INTRODUCTION

IT IS WELL KNOWN THAT THE CORRELATIONS BETWEEN VARIOUS MEASURES OF SLEEPINESS AND ALERTNESS ARE RELATIVELY MEAGER. JOHNS,1 IN A REVIEW OF the area, cited studies by Sangal et al2,3 showing correlations between the Multiple Sleep Latency Test (MSLT) and the Maintenance of Wakefulness Test (MWT) to range from \( r = .41 \) to \( r = .52 \). Based upon these data, Sangal et al2,3 concluded that the MSLT and MWT seem to measure somewhat different abilities. In another study that included both MSLT and MWT conditions in addition to conditions in which subjects were instructed to fall asleep while sitting and to stay awake while lying down, Bonnet and Arand4 found that correlations between conditions decreased as they became more disparate (the correlation between MSLT and MWT was \( r = .287 \)). Bonnet and Arand4 also showed that heart rate was significantly higher during the MWT as compared with the MSLT and that heart rate and sleep latency were significantly correlated. This led them to conclude that the MWT probably differed from the MSLT in that additional components of arousal (sleep position, effort to remain awake, light) allowed subjects to remain awake longer in the MWT but that these arousal effects could be independent of sleepiness and therefore would serve to decrease the correlations between MSLT and MWT.

JOHNS1 also reported that correlations between MSLT results and subjective sleepiness as measured by the Epworth Sleepiness Scale (ESS) are low. The average correlation from 9 studies published at that time was \( r = -.3 \), and this included 1 study with 522 subjects (\( r = -.27 \)).5 Such results emphasize that many individuals with physiologic sleepiness based upon MSLT findings report normal subjective alertness. One reason for this may be that the ESS is a trait measure while the MSLT and MWT can directly reflect acute changes in sleep schedules. However, even normal adults carefully screened to have normal sleep times have been found to have short latencies on the MSLT. One report by Harrison and Horne6 found 2 such subjects who were then recorded in the laboratory for several nights, including 3 nights with 10 hours time in bed while continuing to produce consistently short MSLT results (an average of 5.8 minutes for one and 7.6 minutes for the other). Harrison and Horne identified these subjects as having “High sleepability without sleepiness.” With only 2 (male) subjects, unfortunately, this study was not able to

Disclosure Statement
This was not an industry supported study. Dr. Arand was a co-investigator on a Cephalon study. Dr. Bonnet has received research support from Cephalon and Pfizer.

Submitted for publication July 2004
Accepted for publication November 2004
Address correspondence to: Michael H. Bonnet, PhD (151N), Dayton Department of Veterans Affairs Medical Center, 4100 W. Third Street, Dayton, OH 45428; Tel: (937)267-3910; Fax: (937)267 5317; E-mail: Bonnet. Michael@dayton.va.gov

SLEEP, Vol. 28, No. 6, 2005
more clearly characterize these individuals, identify how common they were, or further resolve the conflict between subjective and objective reports of sleepiness. Another study found that 30% of subjects with short MSLT latencies on screening (group mean of 6.3 minutes) continued to have latencies of less than 8 minutes even after 14 consecutive nights of time in bed extended to 10 hours in the lab. Bishop looked at both daytime sleepiness and rapid eye movement onsets in a group of 139 carefully screened young adults (normal sleep habits, no napping, and no evidence of excessive daytime sleepiness or other sleep disorders, including narcolepsy) and found that 24 (17%) had both MSLT values averaging 6.2 minutes and 2 or more rapid eye movement onsets. The purpose of the current study was to examine a large group of young adults reporting normal sleep, similar to those reported by Bishop, and to form a subject group with normal alertness (ie, MSLT > 10 minutes) to compare with groups who were ‘sleepy’ (ie, MSLT < 7) and who either were subjectively sleepy (Sleepy-Sleepy) or were not (Sleepy-Alert). A number of demographic, sleep, performance, and physiologic variables were examined.

METHODS

Subjects

Subjects were required to be healthy, 18- to 39-year-old men and women. Potential subjects were solicited from research referrals and from ads in the local papers (including local university papers) for participants in sleep research. The majority of individuals applying to participate in the study were students from local universities. Individuals who were considered further completed a screening questionnaire that indicated that they had normal sleep (ie, no sleep problems and sleep latency less than or equal to 30 minutes, wake time during the night of less than or equal to 15 minutes, and 7 to 8 hours of reported sleep) with rare daytime naps and no current history of night work. Subjects who described problems with their sleep were not considered further. Selected subjects did not consume excessive caffeine (more than 250 mg of caffeine per day) or more than 2 alcoholic drinks per day. Potential subjects who had histories strongly suggestive of circadian desynchrony (eg, shift workers), sleep apnea, or periodic leg movements were excluded. Subjects with a history of psychiatric care or use of psychoactive medication were excluded. Subjects who had previously slept in a sleep laboratory for any reason were also excluded.

Subjects meeting the above criteria were invited to participate in the study after completing an informed consent and practice on computer tests and questionnaires to be used in the study. Subjects were also screened with a routine complete blood count and urine drug screen. One potential subject was excluded from the study based upon a positive drug screen. All subjects were paid for their participation in the experiment.

Design

After completing the consent, subjects were scheduled for a screen night followed by a baseline night and a phase-advance sleep night (randomly assigned to be either a 3- or 6-hour advance). On the following week, subjects returned for a second baseline night and a second phase-advance night (the advance not given on the first week). Data for this report are exclusively from the screen and baseline nights and days. On the screen night, a standard clinical polysomnogram (performed with Grass Model 78 polygraph – Grass Telefactor, Quincy, MA), including 2 eye channels, central and occipital electroencephalogram channels, chin and leg electromyogram channels, electrocardiogram (ECG), airflow, chest movements (2 channels), and SaO2, was performed. Subjects with an apnea-hypopnea index greater than 10 or a periodic leg movement arousal index greater than 10 were disqualified.

All subjects were assigned their own bedroom with a desk, sink, comfortable chair, and television with video cassette recorder for the course of the study. Subjects participated in the study in groups of 1 or 2 individuals. Subjects completed tests and questionnaires at their individual computer workstation in their room under technician observation via video monitors. The bedroom windows were blocked to eliminate daylight, and subjects performed all study procedures alone in their assigned room. However, subjects were allowed to leave their room between test sessions, and other areas of the laboratory (ie, bathroom, kitchen/break area, monitoring room) had standard windows. There was standard fluorescent lighting throughout, with light levels ranging from about 250 lux at subject desks to about 120 lux at the beds. Subjects were encouraged to work on homework or hobbies during free time and were allowed to interact with technicians or other subjects in common areas of the laboratory. Time cues (other than those that might be provided from the television) were not available in the subject rooms, but no attempt was made to limit access to time cues in the other areas of the lab. Meals and breaks were scheduled in another area of the laboratory that was also within technician observation. subjects performed computer tests and completed the Minnesota Multiphasic Personality Inventory (MMPI) and a sleep history based upon the Stanford Sleep Questionnaire and Assessment of Wakefulness (SQAW). They were fed the same daily menu of food prepared at the lab during the day. Coffee-mate beverages were not available. Subjects usually did not leave the lab during the day and did not engage in vigorous activity. Subjects were allowed to leave the laboratory in the evening after the 4:00 PM MSLT and metabolic observation were completed.

All protocol and nap times cited in this paper were specified for a subject who normally went to bed at midnight and arose at 8:00 AM. However, some subjects normally went to bed somewhat later (or earlier) than these times based upon their stated weekday sleep times on the sleep questionnaire that they had completed when initially volunteering for the experiment. Therefore, bedtime and wake-up time were adjusted to approximate normal weekday times for each individual subject so that subjects were able to continue to maintain their typical routine without circadian shifts. Psychomotor and sleep-latency tests were correspondingly moved to maintain similar circadian timing for all subjects following all nights. However, subjects were chosen to normally spend about 8 hours in bed, and time in bed for all study nights for all subjects was 480 minutes.

Immediately after awakening each morning, subjects had a 20-minute waking metabolic observation that was also used to collect heart-rate data. Starting 2 hours after awakening, subjects had 4 MSLTs at 2-hour intervals. The MSLT followed standard research guidelines. Subjects were put in bed 5 minutes prior to the MSLT start time to allow adequate time for calibrations and correction of any recording problems. Following each MSLT, subjects had a 20-minute waking metabolic observation that was

_SLEEP, Vol. 28, No. 6, 2005_
also used to collect heart-rate data. Between MSLT observations, subjects performed psychomotor performance tests and mood evaluations. The daytime schedule is summarized in Table 1.

Psychomotor tests included a 30-minute visual vigilance test modeled after the Wilkinson Vigilance Test and used in several previous studies.13,14 At the conclusion of this test, computer-generated scores for hit rate, false alarm rate, and the signal detection theory measure of sensitivity unbiased for response productivity, P(A),15 were recorded. Only P(A), which combines hit rate and false alarm data, was analyzed for this report. Subjects also completed a 10-minute simple reaction time test,16 also modified for computer presentation. The median response time was used in the analysis. Finally, a simple visual activation scale, monitoring state subjective alertness or sleepiness,17 was administered. Higher scores indicated greater alertness.

The SQAW12 was completed during the following screening. Trait subjective sleepiness was assessed by summing responses to the series of questions assessing level of sleepiness during the prior 6 months in a number of specific situations, including those from the ESS scale in addition to responses on items relating to poor performance secondary to sleepiness and overall sleepiness.

Sleep recordings (LE-A2, RE-A2, C3-A2, OZ-A1, V5-right clavicle, and time code) were made during nocturnal sleep periods, sleep-latency evaluations, and waking metabolic observations. All sleep and nap recordings were scored in 30-second epochs using Rechtschaffen and Kales18 criteria. Sleep latency was defined as time from lights out to the first epoch of any stage of sleep on all polysomnograms and sleep-latency tests.

**ECG and Metabolic Data Collection**

Throughout the 20-minute daytime sessions, ECG data were recorded through a Grass Braintree (Grass Telefactor, Quincy, MA) system running Gamma software (Grass Telefactor, Quincy, MA) at a sampling rate of 500 samples per second. After collection, the ECG and time data were visualized and checked for artifacts with the Gamma software and output to a separate peak detection program used to construct the tachogram and associated time code. Mean heart interbeat intervals for consecutive 5-minute periods during the 20-minute waking sessions will be reported. In addition, spectral analysis (BMDP Spectral program – BMDP Statistical Software, Inc., Los Angeles, CA) was performed on the same 5-minute periods. Low-frequency power was defined as the total spectral power in the 0.05- to 0.15-Hz frequency band divided by the total spectral power in the 0.15- to 0.50-Hz frequency band. High-frequency power was defined as the total spectral power in the 0.15- to 0.50-Hz frequency band divided by the total spectral power (0.0-0.50 Hz). Further details of ECG data collection and analysis procedures are published elsewhere.19

All metabolic measurements were performed with a SensorMedics Deltatrac Metabolic Monitor (SensorMedics, Yorba Linda, CA). The Deltatrac generates a constant flow of 40 L per minute through a canopy or mask and into the metabolic cart. The high flow pulls all expired air and a significant amount of room air from an external inlet into the machine. The metabolic monitor then calculates the difference between the flow of air from the subject and a separate measure of pure room air to determine oxygen use and carbon-dioxide production by the subject. Further details are published elsewhere.19

For all metabolic observations, oxygen use was automatically averaged and output by the metabolic cart at the end of each minute. Subjects remaining in bed and were instructed to move as little as possible. The lights in the room were turned on, and subjects were allowed to watch television. However, reading or other activities involving movement or body posture were not allowed. During all metabolic recordings, electroencephalogram was recorded to ensure wakefulness. During all metabolic observations, subjects were also monitored by video camera to ensure compliance with the protocol (ie, no change in posture or removal of mask).

**Analyses**

The major planned analysis for the study was a comparison of extreme groups selected on the basis of MSLT following the screening laboratory night and subjective sleepiness based upon SQAW responses. Data were analyzed by a 2-between (extreme group) and repeated-measures analysis of variance with terms for night, time of test (where tests were repeated across the day), and interaction. When nonsignificant interactions were found, data were pooled to test the main effects. Pairwise comparisons were performed with the Newman-Keuls test at the .05 significance level using the Huynh-Feldt corrected degrees of freedom. All reported results in the text refer to statistically significant differences (P < .05) except where noted otherwise.

**RESULTS**

Fifty subjects—mean age 23 years (SD 4.6) and mean weight 152 pounds (SD 21)—completed the study. Thirty-three subjects were women. No subjects were disqualified from the study based upon the presence of sleep apnea (no subjects had an apnea-hypopnea index greater than 5) or periodic limb movements. One subject, despite a history of normal sleep, had sleep latencies of 40 minutes or longer on both the adaptation night and the first baseline night. This subject was given a preliminary diagnosis of psychophysiological insomnia and was deleted from the dataset.

Eleven subjects had MSLT latencies of longer than 10 minutes following the screening night and were assigned to the “Alert” group (Subjective sleepiness for this group ranged from 8-33 on the SQAW measure). Twelve subjects had MSLT latencies of shorter than 7 minutes on the screening night and a SQAW result less than 33 (range 12-32) and were assigned to the “Sleepy-Alert” group. Thirteen subjects had MSLT latencies of shorter
than 7 minutes on the screening night and a SQAW result greater than 32 (range 33-54) and were assigned to the “Sleepy-Sleepy” group. Demographic data from the subjects can be found in Table 2. It can be seen from Table 2 that there was a difference in sex distribution with the Alert group being 64% male while the Sleepy groups were 25% and 8% males. In terms of typical sleep times, there were no differences in sleep latency or typical total sleep time, although the Alert group did report significantly fewer awakenings during the night. The alert groups were very similar on the subjective sleepiness criterion. The subjective sleepiness group, as defined by selection criterion, reported significantly greater sleepiness.

**MSLT Data**

Initial group assignment was based upon MSLT following the screening night, so statistical analysis was not performed on the screening MSLT (data in Table 2). Analyses of variance on the MSLT data from the two baseline nights showed a significant Group by Night interaction ($F_{3,33} = 3.618, P < .01$). These data are plotted in Figure 1. Pairwise comparisons showed only that MSLT in the Alert group was significantly longer than in both sleepy groups on both baseline nights. MSLT was significantly longer in both sleepy groups on the second baseline day as compared with the first, but the means were still at 7 minutes for both groups. The consistency of the MSLT results was also examined by calculating the intraclass correlation of the MSLT data across the 3 nights.¹⁰ The reliability of the MSLT across nights was $r^3 = .804$.

**Sleep Data**

Analyses of the nocturnal sleep data revealed significant night-by-group interactions for total sleep time, sleep efficiency, and wake time during the night. The analyses were all consistent in showing that the Alert group had significantly decreased total sleep time (and correlated minutes of wake and sleep efficiency) compared with the other groups and compared with itself on the screening night compared to all other nights and groups. No other significant differences were found in the sleep data. The sleep data are summarized in Table 3 for the screen night and averaged baseline nights (which did not differ).

**Minnesota Multiphasic Personality Inventory**

Only 1 significant difference was found on the MMPI. The Sleepy-Sleepy group had a significantly elevated PA (paranoia) scale as compared with both other groups ($F_{2,33} = 3.86, P < .05$; respective means were 54, 55, and 63).

**Performance and Alertness**

Data from the 30-minute visual vigilance task, the 10-minute simple reaction time task, and the visual activation scale were analyzed. Data from all of these measures were collected 4 times during each day. For vigilance, there was a significant group by day interaction ($F_{3,33} = 6.45, P < .01$). Comparison of night-by-condition means showed that vigilance sensitivity—$P(A)$—in the Sleepy-Sleepy group was significantly worse than in both other groups on all 3 days. In addition, following the screening night and the second baseline night, $P(A)$ was significantly higher in the Alert group as compared with the Sleepy-Alert group. How-

---

**Figure 1**—Mean sleep latency on the Multiple Sleep Latency Test (MSLT) on 2 baseline days by study group.

---

**Table 2—Demographic Data**

<table>
<thead>
<tr>
<th>Group</th>
<th>Alert</th>
<th>Sleepy-Alert</th>
<th>Sleepy-Sleepy</th>
<th>$F_{2,33}$</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>22.7 ± 2.4</td>
<td>23.0 ± 4.7</td>
<td>22.3 ± 4.2</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>Sex, men/women</td>
<td>7/4</td>
<td>3/9</td>
<td>1/2</td>
<td>5.54*</td>
<td>A(F) &lt; SA = SS $\chi^2$</td>
</tr>
<tr>
<td>Weight, lbs</td>
<td>150 ± 22</td>
<td>149 ± 20</td>
<td>154 ± 24</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>Subjective Latency, min</td>
<td>13.5 ± 9.0</td>
<td>13.2 ± 7.6</td>
<td>15.1 ± 8.4</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Subjective TST, h</td>
<td>7.6 ± 0.5</td>
<td>7.1 ± 0.7</td>
<td>7.4 ± 1.0</td>
<td>2.36*</td>
<td>A &lt; all</td>
</tr>
<tr>
<td>Prior TST, h</td>
<td>7.5 ± 1.6</td>
<td>7.9 ± 0.3</td>
<td>8.2 ± 1.1</td>
<td>20.41*</td>
<td>SS &gt; all</td>
</tr>
<tr>
<td>Subjective Wakes, no.</td>
<td>.36 ± 0.7</td>
<td>1.0 ± 0.6</td>
<td>.77 ± 0.6</td>
<td>3.36*</td>
<td></td>
</tr>
<tr>
<td>SQAW Sleepiness</td>
<td>23.6 ± 7.5</td>
<td>24.2 ± 6.4</td>
<td>38.9 ± 6.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Screen MSLT, min</td>
<td>12.4 ± 1.8</td>
<td>5.25 ± 1.0</td>
<td>4.28 ± 1.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A refers to Alert group; SA, Sleepy-Alert group; SS, Sleepy-Sleepy group; TST, total sleep time; SQAW, Stanford Sleep Questionnaire and Assessment of Wakefulness; MSLT, Multiple Sleep Latency Test.

Data are presented as mean ± unless otherwise indicated.

*Less than other values as indicated in Differences, $P < .05$
ever, these groups did not differ following the first baseline night. These data are presented in Figure 2.

For reaction time, the main effect for group was not significant, but there was a significant group by day interaction ($F_{4,684} = 7.66, P < .01$). Comparison of night-by-condition means showed that reaction time was faster in the Alert group compared with both sleepy groups on all 3 days. The sleepy groups did not differ following the screen night; the Sleepy-Alert group had significantly slower reaction times on the first baseline day and the Sleepy-Sleepy group had significantly slower reaction time on the second baseline day so that, overall, reaction time in both sleepy groups was almost the same (345 milliseconds versus 341 milliseconds across the 3 days compared to 323 milliseconds in the Alert group).

The visual activation scale was a 10-point analog scale on the dimension of sleepiness/alertness. For the visual activation scale, which is plotted in Figure 3, there was a significant group-by-day interaction ($F_{1,205} = 2.58, P < .05$). Comparison of night-by-condition means showed that the Sleepy-Sleepy group was significantly sleepier than both other groups following the screen night. There were no significant group differences following the first baseline night. The Alert group was significantly more alert compared with both Sleepy groups following the second baseline night.

### Metabolic and ECG Variables

The heart-rate data were summarized for 5-minute periods (4 periods per 20-minute interval) to make them consistent with the published literature on heart-rate variability. The data were subjected to a 1-between, 3-within subject analysis of variance. The between variable was extreme group, as identified previously. The within variables were day (Screen, Baseline 1, and Baseline 2), time of day (5 times), and 5-minute interval within each test. The results have primarily been examined for the presence of significant Group interactions. There were no significant 3-way or 2-way interactions. Analysis of variance for the heart period variable showed no significant main effect for group or group by day interaction. However, there were significant interactions for both group by time of day ($F_{4,638} = 11.01, P < .001$), which is plotted in Figure 4, and group by time period within each time of day ($F_{6,615} = 2.81, P < .01$), which is plotted in Figure 5. In both analyses, the Sleepy-Sleepy group had a greater heart period (ie, slower heart rate) at all times of day and throughout each individual ECG collection period as compared to both other groups. The average heart period across the day for the Sleepy-Sleepy group was 1.003 ms.

![Figure 2 — Vigilance sensitivity (P(A)) daily mean across 3 study days by study group. Significant group differences are noted (*).](image1.png)

![Figure 3 — Mean daily scores on a 10-point subjective alertness/activity analog (VAS) scale across 3 study days by study group. Significant group differences are noted (*). Higher numbers indicate greater alertness.](image2.png)

### Table 3 — Sleep Data

<table>
<thead>
<tr>
<th>Screen</th>
<th>Alert</th>
<th>Sleepy-Alert</th>
<th>Sleepy-Sleepy</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 ± 22</td>
<td>451 ± 18</td>
<td>442 ± 18</td>
<td>442 ± 23</td>
</tr>
<tr>
<td>451 ± 18</td>
<td>442 ± 18</td>
<td>442 ± 23</td>
<td>Alert</td>
</tr>
<tr>
<td>1.003</td>
<td>1.003</td>
<td>1.003</td>
<td>1.003</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Baseline 2/3</th>
<th>Alert</th>
<th>Sleepy-Alert</th>
<th>Sleepy-Sleepy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sleep, min</td>
<td>410 ± 41</td>
<td>442 ± 23</td>
<td>453 ± 14</td>
</tr>
<tr>
<td>Sleep stage, percentage of total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>8.3 ± 5.5</td>
<td>8.4 ± 2.5</td>
<td>6.6 ± 3.1</td>
</tr>
<tr>
<td>2</td>
<td>44 ± 7.9</td>
<td>50 ± 7.1</td>
<td>53 ± 10.2</td>
</tr>
<tr>
<td>3</td>
<td>7.4 ± 7.8</td>
<td>6.4 ± 4.8</td>
<td>7.0 ± 7.1</td>
</tr>
<tr>
<td>REM</td>
<td>18.4 ± 7.0</td>
<td>20.4 ± 3.8</td>
<td>20.4 ± 4.4</td>
</tr>
<tr>
<td>Wake time, min</td>
<td>55 ± 34</td>
<td>28 ± 14</td>
<td>21 ± 11</td>
</tr>
<tr>
<td>Sleep efficiency, %</td>
<td>85 ± 8.3</td>
<td>92 ± 4.3</td>
<td>94 ± 2.8</td>
</tr>
</tbody>
</table>

Data are presented as mean ± SD.
REM refers to rapid eye movement sleep.
*Less than all other values, $P < .05$
seconds (heart rate of 59.8 beats per minute) as compared to .933 sec (64.3 beats per minute) and .937 sec (64.0 beats per minute) in the Alert and Sleepy-Alert groups respectively. The significant interactions were based on changes in these latter 2 groups across time. Heart period was significantly shorter in the Sleepy-Alert group as compared with the Alert group at the 8:00 AM time; there was no difference at 10:00 AM, and the Alert group had a significantly shorter heart period at noon and 2:00 PM, with no difference again at 4:00 PM. Across each data-collection period, the Alert and Sleepy-Alert groups did not differ for the first 10 minutes of the test, but the Sleepy-Alert group had a significantly greater heart period (ie, lower heart rate) for the last 10 minutes of the test.

For low-frequency power, the only significant analysis of variance effects were also for the group by time of day (F<sub>.6,40</sub> = 4.23, P < .01) and group by time period within each time-of-day interaction (F<sub>.6,40</sub> = 4.45, P < .01). In both analyses, the Alert group had a greater ratio of low to high spectral power at all times of day (see Figure 6) and throughout each individual ECG collection period as compared with both other groups. The interaction for time of day was based on changes during the day in the 2 sleepy groups: the Sleepy-Alert group had a significantly greater ratio of low to high spectral power at 8:00 AM and 10:00 AM than did the Sleepy-Sleepy group, but there were no other differences between these groups for the rest of the day. There were no significant differences between these groups within each ECG observation.

For high-frequency power, no significant differences were found.

For the analysis of metabolic rate, no significant differences were found.

Correlations

The interrelationship between MSLT, subjective sleepiness, and heart rate was examined by correlation. Many possible correlations were possible. Several previous studies have shown significant within-subject correlations between heart rate and objective sleep latency variables. However, as the current study was concerned with extreme group analyses, within-subject correlations were not deemed as relevant as traditional between subject correlations. To keep the number of correlations manageable, daily means for the following variables were correlated with each other on each of the 3 days: MSLT, visual activation scale subjective sleepiness, SQAW subjective sleepiness (only 1 value per subject collected from the screen day), heart period, and low-frequency ECG power. The correlations for these variables by study day are presented in Table 4. As can be seen from Table 4, the state measure of subjective sleepiness (visual activation scale) was not significantly correlated with MSLT latency on any day. The trait measure of subjective sleepiness (SQAW) was significantly correlated with nap latency only on the day that the measure was actually collected (following the screening night). Heart period was not significantly correlated with nap latency on any day. However, the spectral low-power ECG measure was significantly correlated with nap latency. In fact, the ECG power measure collected following the screen night was the only non-MSLT measure that was significantly correlated with nap latency from all 3 days. However, while the ECG power measure was significantly correlated with respective same-day nap latency following the screen and first baseline night, the value following the second baseline night was not significantly correlated with the MSLT for that day.

DISCUSSION

The current results replicate other studies that have shown that it is common for young adults with short latencies on MSLT evaluations to report normal alertness during the day. In the current sample, approximately the same numbers of subjects were identified in each subgroup. The 11 subjects in the Alert group represented all subjects with MSLT latencies greater than 10. Although not a selection factor, all subjects with MSLT latencies greater than 10 also reported trait subjective alertness on the SQAW (mean of 24). The subjects in the Sleepy-Alert group were chosen to all have MSLT latencies less than 7 and SQAW less than 33 (mean of 24), and 12 subjects were found who met these criteria. The 13 subjects in the Sleepy-Sleepy group were chosen to all have MSLT latencies less than 7 and SQAW greater than 32 (mean of 39). The implication is that these 3 types of individuals are all relatively common, and each represents about 25% of a normal young adult population.

Several previous studies have examined individuals chosen on the basis of normal sleep habits but with extreme values on the MSLT. One series of studies has shown consistent differences in MSLT in these groups that remain across many nights of sleep extension. 30% of subjects continue to have MSLT latencies less than 8 minutes despite 2 weeks of in-lab sleep extension to 10 hours in bed. Such subjects were similar to those reported by Harrison and Horne and earlier identified by Lavie, who
also reported a consistent differential response of these subjects to sleep deprivation. In 1 study, no significant differences in performance on divided attention and vigilance tasks were found when comparing subjects with high and low MSLT values. However, in a recent study, subjects with long MSLT latencies had improved performance on a ‘stop light’ task compared with subjects with short MSLT latencies. The current finding of decreased performance in both sleepy groups replicates this latter finding.

The consistency of MSLT results in previous studies was replicated in the current study and extended to both sleepy subgroups. Mean MSLT latencies in both sleepy groups remained at 7 minutes or less, and the MSLT latencies in the Alert group remained above 10 minutes with some regression toward the mean in all 3 groups across nights. This reliability, in concert with the substantial intraclass correlation, implies that group placement in this study, as in previous studies, was not based upon random variability or unique events, such as a single night of poor sleep, and implies that MSLT findings have a large trait component. The implication is that underlying baseline differences are real and probably not related to chronic partial sleep deprivation in subjects with normal sleep habits.

In addition to the traditional examination of individuals with short and long MSLT values, the current study further divided those groups based upon a subjective trait assessment of likelihood of falling asleep in a number of sedentary situations. Subjects could not be found who reported falling asleep when sedentary but who had long latencies on the MSLT. However, among subjects with short latencies on the MSLT, about half reported subjective alertness equivalent to that seen in subjects with long MSLT latencies (the Sleepy-Alert group), and about half reported sleepiness when sedentary (the Sleepy-Sleepy group). The groups with short MSLT values differed on a number of dimensions. The Sleepy-Sleepy group consistently had decreased vigilance sensitivity compared with the Sleepy-Alert group, although simple reaction time in the groups was similar. The reaction time test may not have differentiated as well because it is much shorter than the vigilance test (10 versus 30 minutes). The Sleepy-Sleepy group had increased subjective sleepiness on the screening day. They also had lower heart rate throughout the study compared with the Sleepy-Alert group and decreased low/high spectral heart power compared with the Sleepy-Alert group at 8:00 AM and 10:00 AM. In addition, they had higher scores on the paranoia scale on the MMPI.

These numerous psychomotor, subjective, and physiologic differences suggest that normals with short MSLT values can be meaningfully divided based upon trait behavior when sedentary. The cardiac measures may help to explain these group differences. All 3 groups differed reliably on both heart period (heart rate) and low/high spectral power (ie, analogous to sympathetic nervous system activity), with Sleepy-Sleepy subjects consistently having the slowest heart rate and lowest sympathetic activity. There were also a number of significant correlations between MSLT latencies and cardiac spectral power levels. Numerous studies have previously shown that sleep latency is correlated with heart rate, so it is not surprising that normal young adults with low heart rates fell asleep quickly on the MSLT. Low heart rate is commonly associated with decreased sympathetic activity. For example, it has been shown that patients with primary insomnia have increased heart rate and sympathetic activity compared with normal sleeping controls and also have longer latencies on MSLT. Such findings suggest that a similar phenomenon exists on the other end of the spectrum: individuals with less cardiac activation have less sympathetic arousal and therefore cannot maintain arousal as well when sedentary to promote performance and also fall asleep more rapidly when given the opportunity. The difference between the 2 sleepy groups may be a matter of degree. Those more prone to report falling asleep when sedentary have even lower resting heart rate and less sympathetic activation. Perhaps they were not distinguished by the MSLT because the values for both groups were so low. It is important to note that recent evidence has failed to show any change in heart rate or heart-rate variability after 4 nights with sleep restricted to 4 hours per night, and this implies that these heart-rate effects are not simply the results of chronic partial sleep deprivation in these groups.

SLEEP, Vol. 28, No. 6, 2005
reduced sleep time before or during the study, and they did not present sleep-stage rebounds. They are probably similar to those individuals with consistently short MSLT values, seen even after significant sleep satiation, as reported in previous studies.627

Other possible explanations of some parts of the data exist and should be considered. For example, are subjects in the Alert group short sleepers and are subjects in the Sleepy groups long sleepers? This would mean that subjects in the Alert group would be relatively sleep satiated and that subjects in the Sleepy groups would be relatively sleep deprived to account for their consistent and differential sleep latencies. Examination of the sleep data from the groups shows that the Alert group had reduced sleep time only on the screen night as compared with the other groups—they were really the only group to show this common first-night effect in the sleep lab. However, if these subjects really were sleep satiated coming into the study, one would have expected the Alert group to continue to have reduced total sleep throughout the study, which they did not have. On the other hand, the stronger first-night effect can also be explained by the fact that the Alert group had increased sympathetic nervous system activity that could have interacted with the stress of the first lab night to produce a greater first-night effect in this group.

To the casual reader, the data might suggest that the subjective differentiation between the groups was not strong or consistent based upon the correlations presented in Table 3. This could be taken to imply that the subjective differentiation between groups was not reliable and that the findings therefore may not generalize. It is important to understand that this study was based upon the observation that the ESS did not correlate well with the MSLT (the average correlation is reported to be about −0.3).1 Subjects in the Sleepy-Alert group were specifically chosen to have short latencies on the MSLT and high subjective alertness. Subjects in the Sleepy-Sleepy group were chosen to have short latencies on the MSLT and low subjective alertness, and this mix guarantees a poor correlation between subjective alertness and MSLT when groups are combined. This poor correlation does not represent poor measure reliability, simply the fact that there is relative independence between MSLT values and subjective ratings of situations that may produce sleepiness in individuals.

Taken as a whole, these data suggest that falling asleep is dependent both upon sleep-system components, such as length of time awake, and trait arousal-system components. Because patients with increased physiologic arousal associated with primary insomnia have higher heart rates and increased sympathetic activity9 with longer MSLT latencies,19,20,21 normal young adults with lower levels of arousal may be able to fall asleep rapidly without prior sleep deprivation. Because sleep deprivation can reduce sleep latencies in patients with insomnia to some extent,35 sleep satiation could increase sleep latency in normal individuals who fall asleep easily to some extent. However, because sleep deprivation does not cure the underlying hyperarousal in patients with primary insomnia, sleep satiation will not remove the underlying hypoarousal in these individuals. Individuals with hypoarousal may not be suitable for sedentary jobs that involve few sources of external stimulation. People at most risk can be identified based upon their historical reports of falling asleep in sedentary situations, but the lack of such a report does not mean lack of risk. Objective evaluation with the MSLT might be one means of identifying individuals most at risk for falling asleep in low-stimulation environments.

REFERENCES