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The impact of extended sleep on daytime alertness, vigilance, and mood

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Abstract

Background and purpose: To measure the effects of prolonged sleep extension on daytime alertness, vigilance, and mood in healthy young adults. Little research has documented the effects of increased sleep on daytime function despite a high prevalence of daytime fatigue and sleepiness in the adult population. Past extension studies report conflicting results with regard to Multiple Sleep Latency Test (MSLT) scores, vigilance, and mood ratings. No study has challenged subjects to maximum sleep extension, defined by an MSLT score of 20.

Patients and methods: Fifteen healthy college students reporting minimal daytime sleepiness were allowed to sleep as much as possible during a sleep extension period. MSLT scores, psychomotor vigilance task (PVT) reaction times, and profile of mood states (POMS) ratings were measured at baseline, mid-extension, and end-extension.

Results: There was a significant increase in both journal and actigraphy sleep totals during all extension segments ($P<0.01$). MSLT scores increased significantly from baseline to both mid- and end-extension ($P<0.01$). Five of eight tabulated PVT measures also improved significantly at mid- and end-extension with respect to baseline ($P<0.05$). POMS vigor and fatigue scores showed a similar improvement ($P<0.01$). Seven subjects achieved an MSLT score of 20. Six subjects showed substantial improvements while two subjects obtained relatively little extra sleep and showed little or no MSLT improvement. The maximum extension group displayed exceptional improvements in vigilance and POMS ratings.

Conclusions: Extended sleep leads to substantial improvements in daytime alertness, reaction time, and mood.

Keywords: Sleep extension; Multiple sleep latency test; Psychomotor vigilance task; Daytime alertness; Reaction time; Mood; Sleep debt; Young adults

1. Introduction

Over the years, sleep deprivation has been used as a major tool to elucidate the mechanisms and functions of sleep. By far the majority of reports, however, involve total sleep deprivation [1,2] while relatively few studies involve long-term partial sleep restriction or extension. The paucity of the latter is not congruent with poll results and epidemiological studies [3–7] showing that a high percentage of the adult population experiences excessive daytime sleepiness and fatigue. For individuals who do not have sleep disorders, the cause of excessive sleepiness is assumed to be chronic sleep loss. Supporting this assumption is poll information [5,6] showing that most people habitually sleep less than 8 h a night. Moreover, excessive sleepiness and fatigue often have troublesome and tragic consequences [8,9].

In adult humans, several well-designed laboratory studies have consistently shown that partial sleep reduction over consecutive nights has a cumulative quasi-linear effect that includes progressive deterioration in daytime alertness and performance [10–14]. The studies involving increased nightly sleep time are less consistent. For example, Taub et al. [15] showed decrements in performance on a pinball task following extended sleep, and Harrison and Horne [16] reported little change in auditory vigilance and in Multiple

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Sleep Latency Test (MSLT) scores during 2 weeks of extended sleep. Finally, the large scale dose–response study of sleep loss recently reported by Belenky et al. [13] included a subgroup that spent 9 h in bed for seven nights. This group showed no change in any performance measure over baseline.

Conversely, there are studies showing that sleep extension has beneficial effects. Wehr and colleagues [17,18] reported great improvements in energy and mood in subjects spending 14 h in bed for 4 weeks. In the first study of sleep extension utilizing the MSLT, Carskadon and Dement [19] found significant improvements in scores and non-significant improvements in performance with four nights of extended sleep, attributing the improvement to the reversal of prior partial sleep restriction. Roehrs et al. [20] found that extending time in bed to 10 h a night for 6 days led to increased MSLT scores and improved reaction times, especially for sleepy (baseline MSLT score $\leq$6 min) subjects. A subsequent study by the same investigators [21] found increases in MSLT scores of up to 6 min in sleepy (MSLT score $\leq$6 min) subjects who maintained a 10-h time in bed schedule for 2 weeks. The researchers concluded that the short latencies found at baseline were related to chronic undersleeping. Howard et al. [22] showed that anesthesia residents who extended their nightly sleep were less likely to fall asleep on the job. One night of extended sleep has been shown to significantly improve MSLT scores [23], and even small increases in total sleep can improve mood and vigilance levels [24,25].

One possible solution to the pervasive societal problem of dangerous levels of sleepiness and fatigue would be to increase habitual sleep time throughout the general population. Conclusive evidence that sleep extension will consistently improve waking alertness, psychomotor performance and mood, as opposed to being detrimental or without consequence, would provide compelling motivation to achieve such a solution. In view of the relative scarcity of sleep extension studies, we decided to carry out our own study of sleep extension. We required subjects to sleep as much as possible at their own chosen hours in an effort to reach maximal sleep extension. Daily sleep times, MSLT scores, vigilance, and mood were measured at baseline and during the extension period. Following the approach of Harrison and Horne [16], we also wished to test whether individuals would be able to substantially increase time in a familiar sleep setting without compromising their ongoing work and social commitments.

2. Methods

2.1. Subjects

Fifteen healthy college students (4 women, 11 men) aged 18–23 years (mean 20.1 $\pm$ 1.2 years) were selected from those who responded to campus-wide emails soliciting healthy, normal sleepers (Table 1). Subjects completed a screening questionnaire to exclude those with overt sleep disorder symptoms or those who were taking medications with undesirable sleep-related side effects. None of the 15 volunteers reported illicit drug use or excessive alcohol or caffeine consumption. No exclusions were made based on sleep schedules although applicants were turned away if their daily schedules did not allow at least 10 free hours for sleep per night during the extension period. Participants were also excluded if they did not regularly sleep alone or in their own rooms. After selection, each subject completed the Epworth Sleepiness Scale. Subjects agreed to abstain from alcohol and caffeine use during this time.

Table 1
Subject demographics

Subject	Age	Sex	Pre-study Epworth score
1	19	F	6
2	21	M	5
3	18	F	9
4	21	M	10
5	21	M	6
6	21	M	3
7	19	M	10
8	19	M	9
9	20	M	0
10	19	M	10
11	20	M	10
12	20	F	n/a
13	23	F	11
14	20	M	n/a
15	20	M	7

2.2. Sleep measures

Subjects were equipped with wristwatch-like actigraphs on the dominant wrist to measure sleep–wake activity (Ambulatory Monitoring, Inc., Ardsley, NY). Actigraphy is a widely accepted method to quantify sleep in healthy individuals [26] and obviates the much more difficult, burdensome and expensive use of continuous all night brain wave recording [27]. In addition to actigraphy, subjects recorded bedtime, estimated sleep latency, rise time, hours napped, total nighttime sleep, and a subjective rating of daytime mood (1–10 scale of daytime sleepiness and overall mood) in daily sleep logs.

2.3. Study design

The study was organized into three phases: baseline (7 days total), early-extension (days 1–7), and late-extension (days 8–end), with day 1 marking the first day of the extension period (Fig. 1). An MSLT was conducted the day after each of the three phases. During the baseline phase, subjects were encouraged to maintain a habitual sleep schedule, but within the limits of no less than 6 h and no

Fig. 1. Study timeline. Each tick mark represents 1 day. Mid-extension MSLT occurred after seven nights of maximal sleep. The late-extension period ranged from 6 to 48 days, with the end-extension MSLT taking place when subjects' outside commitments prevented maximal sleep extension or upon reaching the defined satiation level (maximum subjective alertness ratings, feeling unable to obtain extra sleep).

more than 9 h. The first 2 days of baseline sleep recordings were not documented while subjects accommodated to instrumentation and established a proper sleeping schedule and environment.

Subjects were encouraged to sleep as much as possible during the extension phase, which began on the first night after the baseline MSLT recording. A second MSLT was carried out after 7 days on the extension schedule to measure progress. The late-extension phase began after the second MSLT and ranged from 6 to 48 days. Throughout the study, subjects were continually encouraged to obtain as much sleep as possible. The study ended when individuals reached maximum subjective alertness levels and felt that they were unable to obtain extra sleep (difficulty in falling asleep, maintaining sleep, or 'sleeping in') or when outside commitments prevented further participation.

2.4. Testing: MSLT days

2.4.1. Multiple sleep latency test

Each subject had three daytime MSLTs: the first at the end of baseline (baseline MSLT), the second at extension day 7 (mid-extension MSLT), and the third on the final day of the study (end-extension MSLT). Five trials were conducted at 2-h intervals. Instead of the traditional 1000–1200–1400–1600–1800 schedule, subjects began their first trial 2 h after morning awakening, thus allowing subjects to maintain their habitual sleep patterns. EEG (C3/C4/O1/O2), EOG, and submental EMG electrodes were used to monitor sleep and wakefulness, in particular to detect the disappearance of alpha activity indicating sleep onset. Before each trial, subjects rested comfortably in a quiet, dark bedroom with their eyes closed and were instructed to try to fall asleep. Standard MSLT protocol guidelines [28] were meticulously followed.

2.4.2. Performance testing

The psychomotor vigilance task (PVT) was administered 5–10 min after each MSLT trial. This computerized handheld device is used in standard protocols to measure reaction time and is sensitive to the effects of daytime fatigue [13,29]. Each 10-min trial consisted of a series of bright lights to which subjects reacted by pressing a button with their dominant index finger. The time interval between the appearance of the bright light and the subject's reaction was defined as the reaction time. The interval between light stimuli ranged from 1.5 to 7 s with 120–140 stimuli during each 600-s (10-min) trial. Data were stored in the device and downloaded to a computer. The subjects were familiarized with the PVT before testing began.

2.4.3. Profile of mood states

The profile of mood states (POMS) questionnaire was administered at three separate times on MSLT days (after trials 1, 3, and 5). Subjects evaluated frequency of 65 feelings (e.g. 'active', 'gloomy' 'restless', etc.) over the past 7 days as 'not at all', 'a little', 'moderately', 'quite a bit', and 'extremely'.

2.5. Data analysis

Group total sleep time, MSLT scores, PVT results, and mood ratings recorded during each extension period were compared to baseline data using Student's *t*-tests as well as multiple regression analysis to control for inter-subject differences and time of day.

'Satiated' versus 'unsatiated' subgroup differences in performance and mood scores were compared using Student's *t*-tests. Subjects were assigned to these subgroups based on MSLT scores (see results). Multiple regression was not performed due to the reduced sample size.

3. Results

3.1. Group sleep totals

Total daily sleep times for baseline, early- and late-extension periods are presented in Table 2. There was a significant increase in both subjective (journal) and objective (actigraphy) sleep totals during all extension segments compared to baseline ($P<0.01$). For journal and actigraphy recordings, the highest sleep totals occurred on extension days 1–3. Both measures of total sleep time decreased progressively during the extension period. Journal sleep averages for each segment showed a trend towards being higher than actigraphy sleep times. This finding is consistent with observations that actigraphy accounts for intra-sleep period awakenings that are not recalled by the subject.

Table 2
Group ($N=15$) total sleep time

Activity measure	Baseline[a]	Early-extension		Late-extension	
		Days 1–3	Days 4–7	Days 8–10[b]	Final[c]
Journal	447±35	593±67	569±57	549±60	512±74
Actigraphy	421±53	562±69	536±49	496±67	500±76

Mean±SD. All times in minutes.
[a] Average of five baseline days before first MSLT.
[b] Journal versus actigraphy $P<0.05$.
[c] Final 3 days up to night before third MSLT.

3.2. Effects of extra sleep

Sleep extension was consistently associated with improvements in MSLT scores, reaction time, and mood ratings.

3.2.1. Sleep latency

Baseline, mid-extension, and end-extension MSLT data are illustrated in Fig. 2. Mean latencies increased significantly from the baseline to both mid- ($P<0.01$) and end-extension MSLTs ($P<0.01$). Multiple regression analysis showed that after controlling for inter-subject differences and time of day, overall there was an increase in the MSLT of 5.7 min (95% CI 4.1–7.3) at mid-extension compared to baseline and an increase of 8.5 min (95% CI 7.0–10.1) at end-extension compared to baseline.

As opposed to baseline, individual sleep latencies during the extension period tended to lengthen throughout the day with maximum latencies at the end of the day. Multiple regression analysis confirmed this as well. Controlling for inter-subject differences and extension segment, the fourth and fifth MSLT trial results were, respectively, 2.0 min (95% CI 0.01–4.1) and 4.1 min (95% CI 2.1–6.1) greater than the result for the first MSLT trial.

3.2.2. Performance

Group reaction time performance results are presented in Table 3. The majority of performance measures improved during the extension period with respect to baseline. The improvement was statistically significant ($P<0.05$) for five of the eight values at both mid- and end-extension (see Table 3). On the other hand, group performance values did not change significantly from mid- to end-extension.

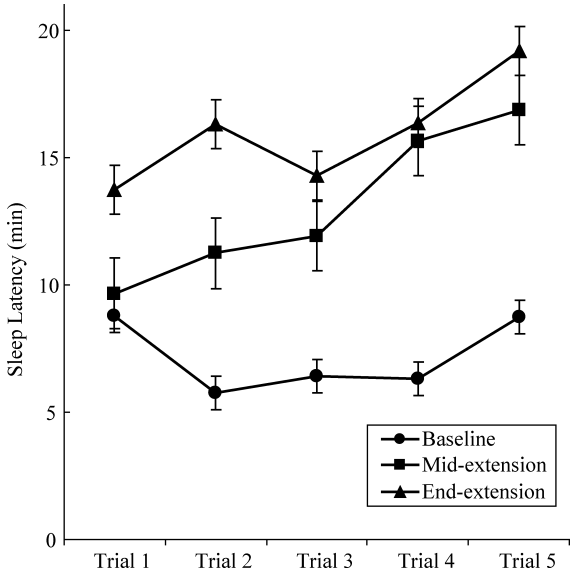

Fig. 2. Group latencies (minutes) on baseline, mid-extension and end-extension MSLTs. Trials were administered 2 h apart, with trial 1 occurring within 2 h of morning awakening. Error bars represent standard error of the mean.

Table 3
Group psychomotor vigilance task performance

	Baseline	Mid-extension	End-extension
All subjects			
Mean reaction time (ms)	265±39	226±31*	227±36*
Maximum reaction time (ms)	812±1228	502±552	485±277
Minimum reaction time (ms)	183±26	169±23	168±22
Median reaction time (ms)	247±32	215±28*	216±31*
No. of times RT>500 ms ('lapses')	1.08±1.5	0.35±0.7	0.40±0.8
Mean: fastest 10% times (ms)	199±26	180±23*	180±22*
Mean of the reciprocal of RT/1000 ms	4.05±0.52	4.65±0.57*	4.65±0.67*
Mean of the reciprocal of the slowest 10% RT/1000 ms	2.66±0.53	3.31±0.60*	3.36±0.80*

Mean±SD. *$P<0.05$ compared to baseline.

3.2.3. Mood

Average daily POMS vigor and fatigue scores also improved during the sleep extension period (Table 4). These scores represent the average vigor and fatigue scores for POMS administered after MSLT trials 1, 3, and 5 (approximately 1100, 1500, and 1900). Multiple regression analysis showed that after controlling for inter-subject differences, the improvement in vigor score compared to baseline was 3.6 (95% CI 1.2–5.9) at mid-extension and 8.0 (95% CI 5.6–10.3) at end-extension. The overall improvement (decrease) in fatigue scores was 7.4 (95% CI 5.5–9.2) at mid-extension and 10.4 (95% CI 8.5–12.2) at end-extension.

3.3. Separation and comparison of subgroups based on 'sleep satiation'

The 15-member subject pool was later separated for descriptive purposes based on progression to 'sleep satiation' defined by an extension MSLT score of 20 (Table 5). Seven out of 15 subjects were classified as 'satiated'. One of these seven subjects was included in the satiation group with an end MSLT score of 19.9 based on one trial of 19.5 and 20 on the other four. Another subject whose final MSLT score was 17.5 but who scored 20 on the mid-extension test was also included with the satiated group. All others were classified as 'unsatiated' regardless of improvement in any other measures. Total daily sleep time, reaction time, and POMS scales were not figured into

Table 4
POMS vigor and fatigue scales on MSLT days

	Baseline	Mid-extension	End-extension
All subjects (N=15)			
Vigor	11.8±7.6	15.4±7.6	19.4±8.6*
Fatigue	11.2±5.2	3.8±4.6*	0.9±1.7*

Mean±SD. POMS questionnaires were administered after MSLT trials 1, 3, and 5 (approximately 1100, 1500, 1900) during indicated study phase. *$P<0.01$ compared to baseline.

Table 5
Mean MSLT scores and subgroup classification

Subject	Baseline MSLT		Mid-extension MSLT		End-extension MSLT		Subgroup classification[a]
	Mean	Range	Mean	Range	Mean	Range	
1	2.5	1.0–4.5	9.9	2.5–17.0	14.8	9.0–20.0	Unsatiated
2	10.3	4.0–20.0	9.0	4.0–16.0	10.3	4.5–20.0	Unsatiated
3	5.8	3.0–10.5	9.9	3.5–15.5	11.8	6.5–20.0	Unsatiated
4	16.9	13.0–20.0	19.1	17.5–20.0	20.0	20.0–20.0	Satiated
5	5.2	4.0–7.0	8.0	5.0–10.0	10.8	5.0–20.0	Unsatiated
6	4.8	3.0–11.0	13.6	4.0–20.0	20.0	20.0–20.0	Satiated
7	3.2	3.0–3.5	16.0	10.5–20.0	19.9	19.5–20.0	Satiated
8	7.1	3.0–12.5	17.1	10.0–20.0	20.0	20.0–20.0	Satiated
9	11.5	5.5–20	20.0	20.0–20.0	17.5	7.5–20.0	Satiated
10	12.6	11.0–15.0	11.8	4.0–20.0	17.6	13.5–20.0	Unsatiated
11	8.2	4.0–13.0	13.1	4.0–20.0	9.2	5.0–20.0	Unsatiated
12	2.5	1.0–4.0	14.5	6.5–20.0	20.0	20.0–20.0	Satiated
13	4.8	2.0–9.5	14.6	10.0–20.0	12.9	2.0–20.0	Unsatiated
14	11.1	6.5–17	12.9	7.0–20.0	20.0	20.0–20.0	Satiated
15	4.9	3.0–7.0	6.0	1.0–18.0	13.6	5.0–20.0	Unsatiated

[a] Based on MSLT score of 20.

the classification. MSLT results for the entire group as well as each subgroup are presented in Fig. 3.

3.3.1. Total sleep time

Total sleep time results for the subgroups are shown in Table 6. There was no significant difference in subjective or objective reports of sleep time between the groups except for the journal records for days 4–7 when the satiated group had greater total sleep time ($P < 0.05$). The observation of higher journal totals versus actigraphy persisted within the subgroups, although there were no statistically significant differences.

3.3.2. Performance

Reaction time data revealed faster times in mid- and end-extension compared to baseline for satiated subjects (Table 7). The satiated group showed improvements in the majority of performance measures despite slower baseline reaction times than the unsatiated group. The unsatiated group did not demonstrate the same improvements, although the small sample sizes provided low statistical power for this analysis.

3.3.3. Mood

Mean POMS vigor and fatigue scores during sleep extension showed improvement in both subgroups (Table 8). While the scores for the entire group improved significantly during sleep extension (see Table 4), subgroup separation demonstrated moderately better vigor and fatigue scores and worse baseline ratings in the satiated group as compared to the unsatiated group. As a result, satiated individuals had a greater net change in mean vigor (+10.1) and fatigue (−10.0) ratings than unsatiated individuals (+5.3 and −8.9, respectively).

4. Discussion

In our study, sleep extension to nightly amounts substantially more than habitual sleep times significantly improved group MSLT scores, reaction time measures, and mood scales. The mean improvement in MSLT scores for the entire group was a robust 8.6. Given that subjects who reached an MSLT score of 20 by definition could not

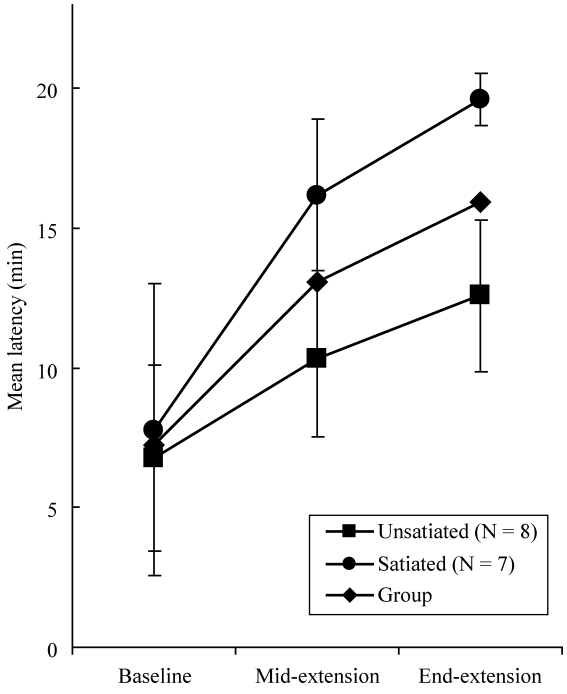

Fig. 3. Group and subgroup mean latencies at baseline, mid-extension, and end-extension. Error bars represent standard deviations of mean latencies represented by each data point.

Table 6
Subgroup total sleep time

Group	Activity measure	Baseline[a]	Early-extension		Late-extension	
		Average	Days 1–3	Days 4–7	Days 8–10	Final[b]
Satiated	Journal	455±30	604±48	603±36	543±52	526±47
	Actigraphy	418±47	573±55	554±36	494±79	489±86
Unsatiated	Journal	441±39	583±82	539±57	553±69	501±50
	Actigraphy	424±61	553±82	521±56	497±62	508±47

Mean±SD. Mean is average of individual averages for each segment presented.
[a] Average of five baseline days before first MSLT.
[b] Final 3 days up to night before third MSLT.

have further improvement in their scores, these overall results are fairly impressive.

For descriptive purposes, we divided the subjects into a group who successfully eliminated sleepiness during sleep extension (the satiated subgroup) and those who did not. For the satiated subgroup (seven subjects), the mean improvement in MSLT scores over baseline was 11.8, and for the remaining eight subjects, the mean was 5.6. In addition, all of the subjects in the satiated group felt better, all showed great improvement in mood subscales, and all showed a marked PVT improvement. One satiated subject had an unusually slow baseline mean reaction time (329.9 ms) but nonetheless improved substantially during sleep extension. The other six improved to a very fast mean reaction time of 198.3 ms (range 183.9–208.1) from a baseline mean of 255.3 ms. This baseline value is in the range of reported norms [13,30,31], suggesting that normative data are actually sleep deprived data. The unsatiated group had a very similar baseline PVT mean score of 259 ms with only a small improvement of the subgroup mean at end-extension (245.1 ms). Roughly similar results were seen with the vigor and fatigue subscales, i.e. the satiated subgroup showed greater improvements.

We did not attempt to relate changes in waking functions to daily amounts of extended nightly sleep. All subjects slept more than their baseline means on at least some nights. However (see below), we were uncertain as to how much of the extended amounts actually represented 'extra' sleep for individual subjects over recorded baselines. Nonetheless, given the very clear improvements in the satiated group, we add our study to the body of evidence [17–23] supporting the conclusion that extended sleep for at least several nights is likely to have substantial beneficial effects for waking alertness, mood and performance.

On the other hand, is it possible that long term nightly sleep extension could have no benefit or even be deleterious for at least some individuals? We cannot be absolutely certain. The scientific literature contains only three sleep extension studies finding no objective improvements in functioning. The Taub et al. [15] study reporting decrements in performance on calculation, vigilance, and pinball tasks had only two nights of sleep extension. The sleep extension study reported by Harrison and Horne [16] required

Table 7
Subgroup PVT performance

	Baseline	Mid-extension	End-extension
Satiated subjects (N=7)			
Mean reaction time (ms)	271±44	213±34*	204±30*^
Maximum reaction time (ms)	1000±1754	411±121	331±97^
Minimum reaction time (ms)	186±29	164±27	160±19
Median reaction time (ms)	251±32	206±34*	198±29*^
No. of times RT>500 ms ('lapses')	1.29±1.84	0.17±0.38	0.06±0.24
Mean: fastest 10% times (ms)	201±28	176±28	170±19*
Mean of the reciprocal of RT/1000 ms	3.99±0.54	4.89±0.66*	5.07±0.60*^
Mean of the reciprocal of the slowest 10% RT/1000 ms	2.65±0.67	3.62±0.59*^	3.97±0.67*^
Unsatiated subjects (N=8)			
Mean reaction time (ms)	259±36	237±25	245±29^
Maximum reaction time (ms)	644±340	612±791	631±328^
Minimum reaction time (ms)	180±24	173±18	175±22
Median reaction time (ms)	243±32	223±20	232±25^
No. of times RT>500 ms ('lapses')	0.91±1.12	0.57±0.92	0.74±0.95
Mean: fastest 10% times (ms)	197±27	182±18	185±22
Mean of the reciprocal of RT/1000 ms	4.11±0.55	4.45±0.40	4.32±0.52^
Mean of the reciprocal of the slowest 10% RT/1000 ms	2.67±0.39	3.00±0.48^	2.82±0.47^

Mean±SD. *$P<0.05$ compared to baseline within subgroup. ^$P<0.05$ compared to corresponding result in other subgroup.

Table 8
Subgroup POMS vigor and fatigue scores

	Baseline	Mid-extension	End-extension
Satiated group (N=7)			
Vigor	11.1±6.4	17.3±7.2	21.2±8.0*
Fatigue	12.2±5.7	2.1±2.7*	0.2±0.5*
Unsatiated group (N=8)			
Vigor	12.5±8.5	13.8±7.6	17.8±9.0
Fatigue	10.3±4.6	5.3±5.4	1.4±2.1*

Mean±SD. POMS questionnaires were administered after MSLT trials 1, 3, and 5 (approximately 1100, 1500, 1900) during indicated study phase. *$P<0.05$ compared to baseline.

10 subjects to spend 10 h in bed for 14 consecutive nights, and utilized mood questionnaires, the Wilkinson Auditory Vigilance Task, and MSLT measurements. These three daytime measures showed no significant changes during the period of extended sleep in relation to baseline values. It is noteworthy that their baseline MSLT scores showed unusual alertness (mean 16.2) allowing little room for improvement although total sleep time did nonetheless average 1 h more than baseline on extended nights. Finally, the large scale dose–response study recently reported by Belenky et al. [13] included a subgroup that spent 9 h in bed for seven nights. This group showed no change in any performance measure from baseline. Given that the reported average sleep time during the 9 h in bed was 7.9 h, it appears that relatively little extra sleep if any was obtained.

In this study and indeed in almost every reported study of sleep, it cannot be assumed that the baseline values for nightly sleep represent subjects' specific homeostatic sleep requirements. Baseline time in bed is almost always arbitrarily limited to 8 h or less and/or there are too few baseline nights. The study reported by Wehr and colleagues [17,18] may be the single instance where data that could be equated with the subjects' daily sleep requirement were obtained. The entire group of subjects was studied long enough to arrive at a steady state period of at least a week where they could not sleep more than the group mean of 8 h 15 min in spite of remaining on the schedule of 14 h in bed in a darkened room. It might therefore be assumed that this final amount was the mean homeostatic requirement for these young adults. Their laboratory baseline total sleep was 7 h 36 min which might actually have entailed a small amount of sleep loss. In our study, we requested subjects to sleep their 'usual amount' during baseline. We have assumed their baseline values were close but not exactly equal to their daily homeostatic sleep requirements. While the results involving daytime measurements would be clearer if changes could be correlated with the precise amount of each subject's sleep debt reduction, this is not currently possible for the reasons mentioned above.

We take the theoretical position that every human being has a specific amount of sleep that must be obtained each day on the average to satisfy the daily homeostatic sleep requirement. Elsewhere [32–34], we have hypothesized that less than this daily requirement leads to progressively increasing sleep tendency and more than this leads to a progressively decreasing sleep tendency. The cumulative amount of lost sleep is commonly referred to as 'sleep debt'. Given that the current widely accepted model of homeostatic sleep regulation [35–37] is at least very similar if not identical among individual human beings, the progressive impairment of daytime function during partial sleep deprivation may be attributed to a progressively larger sleep debt. Progressive improvements in waking functions during sleep extension can be conceptualized as the effect of reducing sleep debt.

As noted by other investigators, individuals who state that daytime sleepiness is not a problem can have MSLT scores in the so-called pathological range. Eight of our subjects had baseline MSLT scores of less than six. If a so-called 'pathological' MSLT score is indicative of a very strong sleep tendency, it seems that many people are unaware that they have an increased likelihood of falling asleep. In this regard, we must report a very poor correlation between pre-study Epworth values and baseline MSLT scores in our study ($r=0.012$) supporting the lack of self-awareness.

Future research should focus on both partial sleep deprivation and sleep extension, given their importance to individual and societal well being. Such studies should also target the issue of individual homeostatic sleep requirement. A specific amount of sleep could be a constitutional characteristic of an individual or could vary 'adaptively' as suggested by Belenky et al. [13]. If we encourage individuals to obtain adequate sleep and/or to reduce their sleep debt, it would be helpful if they knew their daily homeostatic sleep requirement. As the data suggest, basing such knowledge only on the way one feels in the daytime could be quite misleading. Here again, a scientific basis for clearly understanding the relationship between sleep time at night and the way we feel in the daytime (as opposed to how we perform) is badly needed.

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