Sleep latency testing as a time course measure of state arousal

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SUMMARY The purpose of this study was to determine how long the effects of a brief period of physiological arousal persisted using repeated sleep latency testing and measurement of heart rate. Thirteen normal sleeping young adults spent two non-consecutive nights and the following days in the laboratory. On each day, subjects had five sleep latency measurements – at 09:00, 09:30, 10:00, 10:30, and 11:00 hours. The 09:00 test was a premanipulation baseline. Following this nap, subjects either walked for 5 min (on one day) or rested in bed for 10 min (on another day) prior to the 09:30 hours sleep latency test. Significant increases in sleep latency were found at 09:30, 10:00, and 11:00 hours following the single 5-min walk as compared with resting in bed (mean sleep latency after the walk was 11.7 min compared with 7.1 min for the resting condition). Heart rate was significantly higher throughout all of the postmanipulation naps following the walk. The elevated sleep latency is probably secondary to the changes in underlying physiological arousal as measured in this study by heart rate.

KEYWORDS arousal, heart rate, multiple sleep latency test, sleep, sleep disorders, sleepiness

INTRODUCTION

Sleep latency has been used as an objective measure of sleepiness for 30 years. It is the basis of the multiple sleep latency test (MSLT) and has face validity based on the demonstration of expected sleep latency changes following partial and complete sleep deprivation (Bonnet and Arand, 1994; Carskadon and Dement, 1979, 1982; Carskadon and Dement, 1981). However, sleep latency has also been shown to be affected by physiological and behavioral factors (Bonnet and Arand, 1995; Harrison and Horne, 1996; Roehrs et al., 1990; Stepanski et al., 1988). Thus sleep latency is not simply a reflection of underlying sleepiness.

Sleep latency is related to physiological arousal as indexed by heart rate. For example, sleep latencies were significantly shorter and heart rate was higher when measured after watching television as compared to following a 5-min walk in both normal subjects and insomnia patients (Bonnet and Arand, 1998, 2000). In those studies, sleep latency on the MSLT was also decreased after partial sleep loss as compared with normal sleep, and the sleep loss and physiological arousal effects were independent (Bonnet and Arand, 1998, 2000). This implies that sleep latency responds to the effects of physiological arousal as well as underlying sleepiness, and the effects are additive.

Therefore, the measurement of sleep latency is complicated by the fact that sleepiness accumulates at a slow and relatively continuous rate (process S) as a function of time awake, but also is related to physiological arousal, which has both trait and short acting state components (Bonnet and Arand, 2000). Physiological arousal, as measured by heart rate, has been shown to be higher when people sit up (compared with lying down) (Huikuri et al., 1994), stand (Lechin et al., 1995; Sloan et al., 1994), or perform mental arithmetic (Allen et al., 1987; Szabo and Gauvin, 1992), or other real world activities of varying difficulty (Jorna, 1993; Myrtek et al., 1996). Consequently, although underlying sleepiness may not change measurably in a short period of time, normal activity can increase the level of physiological arousal and have a large impact on sleep latency. How long such effects may persist is not known because previous studies have not examined the time course of episodic arousal effects on sleep latency.

The purpose of the current study was to use one activity manipulation and to measure sleep latency several times in the
2 h immediately following the activity to determine the time course of sleep latency change. It was hypothesized that sleep latencies following a normal daytime activity such as walking would be significantly longer than those following inactivity (watching television) and that this effect would diminish in a consistent manner during the 2 h following the activity.

**METHODS**

**Subjects**

Potential subjects were solicited from the university environment. Selected subjects were required to be healthy, 18–35-year-old males or females without significant history of shift work or benzodiazepine use. Potential subjects using more than 250 mg of caffeine per day were excluded. Potential subjects who smoked more than one-half a pack of cigarettes per day or who could not easily tolerate laboratory stays where smoking would not be permitted were excluded. Selected subjects denied problems with their sleep. Specifically, they reported that their sleep latency was < 30 min and that they were not bothered by frequent awakenings or early morning awakening. They did not usually take naps on weekdays. They reported that their usual time in bed on weekdays was between 7 and 9 h. Individuals meeting these criteria and expressing an interest in participating in the study were invited to the laboratory to complete a practice session on study tests before being scheduled for the study.

**Time**

All protocol and nap times cited in this paper were specified for a subject who normally went to bed at 23:00 hours and arose at 07:00 hours. Selected subjects normally went to bed on weeknights between 22:00 and 01:00 hours (mean 22:48 hours). Laboratory bed times and wake times were shifted to approximate normal weeknights for subjects (range 21:45–24:00 hours with a mean of 22:42 hours), but all nocturnal sleep periods were 8 h in length. Daytime testing and sleep latency tests were correspondingly moved to maintain similar circadian timing for all subjects on all nights.

**Design**

Subjects spent two non-consecutive nights, usually 1 week apart (median of 7 days), in the laboratory. On the following mornings, subjects remained at the laboratory where they took part in a sleep latency test protocol and performed brief computer tests. The daytime schedule is summarized in Table 1. Prior to the sleep latency test protocol, subjects were fed breakfast (caffeinated beverages were not available) and had the opportunity to use the bathroom (so that it would be unlikely that they would need to use the restroom again during the 2-h test protocol). Electroencephalograph (EEG) and electrocardiograph (EKG) were recorded throughout all of the sleep latency tests. EEG was also monitored to assure wakefulness throughout the Rest in Bed time.

On each day the baseline nap was followed by either a 5-min walk or 10 min of watching television while lying in bed. Immediately following the walk or watching TV, subjects were put in bed, and MSLT calibrations were performed. Lights were turned out and sleep latency tests began in 3–4 min. After the nap, subjects performed 5 min of computer tests (sleepiness and mood evaluations) at a desk in the bedroom and then were prepared for their next sleep latency test. A total of four sleep latency evaluations were performed following the Walk or Rest in Bed manipulation. Subjects normally did not leave the bedroom area (except for the single 5-min walk or possibly to go to the bathroom) during the course of the naps to minimize exposure to light, social interaction or other arousing events. Subjects were free to leave the laboratory at the end of the study (typically before noon).

Six of the subjects were randomly assigned to have the ‘Walk’ condition following the first night. The remaining subjects had the ‘Rest in Bed’ condition following the first night.

All subjects were assigned their own room for the course of the study. Each room contained a standard hospital bed and furniture including a desk with an Apple IIGS computer. Subjects participated in the study in groups of one to two individuals. Subjects completed tests and questionnaires at their individual computer workstation under technician observation. Meals were scheduled in another area of the laboratory, which was also within technician observation.

Mood was assessed with the Profile of Mood States (POMS) and a sleepiness rating scale.

Sleep recordings (LE – A2, RE – A2, C3 – A2, OZ – A1, V5 – right clavicle, and time code) were made during nocturnal sleep periods, naps, and MSLT evaluations. On the first night in the laboratory, airflow, chest movements and leg EMG were also measured so that any subject found to have sleep apnea or periodic leg movements could be excluded from the study. No subjects were excluded for these reasons. All sleep and nap

**Table 1** Daytime schedule*  
<table>
<thead>
<tr>
<th>Time</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>07:00–07:30 hours</td>
<td>Breakfast</td>
</tr>
<tr>
<td>08:00 hours</td>
<td>Computer tests</td>
</tr>
<tr>
<td>09:00 hours</td>
<td>Sleep latency test</td>
</tr>
<tr>
<td>09:20 hours A: Walk (5 minutes)/B: Rest in bed awake</td>
<td></td>
</tr>
<tr>
<td>09:30 hours</td>
<td>Sleep latency test</td>
</tr>
<tr>
<td>10:00 hours</td>
<td>Computer tests</td>
</tr>
<tr>
<td>10:20 hours</td>
<td>Computer tests</td>
</tr>
<tr>
<td>10:30 hours</td>
<td>Sleep latency test</td>
</tr>
<tr>
<td>10:50 hours</td>
<td>Computer tests</td>
</tr>
<tr>
<td>11:00 hours</td>
<td>Sleep latency test</td>
</tr>
<tr>
<td>11:20 hours</td>
<td>End</td>
</tr>
</tbody>
</table>

*Seven of the subjects had their resting wake following the first night and six of the subjects had the Walk following the first night. Computer tests included a Visual Activation Scale and the Profile of Mood States.
recordings were scored in 30 s epochs using Rechtschaffen and Kales (1968) criteria.

Resting wake

For resting wake observations, subjects laid down in bed and watched a TV that was placed in an elevated position at the foot of their bed. They were free to choose a channel from the local network stations available. The room lights remained on. Subjects were told to lie in bed, watch TV, and stay awake. EEG was monitored continuously for the 10 min, and the technician interacted with the subject if eye closure was noted on the video monitor or if signs of impending stage 1 sleep were noted on the polygraph. At the end of the 10 min, the technician entered the room, told the subject the nap would be next, and turned off the room lights. Sleep latency test calibrations and the sleep latency test followed immediately.

Five-minute walk

Subjects were instructed to take a 5-min walk. This walk usually included walking down two flights of stairs to the ground floor and walking around on the first floor or outside of the sleep laboratory building. Subjects were given a rough estimate of how far previous subjects had gone in 5 min but were not accompanied or paced. It was common for subjects to be exposed to other patients, bright light, and moderate temperature change (data for this study were collected in spring and summer). The walk was designed primarily as a 5-min break from the laboratory to induce stimulation common to patients in an outpatient hospital environment. On the rare occasions when subjects came back to the lab more than 30 s early, they were sent back to walk down the hallway and return. When subjects returned, they removed their shoes and were reconnected to the polygraph machine. Room lights were turned on, and the sleep latency test calibrations began.

Following standard calibrations (Carskadon, 1994), research sleep latency tests were performed. Subjects were allowed a maximum of 20 min in bed. However, subjects were awakened earlier and the test terminated if sleep spindles, k-complexes, or REMs occurred. Sleep latency was scored in 30-s epochs to the onset of any stage of sleep (usually stage 1). Technicians running the naps were naïve to the specific purpose of the study. Their protocol primarily stressed the correct timing of events so that naps started and ended at the correct time within the study design.

EKG data collection

Throughout the daytime test sessions, EKG data were digitized by a National Instruments NB-MIO-16 AD Board sampling at a rate of 500 samples per second. The EKG data were recorded through a Grass Braintree system running Gamma Version 4 software (Grass Telefactor, West Warwick, RI, USA). After collection, the EKG and time data supplied by the Gamma software were visualized and checked for artifacts and output to a separate peak detection program used to construct the tachogram and associated time code. Mean heart interbeat intervals for the first 5-min period of wakefulness during the sleep latency tests were determined. On occasions where subjects fell asleep prior to 5 min, interbeat intervals were analyzed only to the point of appearance of stage 1 EEG.

Analyses

The major outcome variables in this study were sleep latency on the sleep latency test and heart rate. Repeated measures ANOVA with effects for condition (Walk versus Rest) and time was performed with the hypothesis that there would be a significant time by condition interaction. Pairwise comparisons were performed with the Newman–Keuls test at the 0.05 significance level using the Huynh–Feldt corrected degrees of freedom. Where significant interactions were not found, the interaction error variance was pooled to test main effects.

RESULTS

Thirteen normal young adults, age 26 (SD 6.3), and weight 166 lbs (SD 35), participated in the study. Five subjects were female. Six subjects participated in the Rest in Bed condition first.

Sleep data

The EEG data from the laboratory nights were scored and compared. There were no significant differences from the first to second night, and no subjects were eliminated from the study based upon sleep disorders. The average total sleep time was 448 (SD 23.8) min.

Sleep latency data

Sleep latency data from the first naps on each day (prior to the experimental manipulation) were compared first to establish a baseline. There was no significant condition difference between these values ($t_{12} = 0.431$, NS) as expected. The mean latencies for these naps were 8.2 and 7.5 min respectively for the Rest in Bed and Walk conditions. The sleep latency data for the baseline and the four naps that followed the manipulation are plotted in Fig. 1. The ANOVA for the postmanipulation naps indicated a significant time by condition interaction ($F_{3,36} = 3.089$, $P = 0.039$). Pairwise comparisons showed that sleep latencies were longer following the Walk condition in all naps except the third.

EKG data

The average of interbeat intervals from the first 5-min segment of each MSLT were analyzed unless the subject fell asleep in < 5 min. For subjects who fell asleep more quickly, the analysis for interbeat interval stopped at the point where the EEG shifted to stage 1.
Interbeat interval data from the first naps on each day (prior to the experimental manipulation) were compared first to establish a baseline. There was no significant difference between these values ($t_{12} = 0.389$, NS). The mean interbeat intervals for these naps were $0.96$ s (SD $0.10$) and $0.95$ s (SD $0.12$) respectively for the Rest in Bed and Walk conditions.

The interbeat interval data for the baseline and the four naps that followed the manipulation are transformed to heart rate and plotted in Fig. 2. The $\text{anova}$ for the postmanipulation naps showed no significant interaction. There was a significant main effect ($F_{1,46} = 10.69$, $P < 0.005$). Interbeat intervals were $1.004 \pm 0.11$ (heart rate = 59.7 bpm) and $0.968 \pm 0.09$ (heart rate = 62 bpm) respectively for the Rest in Bed and Walk conditions.

**Mood**

Subjective sleepiness and POMS scale data collected after each of the postmanipulation naps were examined. Significant differences were not found on the subjective sleepiness scale and the POMS fatigue and vigilance scales. However, significant main effects were found for condition for the POMS tension ($F_{1,44} = 6.85$, $P < 0.05$; mean values 3.0 and 2.3 respectively following Rest in Bed and Walk Conditions) and anger ($F_{1,27} = 6.31$, $P < 0.05$; mean values 3.0 and 2.2 following Rest in Bed and Walk Conditions) scales. Both tension and anger were significantly lower following the Walk as compared with the Rest in Bed condition.

**Correlations**

To further assess the relationship between heart period and sleep latency on the naps, correlations were performed. Each subject had a total of 10 naps. This was sufficient data to allow correlation between heart period and latency for all of the naps within each subject (resulting in 13 correlations). These correlations were transformed to $z$-scores and averaged and compared with the expected result (0) with a $t$-test. When transformed back, the average correlation was $r = -0.28$. The $t$-value was $t_{12} = 2.021$ ($P < 0.05$) with the directional hypothesis that heart period would be longer (heart rate slower) when nap latencies were shorter.

**DISCUSSION**

Several studies have shown that moderate activity (Bonnet and Arand, 1998, 2000) or even simple movements like sitting or standing (Bonnet and Arand, 1999) can have a significant impact on heart rate and sleep latency measures that follow within a few minutes. The current study was designed to determine how long a brief period of activity might continue to influence sleep latency measurements. The data indicate that the state physiological arousal associated with one 5-min period of mild to moderate activity (walking with miscellaneous surround stimulation) was sufficient to significantly increase nap latencies and heart rate for at least 95 min compared with a resting condition. Because sleep latencies and heart rate remained elevated at the final test point, it is possible that significant increases in sleep latencies and heart rate may have continued for more than 95 min. The acute heart rate increase associated with the walk was similar to that seen in earlier experiments (Bonnet and Arand, 1998, 2000). However, the correlation between heart rate and sleep latency was not as high as in earlier studies (Bonnet and Arand, 1999, 2000). This probably reflects the fact that, in earlier studies, heart rate was always recorded within a few minutes of an activity manipulation so that heart rate and sleep latency measures were more clearly distinct from resting measures. In the current study, there was only one episode of physiological arousal so that more observations entered into the correlation were closer to the basal condition.
Figure 1 shows that sleep latency in the two conditions was equivalent just before the experimental manipulation, and was actually non-significantly longer in the condition where subjects received Rest in Bed. The data show a 3-min decrease in sleep latency from the baseline observation at the 09:30 hours nap in the Rest in Bed condition. This decrease looks very similar to the parallel decrease in sleep latency seen between the 09:30 and 10:00 hours sleep latency tests in the Walk data and probably reflects the same phenomenon. After getting up in the morning, subjects went to the bathroom, had breakfast and were exposed to daylight and social interaction in the lab. Physiological arousal associated with these activities would be expected to increase the baseline sleep latency and produce a sleep latency consistent with the first latency in a standard MSLT. Lack of continuing physiological arousal in the Rest in Bed group allowed a decrease in sleep latency by the 09:30 hours nap that was reflected 30 min later in the Walk group after they had spent 30 min in the non-arousing nap-test environment.

By strict definition, this study is not a study of the MSLT because the sleep latency tests were all given in the morning, and the time between test onsets was only 30 min. Nonetheless, the current results have implications for MSLT testing. The MSLT is presented as a test that is exclusively responsive to the sleep system. The results of the current study and several others (Bonnet and Arand, 1998, 2000), show that sleep latency can have a wide variation in normal young adults after normal nights of sleep under highly controlled laboratory conditions. Some individuals may argue that the conditions of the current study (sleep latency testing after watching TV while lying in bed or after walking for 5 min) would not be acceptable in a ‘true’ MSLT protocol. Unfortunately, both situations are common in most MSLT environments and neither is precluded by standard MSLT directions (Carskadon, 1986). The lack of a standard environment for the MSLT means that there is no true ‘baseline’ level for the test. Bed rest with enforced wakefulness was chosen as the baseline for the current study because that is the condition that most effectively limits sources of extraneous arousal that now are known to artificially increase sleep latency. In many MSLT settings, there is relatively little control of environmental stimuli between nap attempts, and this probably produces increased measure variability and somewhat longer sleep latencies. In one large study where normal young adults primarily sat at a desk and performed computer tests between MSLT observations, the mean MSLT for the group of 50 subjects was 7.4 min (Bonnet and Arand, 2003). This mean approximates the mean of the four naps from the Rest in Bed condition of the current study and reinforces numbers in this range as measures of sleep tendency with reasonable control of physiological arousal. This understanding is critical because, when study groups have been observed to have average sleep latencies in the 7-min range, studies have been criticized for not controlling for chronic partial sleep deprivation or for choosing unusual subjects. However, such results may only reflect more careful control of arousing stimuli in the lab environment.

Based upon the results of this study, our daytime evaluations are currently performed in sleep rooms with all external light blocked, and participants are encouraged to spend as much time as possible sitting in a chair or at a desk in the bedroom area between naps. These provisions probably help to stabilize MSLT evaluations within lab but do not give guidance to help compare findings across labs or to compare ‘normative’ data that did not control sources of extraneous arousal. It is assumed that many studies involving the MSLT have allowed participants to be exposed to light and activity similar to that used in the Walk condition from the present study and that many reported normal MSLT values are similar to the approximate 11.5-min average value found here after activity because subjects have been exposed to more significant physiological arousal.

If physiological arousal effects are important in determining sleep latency on a nap, could the current study results be explained by motivation or demand effects (i.e. the subjects wanted to cooperate and produced more arousal or the technicians non-verbally demanded more arousal and longer latencies following the walk)? First, such a criticism requires acceptance of the major hypothesis of the experiment that level of physiological arousal can determine sleep latency. It is clear that the subjects did not perceive increased physiological arousal demands associated with the walk condition because their mood reports after the walk showed them to be significantly less tense and less angry than in the Rest in Bed condition. If anything, these mood results would be predicted to produce relaxation rather than a conflicted demand situation. In addition, motivation effects were minimized as subjects were not given any kind of exercise or sleep latency goal, instruction, or reward. However, motivation itself could certainly have a significant impact on the MSLT. Research needs to address the fact that patients taking any MSLT frequently have high motivation (to keep a driver’s license or obtain stimulant medication), and that this variable is uncontrolled in virtually all studies that involve sleep latency testing.

Finally, the results of this study show that repeated sleep latency testing can be used to measure changes in level of arousal across relatively short periods of time. Similar tests, for example, could be used to document the effective life of stimulants in treating individual narcolepsy patients with much improved resolution than the standard MSLT, which, by its nature, can only differentiate changes with a 2-h resolution.

In summary, sleep latency is a combination of sleep need, circadian time, and state and trait arousal influence. Seemingly inconsequential amounts of activity and bright light exposure can influence sleep latency for 95 min or longer. The role of more complex arousing stimuli remains to be determined.

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REFERENCES


