graphs was due to some subjects not having observations under all conditions. For example, five subjects never failed to give a cognitive report during REM. The three horizontal lines of each "box" portray percentiles with p values of, from top to bottom, 75, 50, and 25. The horizontal lines immediately above and below each box

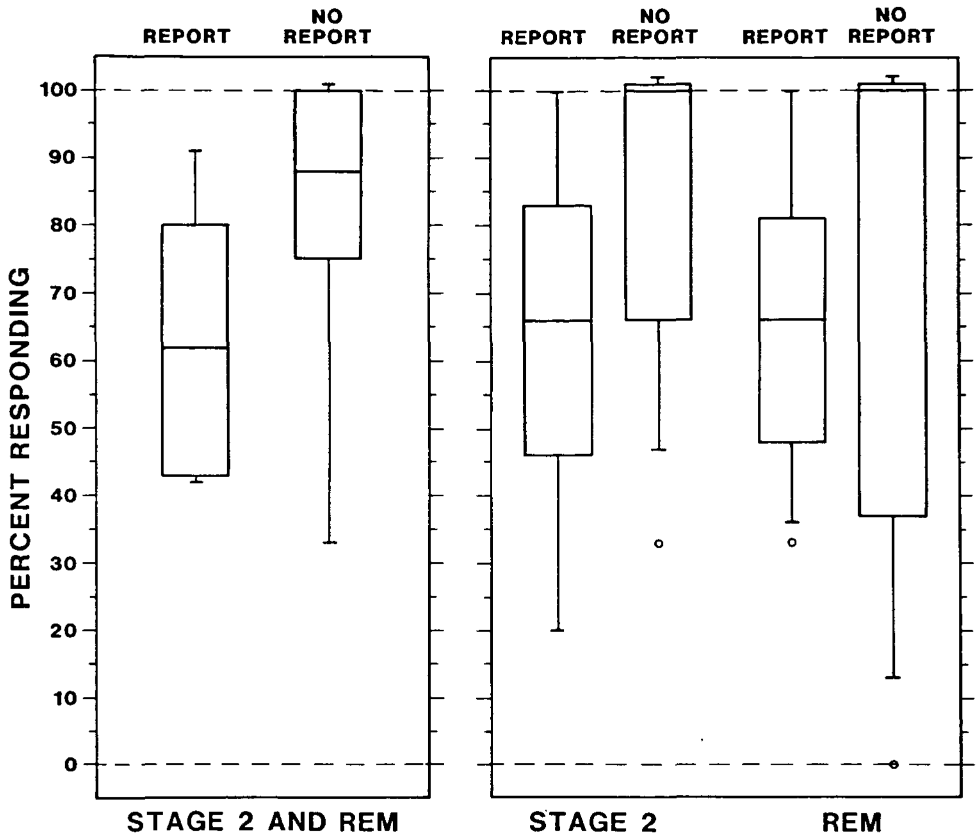

FIG. 1. The distribution of behavioral responding by report and no report for Stage 2 and REM together, Stage 2 alone, and REM alone.

portray the 90th and 10th percentiles, respectively. The circles are individual subject values that fell above the 90th or below the 10th percentiles.

It can be seen from Fig. 1 that for Stage 2 and REM trials together, cognitive activity was associated with reduced behavioral responsivity. Specifically, the median percentage of response was 63% on report trials and 88% on no-report trials. A Wilcoxon matched-sample signed-ranks test indicated that the differences in the locations of the samples were statistically significant ($p < 0.01$). Similar differences between instrumental response distributions can be seen between report and no-report trials for Stage 2 and REM trials separately. Wilcoxon tests indicated significant differences between report and no-report trials for Stage 2 ($p < 0.01$), but the difference was not significant for REM. Note that during both Stage 2 and REM half or more of the subjects responded on every trial when no report was obtained. The lack of significance for REM trials may have been due to the smaller number of subjects with observations under both report and no-report conditions and/or the variability under the no-report condition.

Incorporation and instrumental responses

Incorporation was defined as a cognitive report in which both judges found evidence of incorporation of the stimulus and/or response into ongoing sleep mentation. The judges agreed on the presence and type of incorporation on 92% of the cognitive reports. To control for the stage-related differences in the likelihood of a cognitive report, calculation of the proportion of trials with incorporation was based on the trials in which a cognitive report was obtained. Incorporation was evident in a mean of 40.8% (±23.5) of the REM trials and 37.4% (±37.2) of the Stage 2 trials. The differences between Stage 2 and REM sleep means were not statistically reliable.

Trials with evidence of incorporation (incorporation trials) were associated with lower levels of responsivity than trials with no evidence of incorporation (no-incorporation trials). Figure 2 presents Tukey box graphs describing the distribution of percentage responding on incorporation and no-incorporation trials for Stage 2 and REM together (based on 13 subjects) and Stage 2 (based on 7 subjects) and REM (based on 12 subjects) separately. It can be seen that the likelihood of an instrumental response for Stage 2 and REM combined was lower on incorporation trials (50%) than on no-incorporation trials (79%) and that the response distributions were similar for Stage 2 and REM separately. Statistically significant differences were found using the Wilcoxon test for Stage 2 and REM combined ($p < 0.01$). The differences for Stage 2 and REM alone were not statistically different.

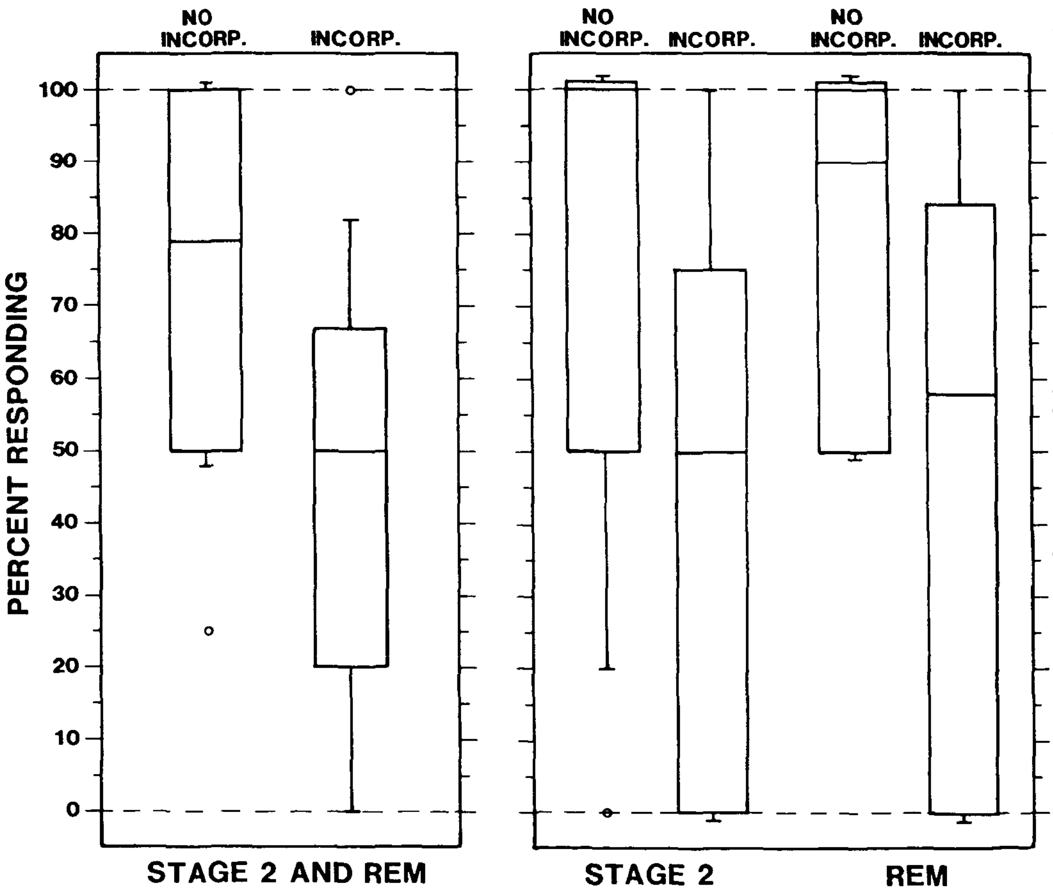

FIG. 2. The distribution of behavioral responding by incorporation and no incorporation for Stage 2 and REM together, Stage 2 alone, and REM alone.

Comparison of Figs. 1 and 2 suggests that the difference in percentage responding on report and no-report trials was due mainly to the lowered level of responding in association with incorporation. For Stage 2 and REM trials together, the level of responding on report trials with no incorporation (79%) was not different (by the Wilcoxon test) from the level of responding observed on trials with no cognitive reports (88%).

DISCUSSION

To summarize, it was found that (a) the likelihood of responding to an external stimulus presented during sleep was lower on trials with reports of cognitive activity (report trials) than on trials without reports of cognitive activity (no-report trials); (b) responding was less likely when the stimulus and/or response was incorporated into ongoing cognitive activity relative to no incorporation; and (c) responding on no-incorporation trials did not differ from responding on no-report trials. These relationships were apparent when examining Stage 2 and REM trials either in combination or separately, although statistical significance was consistently obtained only for the combined trials.

The finding of reduced sensitivity to external stimulation when accompanied by cognitive activity is consistent with the hypothesis that the sleeper is focusing attention on inner cognitive events such as dreaming, thinking, imaging, etc. Although Foulkes (7) discussed this hypothesis only in relation to the paradoxical cooccurrence during REM sleep of diminished responsiveness and EEG activation, the present data suggest that the same relation may hold during non-REM sleep. Caution must be used, however, in interpreting the present data as being strongly supportive of this hypothesis. One concern is that there were no reliable differences in responding between no-report trials and no-incorporation trials. That is, when the report trials were broken down into trials with and trials without evidence of incorporation, it was found that the level of responsiveness when there was no evidence of incorporation was as high as when there was no report of cognitive activity. This may have been due to a measurement limitation in that several subjects responded to 100% of both the no-report trials and the no-incorporation trials. On the other hand, it may be that cognitive activity is antagonistic to responding only when incorporation occurs.

The finding that incorporation trials were associated with reduced likelihood of responding is consistent with Freud's notion (8) that dreams serve to protect sleep. Incorporation may serve to rob a stimulus of its original meaning so that if a stimulus is successfully integrated within a dream, the sleeper is undisturbed (16). As suggested in the review by Arkin and Antrobus (9), the stimulus response was most frequently represented indirectly in the verbal reports. Although there were insufficient observations to permit formal analysis, inspection of the subjects' cognitive reports suggests that the greater the meaning of the tone was changed in incorporation, the less likely was the subject to either respond or arouse. For example, the following report contains direct references to the tone and was obtained on a trial where the subject responded: "I remember I was dreaming that I was hearing the tone, but it was real, real, real, real high pitched and it hurt my ears and I was crying . . . that's all I remember."

In the next report, there is an apparent transformation of the meaning of the signal, and the subject failed to respond: "That man . . . on Fantasy Island was ringing his bell and trying to get the people to come together so they could meet and talk about what was going to happen.

Sleep stage and incorporation

The likelihood of incorporation was similar across Stage 2 and REM sleep. This is in contrast to the findings of Hoelscher et al. (14), where incorporation of stimuli into sleep mentation was reported to be more likely during REM sleep. It is noteworthy that Hoelsher et al.'s overall response rate was low (19%) relative to other studies and that their Stage 2 data are based on only 17 verbal reports. The present study may provide a more stable index of cognitive responding during Stage 2 sleep. That cognitive activity may be similar between Stages 2 and REM is consistent with previous findings. For example, Antrobus (17) found no differences between reports from Stage 2 and REM sleep after holding word length of the verbal report constant. He concluded that higher levels of cortical arousal during REM sleep result in more effective storage and retrieval processes as compared with those in Stage 2 sleep, therefore increasing reporting abilities when aroused from sleep.

The results from this study indicate that a relationship exists between cognitive activity and responsivity to external stimuli during sleep. That Rechtschaffen et al. (12) did not find this relationship suggests that procedural factors (e.g., using a stimulus of increasing intensity) may be important. Another explanation involves the definition of incorporation: Rechtschaffen et al. scored only "obvious" stimulus incoporation; however, a stimulus may sometimes be transposed within the context of ongoing mentation (9). Additional studies of cognitive activity and responsiveness during sleep may provide useful insight into the role of cognition in disorders of initiating and maintaining sleep.

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