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Testing the Rip Van Winkle Effect:
Sleep Extension following Nominal and Restricted Sleep
Testing the Rip Van Winkle Effect: Sleep Extension following Nominal and Restricted Sleep

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Abstract

The negative effects of sleep loss on sleepiness, performance, and mood have been well-documented. Less is known, however, about possible negative effects of sleep extension and findings are inconsistent. This study investigated the Rip Van Winkle effect, comparing the effects of a single night of sleep extension (11 h time-in-bed, TIB) to control sleep (8.5 h TIB) following three nights on a nominal (8.5 h TIB) or restricted (6.5 h TIB) sleep schedule. Nine healthy males (mean age 21 y; mean habitual sleep 7.9 h) participated in a four-way cross-over design. Participants completed sleepiness and mood scales, a range of performance tasks, and multiple sleep latency tests approximately every two hours following in-laboratory baseline and experimental nights. Objective sleepiness was reduced (i.e., sleep onset latency was delayed) following sleep extension under both nominal and restricted baseline conditions. Self-reported mood was modestly improved following sleep extension. No changes in subjective sleepiness or objectively measured performance were observed across conditions. The results indicate that one night of sleep extension, following either nominal or restricted sleep, can reduce objective sleepiness but does not appear to consistently alter performance or subjective sleepiness.

Keywords

MSLT; cognitive performance; mood; recovery sleep; sleepiness

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1. Introduction

The negative effects of sleep restriction on alertness, mood, and performance have been demonstrated in laboratory and field studies (1–4). The effects of sleep extension, however, are less well understood. Sleep extension, for the purposes of this paper, refers to a sleep period which exceeds biological sleep need. Early studies of sleep extension observed a phenomenon in which oversleeping was associated with poorer outcomes for mood (5–7) and performance (7–10). Globus (5), in a survey of young adults, reported that respondents more frequently identified with feeling “worn out” rather than feeling “just great” after sleep periods greater than 10 hours under conditions of no prior sleep debt. Further, when asked to rank negative feelings associated with oversleeping, respondents from a follow-up study rated “sleepy” as the most common descriptor (6). Taub and colleagues performed a series of studies (7–10) measuring performance and subjective responses following 1–2 nights of extended sleep (>9 h) in the laboratory. The authors reported that auditory vigilance (7–9), complex motor performance (9), sleepiness (10), and mood (7) significantly worsened following extended sleep nights compared to control nights. Further, Roehrs et al. (11) observed that after 1–3 nights of sleep extension, sleep latency tested 2 hours after waking was reduced in a group of alert participants (baseline sleep latency ≤ 16 min). Together, these studies suggest that oversleeping or extended sleep may, counterintuitively, lead to sleepiness and impaired performance.

Not all studies of extended sleep, however, have observed what Taub and Berger (8) described as a “Rip Van Winkle Effect” of oversleeping. After 4–7 nights of sleep extension, improvements have been observed relative to habitual sleep for performance (11–13), sleep latency (11–14), and mood (12, 13). These neurobehavioural benefits of extended sleep have also been observed during subsequent sleep deprivation and recovery (13, 15). These studies measured neurobehavioural changes after multiple nights of sleep extension, suggesting that chronic, rather than acute, exposure to nights of extended sleep may confer benefits to performance, alertness and mood.

In a field study of industry workers, Kubo et al. (16) observed that extending sleep on weekend nights improved psychomotor vigilance performance the following Monday, but that this benefit was not sustained across the week. It should be noted that these workers habitually slept less than their sleep need, and therefore had a cumulative sleep debt leading in to the weekend extended sleep. In the laboratory, chronically sleep-deprived participants (5 nights of 4 hours time-in-bed, TIB) did not return to baseline levels of performance or alertness after a single recovery night of 10 hours TIB (17). Therefore, where extended sleep follows restricted sleep, restoration of performance to baseline may not occur, or may only be short-lived.

It has been argued that sleep in excess of biological need is redundant under well-rested conditions. Nocturnal sleep extension of up to 10 hours for 14 nights, for example, failed to improve measures of objective or subjective sleepiness, mood, or overall performance on an auditory vigilance task (18). Similarly, extending nocturnal sleep by over an hour on one night conferred no change to psychomotor vigilance performance and only modest improvements for sleepiness in the afternoon around the post-lunch dip (19). This argument is further supported by the findings from the Belenky et al. (20) chronic sleep restriction study in which a 9-h TIB group showed no significant improvements in performance or alertness relative to baseline (8-h TIB) or to a 7-h TIB group. These studies suggest that extending sleep opportunity beyond sleep need will have little impact on subsequent performance.

No studies, however, have systematically addressed Globus’ (5) original observations of the subjective effects of extended sleep following nominal versus restricted sleep, or with a repeated measures design. Therefore, the aim of the current study was to measure the effect of sleep extension under conditions of prior nominal and restricted sleep on sleepiness, performance, and mood. According to Globus’ (5) observations, we hypothesised that subjective ratings of sleepiness and mood, as well as objective performance, will be worse following extended sleep under nominal prior sleep conditions compared to prior sleep restriction. Given the mixed evidence for significant increases in sleep onset latency following extended sleep (11–14, 18, 19), we hypothesised that objective sleepiness will be unchanged following a single night of sleep extension with nominal prior sleep and improved following prior restricted sleep.
2. Methods

2.1 Participants

Nine healthy young adult males aged 18-26 years (mean age ± standard deviation: 21.1 ± 2.4 years) participated in the study. Participants reported habitual sleep durations ranging from 7 to 9 hours (7.9 ± 0.6 hours) and were classified as either moderate morning (n=3) or neither type (n=6) on the morningness-eveningness scale (21). Participants provided written, informed consent and received an honorarium for their time. The study was approved by the Medical Committee for the Protection of Human Subjects in Research at Stanford University.

2.2 Study Design

The study consisted of a four-way cross-over design, with the order of conditions randomised. Participants were asked to maintain a regular bedtime routine (2300-0730) for the two weeks prior to the study. During these two weeks, participants were asked to refrain from recreational drug use, to report any medication use, and to limit alcohol and caffeine intake to no more than two drinks per day. Sleep patterns during this time were monitored using sleep diaries.

The study took place over 27 consecutive days, including nine in-laboratory testing nights and days. Table 1 outlines the bed, sleep, wake and rise times for each laboratory study night. There were two baseline-night sleep-time schedules: baseline nominal (N) (2300-0730) and baseline restricted (R) (0100-0730). Prior to each baseline night in the laboratory, participants spent two nights at home on the same sleep schedule as the baseline night (i.e., N or R schedule), thus undergoing three baseline nights for each condition (see Figure 1). Sleep timing at home prior to baseline nights was confirmed with morning and evening telephone calls. All in-laboratory sleep periods were measured using standard polysomnography.

Following the in-laboratory baseline night, participants were assigned to an experimental night of control (C) (2300-0730) or extended (E) (2300-1000) sleep. Participants then spent three washout nights at home on the baseline nominal (N) (2300-0730) schedule before beginning another series of two home nights on baseline schedule, one in-laboratory baseline night and one in-laboratory control or experimental night. The first visit to the laboratory included an adaptation night between the home and laboratory baseline nights on which

Figure 1. Protocol schematic. BL: baseline; MEM: Williams word memory test; POMS: Profile Of Mood States; SLT: sleep latency test; SSS: Stanford Sleepiness Scale; WAVT: Wilkinson auditory vigilance task.
sleep timing was scheduled to match the baseline condition (i.e., nominal or restricted).

Participants were aware of the at-home sleep-wake schedules but not primed for the in-laboratory schedules. During the in-laboratory sessions, participants were possibly aware of differences in conditions, but not necessarily the extent of the differences.

During periods of scheduled in-bed wakefulness on baseline restriction (R), experimental and control (C) nights in the laboratory, participants lay in bed in a dark room listening to the radio. Electroencephalographic monitoring during this time ensured participants did not fall asleep. This design was used in order to control for the effect of light and activity during these wakefulness periods, such that the only difference between conditions was the length of the sleep opportunity.

Food, and in particular the nutritional content of breakfast, was controlled across participants and study days. Breakfast was served shortly after rise time (see Table 1), therefore breakfast was served earlier on baseline days (~0730) compared to experimental days (~1000). All other meals were time-matched across study days and conditions. Caffeine and alcohol consumption were not permitted during the in-laboratory portion study, and limited to two drinks per day during the two weeks before the study. Participants were allowed to walk around campus between testing sessions, i.e., light and time-cues were not controlled.

2.3 Measures

All tests were performed multiple times throughout each day following a night in the laboratory. All tests bouts performed after 1000 (i.e., those test bouts performed on every in-laboratory study day) were included in analyses. Participants were given the same instructions for each test bout to minimise any inadvertent influence from the experimenters.

2.3.1 Polysomnography

Sleep was recorded and scored using the standard methods described in Rechtschaffen and Kales (22). Each participant had electrodes attached to the scalp and face to record electroencephalogram (EEG), electro-oculogram (EOG), and electromyogram (EMG). The sleep recording electrode array included placements according to the 10-20 international system (23) at C3, C4, O1, and O2. Electrodes for the referential recording of EEG and EOG were placed on the mastoids. EOG electrodes were attached to the outer canthi of each eye. Electrodes for the bipolar recording of EMG were placed beneath the chin. All sleep periods (overnight and multiple sleep latency tests) were recorded on Grass Model 7 polygraphs at a paper speed of 10mm/second. EEG and EOG channels were calibrated at 50 microvolts/cm. EEG was recorded with a low frequency cutoff of 0.3 cycles per second and a high frequency filter of 35 cycles per second. All sleep records were scored in 30-second epochs according to the standard criteria (22). Sleep parameters reported include: total sleep time; time spent in Stage 1, Stage 2, slow wave, and rapid eye movement (REM) sleep; number of REM periods; sleep onset latency; and wake after sleep onset.

2.3.2 Multiple Sleep Latency Test (MSLT)

The Multiple Sleep Latency Test (MSLT) was used as an objective measure of sleepiness. For a full description of the MSLT experimental protocol see Carskadon et al. (24). Briefly, participants lay in a dark room (<1 lux) and were instructed to “lie quietly, keep your eyes closed, and try to fall asleep.” The test was terminated after three consecutive epochs of stage 1 sleep, one epoch of any other sleep, or after 20 minutes without sleep onset. The primary outcome measure was latency to sleep onset (first epoch of any sleep stage, i.e., >15 seconds of sleep). Results from SLTs performed at 1200, 1330, 1530, 1730 and 1930 were included in the analysis.

2.3.3 Stanford Sleepiness Scale (SSS)

The Stanford Sleepiness Scale (SSS) is a 7-point Likert-type scale ranging from 1: feeling active; vital; awake, to 7: almost in reverie; sleep onset soon; lost struggle to remain awake (25). Results from scales completed at 1200, 1330, 1530, 1730 and 1930 (i.e., before each SLT) were included in the analysis.

2.3.4 The Profile of Mood States (POMS)

Participants were instructed to rate 65 adjectives on a scale of 0 = not at all, to 4 = extremely, based on how they currently felt. The Profile of Mood States (POMS) (26) is commonly used in sleep research, with the most frequently reported dimension subscales describing fatigue-inertia and vigor-activity, which are reported here (27, 28). Results from scales completed at 1115, 1445, 1645 and 2045 were included in the analysis.
2.4 Performance tests

A performance test battery included the following tasks in order of presentation: Wilkinson auditory vigilance task (WAVT), Williams word memory task (MEM), serial search test (SST), verbal reasoning test (VRT), and pegboard task (PEG). In this paper, only results from the WAVT and MEM will be reported. Results from the SST, VRT and PEG tasks (described by Monk et al. (29)) were statistically consistent with the MEM task and have subsequently been omitted to avoid repetition. Results from tasks performed at 1030, 1400, 1600 and 2000 were included in the analyses.

The Wilkinson auditory vigilance task (WAVT) is a measure of sustained auditory vigilance and is sensitive to sleep loss (30). The task used in this study was 30 minutes in duration. Every 2 seconds during the task, a 400-millisecond tone was presented. These tones were randomly interspersed with “target” tones which were approximately 70 milliseconds shorter. The participants were instructed to press a button in response to these target tones. The outcome measure from this task was number of missed target tones and number of false positives. While no formal hearing tests were administered, all participants demonstrated normal hearing during task familiarisation trials.

The Williams word memory task (MEM) is a measure of short-term memory (31). For this task, a list of 30, 4-letter words was read aloud and spelled (one word every 10 seconds) and participants were instructed to write down each word. Words were selected semi-randomly so that no words were repeated across tests. At the end of the word list, a researcher went through the list with the participant (at a rate of 5 seconds per word) and had them correct any misspelled words. The participant was then given 5 minutes to write down as many words as he could remember, in any order. The outcome measure from this task was the number of words correctly recalled.

2.5 Statistical analysis

Sleep variables were analyzed using a linear mixed-effects analysis of variance (ANOVA) framework. The model included fixed effects of study night: mean of two baseline nominal (N) nights; mean of two baseline restriction (R) nights; experimental control night following nominal baseline (NC); experimental control night following restricted baseline (RC); experimental extended night following nominal baseline (NE); and experimental extended night following restricted baseline (RE). A random intercept over participants was used to account for individual differences (32).

Neurobehavioural outcome measures were analyzed using a linear mixed-effects analysis of variance (ANOVA) framework. Only data from test bouts performed after 1000 were included in the analyses in order to keep the number of test bouts for each experimental day constant. The model included fixed effects of condition (NC, RC, NE, RE) and time-of-day (MSLT, SSS: 1–5; performance and mood: 1–4) and their interaction. A random intercept over participants was used to account for individual differences (32). To investigate our specific hypotheses, significant main effects of condition were further investigated using the following planned comparisons: NC vs. NE, RC vs. RE, and NE vs. RE.

Table 1. Bed, sleep, wake and rise times for each laboratory study night.

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Bed Time</th>
<th>Sleep Time</th>
<th>Wake Time</th>
<th>Rise Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Nominal (N)</td>
<td>2300</td>
<td>2300</td>
<td>0730</td>
<td>0730</td>
</tr>
<tr>
<td>Baseline Restricted (R)</td>
<td>2300</td>
<td>0100*</td>
<td>0730</td>
<td>0730</td>
</tr>
<tr>
<td>Experimental Control (C)</td>
<td>2300</td>
<td>2300</td>
<td>0730*</td>
<td>1000</td>
</tr>
<tr>
<td>Experimental Extended (E)</td>
<td>2300</td>
<td>2300</td>
<td>1000</td>
<td>1000</td>
</tr>
</tbody>
</table>

*On R and C nights, as a control for lighting and activity, participants lay in the dark bedrooms listening to a radio when not scheduled to sleep. Polysomnographic monitoring ensured wakefulness.
3. Results

3.1 Sleep

Sleep variables for each study night are described in Table 2. Analyses confirmed the experimental manipulation of sleep opportunity across conditions, with significantly greater total sleep time (TST) on both experimental extended (E) nights compared to all other nights, and significantly less TST on baseline restriction (R) nights compared to all other nights. Seven participants slept >10 hours on the extension night following nominal baseline sleep (NE); 8 participants slept >10 hours following restricted baseline sleep (RE). Stage 2 and REM sleep was significantly greater for extended sleep conditions compared to all nominal and restricted sleep nights. There were no differences between extended sleep conditions (NE vs. RE) for any sleep variable. The extended sleep following restricted baseline (RE) had significantly more slow wave sleep (SWS) than the nominal (N), restricted (R), and nominal control (NC) nights, but was no different to the restricted control (RC) night.

3.2 Sleepiness

Table 3 shows the means (± SD) for MSLT and each neurobehavioural variable collapsed across time-of-day. Figure 2 illustrates these variables across time-of-day for each condition. There was a significant main effect of condition and time-of-day for MSLT (both \( p < 0.001 \); see Table 4 for statistics), and no significant interaction effect (\( p = 0.18 \)). Planned comparisons revealed that, under conditions of both nominal and restricted baseline sleep, objective sleepiness was reduced following extended sleep compared to control sleep (both \( p < 0.001 \)), with no difference in objective sleepiness between extended sleep conditions (\( p = 0.31 \)).

A significant main effect of time-of-day occurred for SSS ratings (\( p = 0.017 \), with no main effect of condition (\( p = 0.19 \)) nor a condition*time-of-day interaction (\( p = 0.9 \)).

Table 2. Sleep variables for each study night.

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>R</th>
<th>NC</th>
<th>RC</th>
<th>NE</th>
<th>RE</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIB</td>
<td>510</td>
<td>390</td>
<td>510</td>
<td>510</td>
<td>660</td>
<td>660</td>
</tr>
<tr>
<td>TST</td>
<td>489 (19)</td>
<td>383 (8)</td>
<td>491 (11)</td>
<td>493 (15)</td>
<td>620 (40)</td>
<td>625 (22)</td>
</tr>
<tr>
<td>Stage 1</td>
<td>35 (16)</td>
<td>18 (7)</td>
<td>32 (14)</td>
<td>28 (14)</td>
<td>41 (18)</td>
<td>47 (22)</td>
</tr>
<tr>
<td>Stage 2</td>
<td>264 (33)</td>
<td>202 (24)</td>
<td>267 (27)</td>
<td>256 (16)</td>
<td>334 (42)</td>
<td>317 (32)</td>
</tr>
<tr>
<td>SWS</td>
<td>83 (27)</td>
<td>76 (26)</td>
<td>83 (21)</td>
<td>86 (28)</td>
<td>89 (28)</td>
<td>96 (31)</td>
</tr>
<tr>
<td>REM</td>
<td>101 (22)</td>
<td>83 (21)</td>
<td>101 (18)</td>
<td>116 (20)</td>
<td>148 (18)</td>
<td>157 (34)</td>
</tr>
<tr>
<td>REM Periods (n)</td>
<td>4.8 (0.9)</td>
<td>4 (0.9)</td>
<td>4.7 (0.9)</td>
<td>4.9 (0.6)</td>
<td>6.7 (1.1)</td>
<td>6.6 (1.2)</td>
</tr>
<tr>
<td>SOL</td>
<td>9 (9)</td>
<td>4 (2)</td>
<td>13 (10)</td>
<td>5 (3)</td>
<td>10b (10)</td>
<td>7 (5)</td>
</tr>
<tr>
<td>WASO</td>
<td>12 (18)</td>
<td>4 (6)</td>
<td>6 (4)</td>
<td>10 (15)</td>
<td>19 (20)</td>
<td>23 (21)</td>
</tr>
</tbody>
</table>

Notes: Data are presented as means (± SD) in minutes, except for number of REM periods. TIB: time-in-bed (time allowed for sleep only); TST: total sleep time; SWS: slow wave sleep; REM: rapid eye movement; SOL: sleep onset latency; WASO: wake after sleep onset. N: baseline nominal (mean of two nights); R: baseline restricted (mean of two nights); NC: experimental control night following baseline nominal; RC: experimental control night following baseline restricted; NE: experimental extended night following baseline nominal; RE: experimental extended night following baseline restricted. Significant difference (\( p < 0.05 \)) from: *N, *R, *NC/RC, *NC, *RC, *NE/RE, *NE, *RE, all other conditions.
3.3 Mood

A significant main effect of condition \( (p=0.010) \) and time-of-day \( (p=0.001) \) was found for the POMS Fatigue subscale, with no significant interaction effect \( (p=0.32) \). Planned comparisons revealed that under conditions of restricted baseline, Fatigue was reduced following extended sleep compared to control sleep \( (p=0.001) \), with no other significant differences for planned comparisons (Table 4).

A significant main effect of condition \( (p=0.006) \) and time-of-day \( (p=0.024) \) occurred for the POMS Vigor subscale, with no significant interaction effect \( (p=0.26) \). Planned comparisons revealed that, under conditions of both nominal \( (p=0.030) \) and restricted \( (p=0.006) \) baseline sleep, Vigor was increased following extended sleep compared to control sleep, with no difference in Vigor between extended sleep conditions \( (p=0.92) \).

No significant effects were found for any other POMS subscale (data not presented here).

3.4 Performance

A significant main effect of time-of-day occurred for the number of missed target tones on the WAVT \( (p=0.033) \), with no main effect of condition \( (p=0.46) \) nor a condition*time-of-day interaction \( (p=0.45) \). No significant effects were found for the MEM (Tables 3 & 4). Finally, none of the outcome variables on any of the other performance tasks (SST, VRT, PEG; data not presented here) showed statistically significant effects.

Table 3. Sleepiness, mood and performance for each experimental condition.

<table>
<thead>
<tr>
<th></th>
<th>NC</th>
<th>RC</th>
<th>NE</th>
<th>RE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSLT (min)</td>
<td>10.1 (7.4)*</td>
<td>9.4 (6.9)*</td>
<td>14.2 (6.6)</td>
<td>13.3 (7.1)</td>
</tr>
<tr>
<td>SSS</td>
<td>2.9 (0.7)</td>
<td>3.0 (0.9)</td>
<td>2.8 (0.8)</td>
<td>2.8 (0.7)</td>
</tr>
<tr>
<td>POMS Fatigue</td>
<td>3.7 (4.0)</td>
<td>4.3 (4.3)*</td>
<td>3.3 (3.1)</td>
<td>2.4 (2.6)</td>
</tr>
<tr>
<td>POMS Vigor</td>
<td>7.2 (5.8)*</td>
<td>6.6 (5.9)*</td>
<td>9.0 (6.2)</td>
<td>8.9 (6.6)</td>
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<tr>
<td>WAVT (No. missed)</td>
<td>1.6 (2.5)</td>
<td>1.4 (2.0)</td>
<td>1.3 (1.7)</td>
<td>1.0 (1.0)</td>
</tr>
<tr>
<td>MEM (No. correct)</td>
<td>15.0 (4.1)</td>
<td>14.1 (4.3)</td>
<td>14.6 (4.9)</td>
<td>14.8 (5.1)</td>
</tr>
</tbody>
</table>

Notes: Data are means \( (\pm SD) \). MSLT: multiple sleep latency test; SSS: Stanford Sleepiness Scale; POMS: Profile of Mood States; WAVT: Wilkinson auditory vigilance task; MEM: Williams word memory task. NC: experimental control night following baseline nominal; RC: experimental control night following baseline restricted; NE: experimental extended night following baseline nominal; RE: experimental extended night following baseline restricted. Significant difference \( (p<0.05) \) from: *NC, **RE.
Table 4. Results from the linear mixed-effects ANOVA for neurobehavioural outcomes.

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>F</th>
<th>P</th>
<th>Planned comparisons (p-values)</th>
<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NC v NE</td>
<td>RC v RE</td>
<td>NE v RE</td>
<td></td>
</tr>
<tr>
<td><strong>MSLT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Condition</td>
<td>3,152</td>
<td>11.779</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>0.311</td>
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</tr>
<tr>
<td>Time-of-day</td>
<td>4,152</td>
<td>22.318</td>
<td>&lt;0.001</td>
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<td>Cond*Time</td>
<td>12,152</td>
<td>1.384</td>
<td>0.179</td>
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<tr>
<td><strong>SSS</strong></td>
<td></td>
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<td></td>
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<td></td>
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<tr>
<td>Condition</td>
<td>3,152</td>
<td>1.620</td>
<td>0.187</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Time-of-day</td>
<td>4,152</td>
<td>3.111</td>
<td>0.017</td>
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<td>Cond*Time</td>
<td>12,152</td>
<td>0.525</td>
<td>0.896</td>
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<tr>
<td><strong>POMS Fatigue</strong></td>
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<tr>
<td>Condition</td>
<td>3,120</td>
<td>3.917</td>
<td>0.010</td>
<td>0.510</td>
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<td>Time-of-day</td>
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<td>7.575</td>
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<tr>
<td>Cond*Time</td>
<td>9,120</td>
<td>1.172</td>
<td>0.319</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>POMS Vigor</strong></td>
<td></td>
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<td></td>
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<tr>
<td>Condition</td>
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<td>4.366</td>
<td>0.006</td>
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Notes: MSLT: multiple sleep latency test; SSS: Stanford Sleepiness Scale; POMS: Profile of Mood States; WAVT: Wilkinson auditory vigilance task; MEM: Williams word memory task. NC: experimental control night following baseline nominal; RC: experimental control night following baseline restricted; NE: experimental extended night following baseline nominal; RE: experimental extended night following baseline restricted.
Figure 2. Mean (± SEM) values for MSLT and neurobehavioural outcomes across time-of-day for each condition. Some scales reversed so that all panels show higher alertness and performance in upwards direction. NC: experimental control night following baseline nominal; RC: experimental control night following baseline restricted; NE: experimental extended night following baseline nominal; RE: experimental extended night following baseline restricted.
4. Discussion

This study experimentally investigated the effect of extending sleep on sleepiness, performance and mood following nominal and restricted sleep using a repeated measures cross-over design. The results indicate that a single night of sleep extension >10 hours reduced objective sleepiness and improved subjective vigor following both nominal sleep and moderate chronic sleep restriction. The benefits of extended sleep, however, were not observed on other measures such as subjective sleepiness and a range of performance tasks. The disconnect between objective and subjective measures of sleepiness described here may help to explain the counter-intuitive ‘worn out’ or ‘Rip Van Winkle’ phenomenon observed by Globus and Taub (5, 8), while conforming to the theory of homeostatic sleep propensity.

Significant improvements in objective sleepiness as measured by the MSLT were observed after extended sleep, following both prior nominal and restricted sleep. These findings are in keeping with previous studies (11–14, 33). Participants in this study, however, did not appear to be subjectively aware of improvements to sleep onset latency, reporting no change in subjective sleepiness between nominal and extended sleep conditions. Closer inspection of the data revealed that approximately half the participants reported a decrease in sleepiness following extended sleep, while the other half reported an increase in sleepiness under the same conditions (see Figure 3). These results perhaps reflect Globus’ (5) original description of those who feel “worn out” when they oversleep, while others feel “just great”. There was, however, no obvious difference between those who rated sleepiness as higher or lower with regard to habitual sleep duration. Although our limited sample size restricts further investigation of this hypothesis, these findings highlight the individual variation in the subjective perception of sleepiness after extended sleep and the potential for a Rip Van Winkle syndrome following a night of extended sleep in some individuals. Although participants were not primed for the sleep schedules in the laboratory, it is possible that those more aware of the differences in conditions were biased in their subjective responses. Further research is needed to explore predictive individual factors to determine which individuals would feel great, as opposed to worn out after longer sleep. Also highlighted is the need to measure both subjective and objective outcomes. Subjective effects should not be dismissed, as subjective experience is important for quality of life and can influence behaviour; over-estimation of alertness is potentially hazardous in safety-critical scenarios.

Figure 3. Change in objective (MSLT) and subjective (SSS) sleepiness after extended sleep (NE) compared to control sleep (NC) (both nights following nominal baseline sleep) for each participant.

Note: Change in SSS is displayed as the inverse so that a positive change in both measures represents a reduction in sleepiness. Closed circles represent change in MSLT in minutes; open circles represent change in SSS in scale units. Figure shows that: a) objective and subjective measures do not correlate; b) objective sleepiness was reduced under conditions of sleep extension for all participants; and c) participants varied as to whether they rated their sleepiness as reduced following sleep extension.
The current study assessed neurobehavioural outcomes after a single night of sleep extension following either nominal or restricted sleep. Although we observed no changes on a range of performance measures under each condition, Taub and colleagues showed deficits in performance on an auditory vigilance task and no change on a calculation task relative to control sleep after one (8) and two nights of extended sleep (9). While the findings of Taub et al. suggest that one or two extension nights may be detrimental to performance, Kamdar et al. (12) reported significant improvements on a psychomotor vigilance task (PVT) following one week of extended sleep. These conflicting results indicate that the relationship between extended sleep and performance is not straightforward and may be mediated by the type of task used or the duration of the extended sleep condition. With regard to task type, in the current study, participants were tested on a range of performance tasks assessing vigilance, memory, verbal reasoning and motor skills. Despite this range of tests, none were sensitive to the effects – positive or negative – of one night of extended sleep.

It is worth noting, however, that the only task to show a positive response to extended wakefulness has been the PVT (12, 13). The PVT is a well-validated task known to be sensitive to the effects of sleep loss, hours of wakefulness, time-of-day and sleep inertia (2, 20, 34–38). It may be that other tasks, which vary in their sensitivity to sleep manipulations, are not sensitive enough to detect potential effects of sleep extension. The only study to describe improvements on non-PVT tasks (i.e., divided attention, auditory vigilance) did not include a control group to determine whether the observed improvements were due to a practice effect (11). The current study used a range of performance measures, but did not include the PVT. Therefore, we cannot determine whether the lack of performance effects observed was due to the sensitivity of the tasks used or the absence of measurable effects. The test battery did include, however, a task which Taub and colleagues (8, 9) reported negative effects on following sleep extension (WAVT; 15- and 45-minute version). It was expected, then, that our 30-minute version would result in similar findings. Roehrs et al. (11), however, only observed a significant improvement in performance following sleep extension in the last 10 minutes of a 40-minute auditory vigilance task. Therefore, our 30-minute task may have missed the improvements to sustained vigilance observed after 30 minutes. It is important to consider the type of task used to assess the effects of extended sleep and to determine whether cognitive domains are differentially affected. Harrison and Horne (18) argue, however, that such small changes to daytime functioning indicate that sleep extension is unnecessary from an ecological perspective. It could also be argued that the 4-minute reduction in sleep onset latency observed here is not a reasonable return on the investment of 2.5 hours of extended sleep opportunity. Therefore, further investigation in this area, at least under prior non-restricted conditions may not be warranted.

Under the condition of prior sleep restriction, we observed no beneficial effect of extended sleep on performance. This may suggest that one 11-hour nocturnal sleep opportunity is not enough to significantly rescue performance relative to an 8.5-hour sleep opportunity. Previously, Banks et al. (17) showed that a 10-hour sleep opportunity was not enough to
recover performance to baseline levels after five nights of restriction to 4 hours TIB. The 10-hour recovery night did, however, significantly improve performance relative to the 8-hour recovery opportunity. The moderate sleep restriction in the current study may not have been enough to show demonstrable differences between an 8.5-hour and 11-hour recovery opportunity.

The experimental manipulation of sleep was successful in this study, with an average of 10.4 hours of sleep in the extended sleep conditions compared to an average of 8.2 hours of sleep on nominal nights. Previous studies of sleep extension and ad libitum sleep have reported an average of 9.1-9.6 hours sleep (9,10,39). Given the success of the experimental manipulation, it raises the question of whether the participants were fully rested in the nominal sleep condition, or whether this condition, in fact, resulted in mild chronic sleep restriction. Time-in-bed was set at 8.5 hours in the nominal and control sleep condition. Given that only one participant reported an habitual sleep time greater than this TIB (9 hours), we would not expect that the potential restriction caused by an 8.5-hour sleep opportunity would obscure any differences between the nominal, restriction and extension conditions. In addition, our participant selection criteria and within-subjects design minimised the effects of individual variability with regard to sleep need, thus maximizing our ability to detect differences between conditions.

As expected, extended sleep periods contained more REM sleep than nominal and control sleep episodes (10, 40). REM sleep is circadian controlled and peaks in the morning (40), when our sleep extension period occurred. However, Taub et al. (9) also observed an increase in REM sleep in their sleep extension condition, despite time of wake (0900) being controlled between conditions. Further, Verdone (39) showed that REM increases linearly across nights of sleep extension. A theory for the mechanism by which increased levels of REM may impair subsequent daytime performance or reduce feelings of alertness has yet to be described. With regard to sleep inertia, there is no clear association between waking from REM sleep and sleep inertia symptoms (41–43). Sleep inertia is usually discussed with regard to the amount of SWS in the prior sleep episode. Given SWS did not differ greatly between experimental conditions in our study or others (9), this is unlikely to have influenced subsequent daytime performance. Further, all test bouts reported in the current study were performed at least 30 minutes after waking, and visual inspection of the data did not reveal any sleep inertia trends in the first test bout relative to subsequent test bouts.

It is possible that the worn out feeling and poor mood reported by Globus (5) after extended sleep may be due to longer time without food/caffeine. These factors were controlled in this study with caffeine excluded on study days and a standardised breakfast provided following experimental nights. Variations in habitual caffeine use may, however, lead to differences in experienced withdrawal and perhaps partially account for differences in subjective feelings after extended sleep. Habitual caffeine use may be a predictive factor for the worn out feeling experienced by some individuals after a long sleep episode. While habitual caffeine use was not recorded in this study, it may be an interesting variable to include in future studies of sleep extension.

It has been argued that it is not sleep extension per se that is responsible for negative effects, but rather the change in circadian timing of sleep (10). Our study was not designed to address this question. Taub and Berger (7) also demonstrated that extending, restricting, delaying and advancing sleep by 3 hours all led to degradations in performance and mood compared to habitual sleep. This finding suggests that acute manipulations of sleep can be detrimental to daytime functioning. If changing the timing of sleep is a contributing factor, this may explain why acute sleep extension (e.g., 1–2 nights) generally led to negative outcomes, while longer sleep extension periods (e.g., >4 nights) have shown improvements. That is, it may be necessary to adapt to a new sleep regime of sleep extension before the benefits are observed.

In the current study, sleep extension was achieved by delaying wake time. This introduced a potential confound of hours of wakefulness before test bouts. In this case, one would expect the benefits of extra sleep, in combination with reduced hours of wakefulness, to result in improved alertness and performance. We did not, however, observe any changes to subjective sleepiness or objective performance, therefore it is unlikely that an acute extension of sleep has positive benefits for these outcomes. Further, Taub and Berger (7) observed negative outcomes following sleep extension under both delayed and advanced conditions, demonstrating an effect of sleep extension independent of.
hours of wakefulness.

A potential physiological mechanism for feelings of greater sleepiness following extended sleep is the cortisol awakening response (CAR). The CAR refers to a sudden increase in cortisol immediately after morning awakening (44). Studies have shown that enhancing this response (e.g., with light exposure) can lead to increased arousal levels (45). The CAR has also been observed to be strongest at the habitual wake time, with reduced amplitude at out-of-phase wake times (46). Therefore, it is possible that delayed waking times associated with extended sleep reduce the CAR and, therefore, reduce alertness during the day. Furthermore, state and trait variations in the CAR may explain variations within and between individuals in the response to extended sleep on any given day (47,48). A study with simple measures of CAR (i.e., saliva samples at 15-minute intervals across the first hour after awakening) following extended sleep is warranted to test this hypothesis.

While our study is limited by sample size, the protocol was strengthened by a repeated measures cross-over design allowing for within subject comparisons. It is possible, however, that the null hypothesis was supported for most measures due to lack of power to detect an effect. A larger sample size is needed to confirm these results.

In summary, the findings from this study indicate that one night of sleep extension, following either nominal or restricted sleep, can improve objective sleepiness, but does not appear to consistently affect performance or subjective sleepiness. Individual variation in subjective sleepiness ratings may underlie the phenomenon of feeling worn out after extended sleep. A better understanding of the physiological factors underlying the mechanism of this phenomenon is needed in order to explain the mixed ability to perceive reduced sleep propensity as a reduction in subjective sleepiness.

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We thank the participants and research staff—Joan Mancuso, Sharon Keenan, and William Littell—for their efforts.

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We would also like to acknowledge the passing of co-author Dr. William C. Dement. This posthumous publication is dedicated to the father of sleep research, whose profound and prolific contributions continue to advance and inspire our drive to understand sleep. Sleep well, Bill.

6. References


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