Maintenance of Wakefulness Test and Multiple Sleep Latency Test*  
Measurement of Different Abilities in Patients With Sleep Disorders  
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The multiple sleep latency test and the maintenance of wakefulness test were administered on the same day to 258 consecutive patients whose clinical presentation required evaluation for excessive sleepiness. While the MSLT is the standard test for assessing excessive daytime sleepiness, the MWT may have some clinical advantage over the MSLT when the assessment of daytime alertness is the primary goal. To explore further the relationship between alertness and sleepiness, we have conducted a thorough analysis of the similarities, differences, and correlations between MWT and MSLT. The results of this study show that the coefficient of correlation between MSLT and MWT ($r = 0.41$), although statistically significant, accounts for less than 17 percent of the variability between the two tests. Factor analysis suggests that two factors, alertness and sleepiness, account for 91 percent of all variance. Our data demonstrate that patients with diagnosable disorders of excessive somnolence may be discordant on the two tests (eg, having low sleep latency on MSLT but high sleep latency on MWT). Specifically, we found that some patients with abnormally low MSLT scores were able to stay awake when asked to do so on the MWT, and conversely, some patients who failed to stay awake when asked to do so on the MWT were unable to fall asleep quickly on the MSLT. We conclude that the MWT and MSLT measure different abilities and that the MWT may be a useful adjuvant daytime test in many clinical situations.

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patients are instructed to fall asleep in the MSLT and to stay awake in the MWT, it is unclear whether the two tests are measuring the same or different neurophysiologic mechanisms for sleep onset and for maintaining wakefulness. We designed our study to determine how the two tests are related when both are applied consecutively to a group of patients with the initial complaint of daytime sleepiness. We now report that the correlation between the MSLT and MWT is significant but far from one-to-one and that patients with diagnosable disorders of excessive somnolence may be greatly discordant on the two tests (eg, having low sleep latency on MSLT but high sleep latency on MWT).

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METHODS

We studied a total of 258 patients, 185 men and 73 women, whose mean age was 44.6 (standard deviation = 13.9). Our polysomnographic protocols require that, to the extent that it is medically feasible, all patients should be free, for a minimum of one week prior to sleep laboratory evaluation, of medications that significantly affect the central nervous system. We believe that at least 95 percent of the patients were free of such drugs at the time of study. All had symptoms of daytime sleepiness or sleep apnea and were first administered an all night polysomnogram with a monitoring montage consisting of central and occipital electroencephalogram, digastic electromyogram and eye movement electrodes. The next morning, they were administered a standard diagnostic MSLT which entailed four 20-min long opportunities to fall asleep while lying in bed, which were offered at approximately 10:00, 12:00, 2:00 and 4:00 o'clock. Each MSLT nap was followed within 20 to 60 min by an MWT trial. For MWT trials, patients were seated upright in bed and asked to remain awake for 40 min. Each MWT test was terminated as soon as the patient was clearly asleep, defined as three continuous epochs of stage 1 sleep or any epoch of stage 2 to 4 or REM sleep. The lights were then turned on, the patient was awakened and instructed to stay awake until the next sleep latency test. If no sleep occurred, the test was terminated after 40 min. Four tests were administered during the day, one after each sleep latency nap. Scoring of both MSLT and MWT trials was done in the standard way, with latency being measured to the first epoch of any stage of sleep. Neither sleep latencies on the MWT nor other diagnostic findings were statistically influenced by the duration of the interval between the end of each MSLT nap and the start of each MWT trial.

The data matrix comprised of sleep latencies for the four MSLT and the four MWT trials was subjected to a factor analysis employing the Varimax orthogonal transformation solution.

Patients were then separated into different groups by diagnosis. Mean MSLT data in each group were divided into high and low mean MSLT, using the median MSLT of all patients as the dividing point. MWT data were similarly divided. Four cells (MWT low and
MSLT high, MWT low and MSLT low, MWT high and MSLT high, MWT high and MSLT low) were thus separated within each diagnostic group. The chi-square statistic was calculated for each group on resulting $2 \times 2$ tables.

**Results**

Figure 1 shows box plots that summarize the distributions for the individual MWT trials, as well as the four-trial average for each patient. Box plots are useful ways to present truncated data sets such as those resulting when individual scores frequently reach a protocol-dependent maximum such as 20 min for the MSLT and 40 min for the MWT. Each box encompasses the middle 50 percent of the distribution and the horizontal line within the box represents the median. Note that the median for the fourth MWT trial equaled the maximum value of 40 min. The notches about the horizontal line denote the 95 percent confidence band about the median. The vertical lines above and below denote the extent of the middle 80 percent of the distribution. Outliers above and below the middle 80 percent are denoted by individual dots.

**Figure 2.** Notched box plots for each MSLT nap and for the average of all four MSLT naps. The units for the y-axis are minutes. Each box encompasses the middle 50 percent of the distribution. The horizontal line within the box denotes the median. The notches about the horizontal line denote the 95 percent confidence band about the median. The vertical lines above and below denote the extent of the middle 80 percent of the distribution. Outliers above and below the middle 80 percent are denoted by individual dots.

**Figure 3.** Scatter plot for 258 data points representing 4-trial averages on the MWT (horizontal axis) and 4-nap averages on the MSLT (vertical axis). The units for both axes are minutes. The slanted line represents the linear regression equation and a Pearson correlation of .41 ($p<0.001$). The vertical and horizontal lines are drawn at the median values of the MWT (29.38 min) and MSLT (7.3 min), respectively.

Figure 3 presents the scatter of the four-nap MSLT averages vs the four trial MWT averages for all 258 patients. The correlation between the averages for the MWT and the averages for the MSLT, represented by the slanted line rising from left to right in Figure 3, was significant ($r = 0.41; p<0.001$). However, this correlation accounted for a relatively small portion of the overall variance (less than 17 percent). The vertical and horizontal lines in Figure 3 are drawn at the median values of the MWT (29.38 min) and MSLT (7.3 min), respectively. The four sections formed by these medians divide the sample into sections of concordance and discordance between MWT and MSLT scores. The lower left and the upper right sections represent concordance: the lower left section contains the most somnolent patients who have both low MSLT and low MWT sleep latencies. The upper right section contains the least somnolent patients who have both high MSLT and high MWT sleep latencies. The lower right and the upper left sections represent discordance: The lower right section contains patients who fall asleep quickly when asked to do so on the MSLT but stay awake when asked to do so on MWT. Note the vertical line of dots at MWT = 40 representing some 76 patients who paradoxically stayed awake on each of the four MWT trials yet

**Figure 1.** Notched box plots for each MWT nap and for the average of all four MWT naps. The units for the y-axis are minutes. Each box encompasses the middle 50 percent of the distribution. The horizontal line within the box denotes the median. The notches about the horizontal line denote the 95 percent confidence band about the median. The vertical lines above and below denote the extent of the middle 80 percent of the distribution. Outliers above and below the middle 80 percent are denoted by individual dots.
ranged in MSLT average from a low of about 2 min to a high of 20 min. The upper left section contains patients whose results are also paradoxical: they did not fall asleep quickly when asked to do so on the MSLT but did fall asleep quickly when asked to stay awake on the MWT.

Because this correlation accounted for less than 17 percent of the overall variance, we performed a factor analysis on the four individual trials of the MWT and four individual naps of the MSLT. The first step of the factor analysis produced a correlation matrix. The correlation matrix revealed that within the MWT, its four trials were well-correlated (mean r = .609). Likewise, within the MSLT, its four naps were well correlated (r = .610). These high internal correlations indicate that both the MWT and MSLT are reliable, internally consistent tests and suggest that the low correlation between the MWT and the MSLT is not due to low test-retest reliability between daytime tests in general.

Results of the factor analysis are summarized in Table 1. Three factors emerged: the first factor, which was labelled "alertness," accounted for about 46 percent of the variance and was highly loaded on the four MWT trials. The second factor, which we labelled "sleepiness," accounted for about 45 percent of the variance and was highly loaded on the four MSLT naps. A third factor was identified which accounted for 9 percent of the variance and was loaded on the last nap of the MSLT and the last trial of the MWT.

Since separate alertness and sleepiness factors emerged which correlated with the MWT and MSLT respectively, we wondered how various diagnostic groups scored along the MWT and MSLT dimensions. Four cells were created by dividing the sample into the four sections depicted in Figure 3 and separating the results according to each diagnostic category. Table 2 presents the $2 \times 2$ results ordered according to the five most numerous diagnostic categories: sleep apnea, narcolepsy, idiopathic hypersomnia, depression, and subjective disorders of excessive somnolence with no objective findings (subjective DOES). Four other di-

### Table 1—Factor Score Weights for Orthogonal Transformation Solution-Varimax

<table>
<thead>
<tr>
<th></th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MWT 1</td>
<td>0.321</td>
<td>-0.044</td>
<td>-0.150</td>
</tr>
<tr>
<td>MWT 2</td>
<td>0.348</td>
<td>0.021</td>
<td>-0.694</td>
</tr>
<tr>
<td>MWT 3</td>
<td>0.218</td>
<td>-0.099</td>
<td>0.182</td>
</tr>
<tr>
<td>MWT 4</td>
<td>0.279</td>
<td>-0.161</td>
<td>0.746</td>
</tr>
<tr>
<td>MSLT 1</td>
<td>-0.030</td>
<td>0.377</td>
<td>-0.464</td>
</tr>
<tr>
<td>MSLT 2</td>
<td>-0.053</td>
<td>0.358</td>
<td>-0.318</td>
</tr>
<tr>
<td>MSLT 3</td>
<td>-0.099</td>
<td>0.324</td>
<td>0.142</td>
</tr>
<tr>
<td>MSLT 4</td>
<td>-0.061</td>
<td>0.210</td>
<td>0.742</td>
</tr>
<tr>
<td>Eigen Values</td>
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<td>1.67</td>
<td>0.50</td>
</tr>
<tr>
<td>Variance Contribution</td>
<td>0.46</td>
<td>0.45</td>
<td>0.09</td>
</tr>
</tbody>
</table>

agnostic groups had a small number of patients and were not included in the analysis. They were as follows: traumatic sleep disorder, five patients; parasomnia, four patients; delayed sleep phase, one patient; and insufficient sleep syndrome, one patient.

Inspection of Table 2 discloses several important results. By definition, patients with the diagnosis of narcolepsy (the second diagnostic category in Table 2) had to have a MSLT of 5 min or less. Therefore, there are no patients with MSLT means above 5 (in the two upper cells of the narcolepsy section of Table 2). About 82 percent of patients were concordant for the two tests. This is a very high percentage. The chi-square statistic was highly significant. But 18 percent of patients had high MWT despite having low MSLT averages. Thus, these patients fell asleep when trying to fall asleep, but stayed awake when trying to stay awake. It is possible that this is an effect of the order in which the tests were administered. Since the MWT always followed the MSLT, the MSLT may have refreshed some patients and so they were able to stay awake for the MWT. With respect to sleep apnea, 70 percent of patients were concordant for the two tests. The chi-square was highly significant. Almost one in three (30 percent), were discordant. Although 15 percent had low MSLT and high MWT, thus suggesting again that the MSLT may have refreshed patients for the MWT, an equal number (15 percent) showed
the opposite trend. They took longer to fall asleep when they were trying to fall asleep, but fell asleep quickly when they were trying to stay awake.

Consider, now, subjective DOES without objective findings (the last diagnostic category of Table 2). As with narcolepsy, the distribution is skewed because, by definition, no one had low MSLT scores. Some 73 percent of patients were concordant. The chi-square test was highly significant, but 27 percent of patients fell asleep quickly on the MWT even though they did not fall asleep quickly on the MSLT. The data for idiopathic hypersomnia (third diagnostic category in Table 2) are also interesting. These patients often present with the complaint of being sleepy all the time. They say that they can stay awake if they try, but feel sleepy and tired all the time. Only 48 percent of patients were concordant for the two tests, and 52 percent were discordant; 37 percent fell asleep early during the MSLT, but were able to stay awake when they tried during the MWT. These findings are generally consistent with the clinical presentation of patients with idiopathic hypersomnia. The findings also suggest that the MSLT preceding the MWT did not refresh the patients, and in fact, the order of daytime testing had no consistent effect on the test results. The chi-square test was not significant. The data for depression present quite the opposite picture. Depressed patients complain of being tired and sleepy, with no energy, yet also complain of difficulty falling asleep. About 65 percent of patients were concordant for the two tests. However, 25 percent could not fall asleep early during the MSLT, but could not stay awake for long on the MWT. The chi-square test was not significant.

DISCUSSION

We have systematically explored the relationship between the MWT and the MSLT in 258 consecutive patients evaluated for excessive daytime sleepiness. Our results indicated a small but significant correlation between the MWT and the MSLT (r = 0.41). While this correlation is statistically significant, it is quite small. The statistical significance is due, of course, to the large number of subjects. In reality, the MWT variance only accounts for about 16 percent of the MSLT variance. This relative independence of the MWT and MSLT is consistent with various studies done to quantify sleepiness in patients who complain of excessive sleepiness. In smaller samples of patients, Browman et al. and Sangal and Thomas have reported that the MWT and MSLT do not correlate highly. Johnson et al. reported that in normal volunteers, a variety of performance and polygraphic measures of sleepiness do not always perfectly correlate. Webb has argued that such a lack of correlation should not be a surprise, given the complexity of influences that sleep and alertness have on behavior.

A factor analysis further indicated that the MWT and MSLT do not correlate perfectly and do seem to measure substantially different abilities. Results of the factor analysis are consistent with the hypothesis that the MSLT measures sleep tendency while the MWT measures ability to stay awake. These two factors account for 91 percent of the variance. The brain mechanisms for sleep latency may be different from the mechanisms for maintenance of wakefulness. The third factor, for which no name is obvious, accounted for 9 percent of the variance. This factor may be related to circadian influence and/or motivational influence impinging on behavior during the last polygraphic trial of the day. More information on this factor will come from research on circadian and motivational effects, as well as the quantity and quality of nocturnal sleep parameters.

Chi-square analysis for individual diagnostic categories (Table 2) indicates that the distribution along the dimensions of the MWT range (0 to 40) and the MSLT range (0 to 20) may not be systematic for depression and idiopathic hypersomnia. But for sleep apnea, narcolepsy and subjective DOES, there was a significant association between the MWT and MSLT. This reflects the facts that, within some diagnostic groups, patients tended to have low sleep latencies on both MWT and MSLT, while other patients tended to have high sleep latencies on both tests. However, there were a number of striking discordancies. From Table 2, it is clear that 15 percent of patients with sleep apnea were simultaneously in the bottom 50 percent on the MSLT (ie, the sleepier half) and in the top 50 percent on the MWT (ie, the more alert half). By adding the percentages in the upper left and the lower right cells of each 2 x 2 component in Table 2, one can see that there is MWT-MSLT discordance for 30 percent of patients with sleep apnea, 18 percent of patients with narcolepsy, 52 percent of patients with idiopathic hypersomnia, 36 percent of patients with depression, and 27 percent of patients with subjective DOES. Clearly then, some patients with abnormally low MSLT scores are able to stay awake when asked to do so on the MWT, and conversely, some patients who fail to stay awake when asked to do so on the MWT are unable to fall asleep quickly on the MSLT.

The reason for such MWT-MSLT discordancies is not apparent. However, these discordancies do call into question the exclusive use of the MSLT in making clinical decisions about the extent of disability related to sleep tendency. In a broader sense, it is tempting to speculate that various diagnostic entities may differentially affect the brain mechanisms of sleep tendency and maintenance of wakefulness.

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7th World Congress for Bronchology

7th World Congress of Bronchoesophagology

This world congress will be held at the Mayo Clinic and Mayo Medical Center, Rochester, Minnesota, September 28-October 2, 1992. Deadline for submission of abstracts is May 15, 1992. The congress will be jointly sponsored by the ACCP, the World Association for Bronchology, the International Bronchoesophagological Society, and the American Broncho-Esophagological Association. For information, contact Dr. Udaya Prakash, Secretary General and Director, East-18, Mayo Clinic, Rochester, Minnesota 55905.

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