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Cumulative mild partial sleep deprivation negatively impacts working memory capacity but not sustained attention, response inhibition, or decision making: a randomized controlled trial☆

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ABSTRACT

Background: Twenty-eight per cent (28%) of adults sleep at least 1 hour less than they consider optimal, yet the effects of such cumulative mild partial sleep deprivation on cognitive functions are unknown. The objective of this study was to examine how cumulative mild partial sleep deprivation over 6 nights can impact working memory, sustained attention, response inhibition, and decision making.

Methods: A double-blind placebo-controlled randomized study was conducted to determine the impact of sleep restriction (elimination of 1 hour of sleep relative to the baseline habitual sleep duration) vs placebo (exposure to a lamp with no known therapeutic effect) on cognitive performance. The primary outcomes were performance on tasks that measure working memory, sustained attention, response inhibition, and decision making. The participants consisted of 93 adults (mean age 24.3 years, SD 4.7; 46 men, 47 women) with no reported sleep problem, behavioral issue, or medical issue.

Results: Performance on the working memory capacity task improved between the baseline and experimental sessions for the placebo group but not the sleep-restriction group. Performance on tasks measuring sustained attention, response inhibition, and decision making did not change under either experimental condition.

Conclusion: Cumulative partial sleep deprivation negatively affects performance on a test of working memory capacity but does not affect performance on tests of sustained attention, response inhibition, or decision making.

Introduction

Cumulative partial sleep deprivation occurs when an individual has a shorter sleep duration than the recommended amount (ie, less than 7 hours of sleep per night in adults) over multiple nights without recovery sleep.[1,2] This level of sleep duration is very common in the general population. For example, in a representative survey of the general population, 28% of adults reported sleeping at least 1 hour less than what they considered optimal per night throughout the work week.[3]

Despite the common occurrence of partial sleep deprivation, it is not known how the cognitive functions of adults are affected by reducing the sleep duration by 1 hour per night over 6 nights.[4] This reduction in sleep duration simulates the common sleep deprivation that accrues over the work week. Although previous studies have extensively studied the impact of 2 to 6 hours of cumulative partial sleep deprivation on sustained attention, response inhibition, working memory, and decision making,[4] it is not possible to know the impact of milder deprivation. The reduction in sleep duration used herein simulates the common sleep deprivation that accrues over the work week.[3]

All previous studies examining the impact of sleep deprivation on performance have failed to include a control condition aimed at

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determining to what extent participants' performance was affected by the fact that they were not blind to the nature of the manipulation. This is a problem because expectations based on subjective perceptions of sleep have been shown to affect cognitive performance.[5]

The present study addresses this gap by being the first to include a placebo condition designed to control for the effect of expectation on cognitive impairment secondary to sleep deprivation. Participants in the placebo group were exposed to a lamp with no therapeutic effects and were told, as a deception, that the light would interfere with their sleep cycles to produce an effect equal to 1 hour of sleep deprivation per night. The aim was to separate expectations regarding sleep deprivation from the objective amount of sleep restriction and determine the impact of such restriction on performance.

In summary, this study compared the effect of cumulative partial sleep deprivation (1 hour per night for 6 nights) and placebo (deception to create the expectation of 1 hour of sleep deprivation per night for 6 nights) on cognitive functions and the subjective perception of sleepiness. It was hypothesized that:

1 Exposure to cumulative partial sleep deprivation but not placebo would result in deterioration of performance on tasks measuring working memory capacity, sustained attention, response inhibition, and decision making under known risk;
2 Exposure to both conditions would result in an increase of subjective sleepiness.

Methods

Participants

Healthy participants, ages 18 to 34 years, were recruited through classified advertisements as part of a larger study on the effects of cumulative partial sleep deprivation and alcohol on driving. Participants were stratified by age and sex and then randomized to the different conditions. A randomly selected group did not receive any dose of alcohol during the study; 93 participants of this group were included in the present analyses. Data were collected at the Douglas Mental Health University Institute (Montreal, Quebec, Canada) between January 2014 and May 2017. Fig. 1 shows a flowchart of the recruitment process.

Participants were selected to be medication-free, with the exception of contraceptives. The exclusion criteria were (1) any reported health or sleep problem, (2) being pregnant or breastfeeding, (3) performing shift work, and/or (4) use of illicit drugs.

Design

A double-blind, randomized, controlled design was used to examine the impacts of cumulative partial sleep deprivation and placebo on performance on tasks measuring sustained attention, response inhibition, working memory capacity, and decision making under known risk.

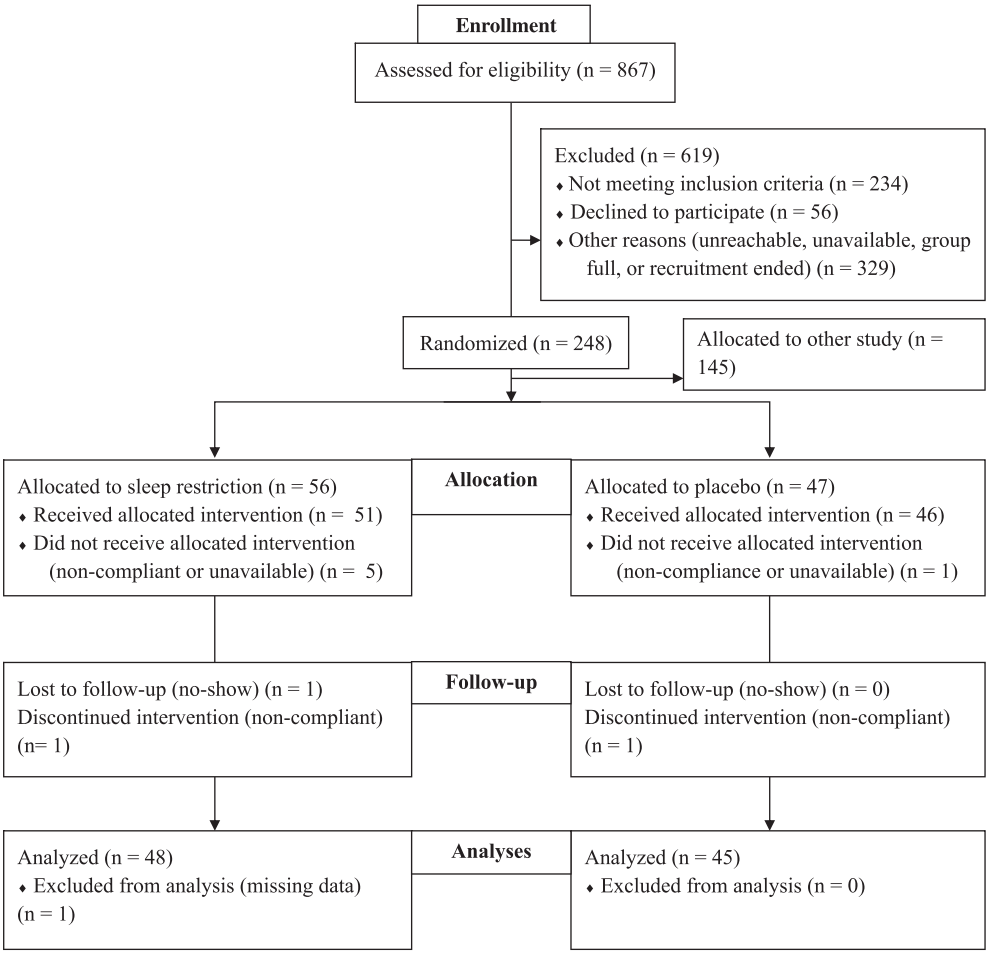

Fig. 1. Participants flow diagram based on the Consolidated Standards of Reporting Trials 2010 statement

Procedure

Prior to enrollment, we screened for the absence of sleep disorders with the Pittsburgh Sleep Quality Index, screened for the absence of alcohol use disorders with the Alcohol Use Disorders Identification Test, and posed questions to explore the health status of potential participants. Only those with no reported sleep problem, behavioral issue, or medical issue were invited to participate in the study. Eligible participants were told to avoid napping for the duration of the study. They completed a baseline protocol designed to objectively evaluate sleep through the use of actigraphy in the natural home environment for 6 consecutive nights. On the last day of the baseline period, the participants were randomly assigned (at a 1:1 ratio) to 1 of the 2 experimental conditions: experimental sleep restriction, in which participants eliminated 1 hour of sleep relative to their baseline habitual sleep duration by delaying bedtime by 30 minutes and waking up 30 minutes earlier than their usual routine, and placebo, in which participants were provided with a factory-fitted light box (HappyLight 2500, Verilux) with a neutral density gel filter that emits light at 2500 lux and instructed to expose themselves to the light for 30 minutes during daylight hours (before 1500 hours) at a minimum distance of 36 in. The light intensity and timing of exposure were chosen to prevent therapeutic effects, and placebo participants were instructed to sleep as they normally would for 6 nights.

At the beginning of each experimental period (baseline, restriction/placebo), each participant received a package that included an actiwatch, a daily log, and a sleepiness questionnaire that included the Visual Analogue Scale (VAS)–Sleepiness. Participants were tested for the use of alcohol, cannabis, opiates, cocaine, amphetamines, methamphetamine, and benzodiazepines using a breathalyzer and salivary analysis. Participants were excluded if they tested positive for recent use. Data were collected on socioeconomic status, as this is a potential confounder of sleep behavior. Participants were instructed to wear the actiwatch on their nondominant wrist, commencing shortly before bedtime and terminating shortly after awakening. On the first day of the baseline week and the last day of the experimental weeks, participants performed the Cambridge Gambling Task (CGT), the Spatial Span (SSP) task and Conners' Continuous Performance Test II (CPT) at 1500 hours. All tests were performed in the laboratory and were supervised by research assistants. Participants and research assistants knew this was a clinical trial in which one arm was a placebo. However, they did not know the nature of the placebo or which condition was the actual experiment. They were debriefed only after the data collection and entry were completed.

Measures

Cambridge Neuropsychological Test Automated Battery

Cambridge Neuropsychological Test Automated Battery is an automated, computerized battery of tests used to assess neuropsychological functions.[6] The tests are performed on a touch screen tablet. For this study, the SSP task and CGT were used to measure working memory capacity and decision making under known risk, respectively.

Spatial Span

This test measures the spatial working memory capacity. This digital version of the Corsi block test[7] examines the subject's ability to remember the order in which visual stimuli are presented. Nine white squares appear on the monitor and then change color sequentially. Each stimulus has a duration of 3 seconds, and there is a 0.5-second delay between stimuli. After another 1-second delay, subjects are asked to indicate the order in which the squares changed color. Subjects complete sequences in which progressively more squares change color (from 2 to 9 squares). After the subject fails a trial 3 times, the test ends. The highest number of items remembered in sequence is taken as the spatial span length, which is a measure of working memory capacity. Test-retest correlation after 4 weeks was reported to be 0.64, which is comparable to other tests of working memory.[8]

Cambridge Gambling Task

The CGT assesses decision making and risk taking. Participants are presented with 10 boxes in a variable ratio of red and blue boxes. The participant must guess whether a token is hidden in a red box or a blue box. Participants start with a number of points and can gamble a proportion of points, which are displayed in either ascending or descending order. Relevant information is presented to the participants, and there is no need for learning or information retrieval during the trial. The outcome measures for the CGT are: (1) deliberation time, which is the mean time (in milliseconds) that the participant takes to choose a color (lower numbers indicate faster reaction times); (2) quality of decision making, which is the mean proportion of trials in which the participant selects the higher probability color outcome (higher scores indicate better decision making); (3) delay aversion, which is the difference in percentage of bet in ascending vs descending conditions (higher scores indicate that betting is increasingly based on the order of presentation rather than deliberation); (4) overall proportion of bet, which is the mean proportion of points bet across all trials (higher scores indicate greater risk taking); (5) risk taking, which is the mean proportion of points bet on trials where the higher probability outcome is chosen (higher scores indicate greater risk taking); and (6) risk adjustment, which is the extent to which betting behavior is moderated by the ratio of boxes (higher scores indicate that risk is more accurately adjusted depending on probability [higher bets with greater probability and lower bets with reduced probability]).

Conners' Continuous Performance Test II[9]

The CPT is a standardized 14-minute test in which 360 letters appear on a screen successively for 250 milliseconds each in 18 consecutive blocks of 20 trials. In each block, the interstimulus interval can be 1, 2, or 4 seconds. Participants are required to press a button in response to a signal (any letter) except when the target signal (X) is presented. The CPT measures dimensions of sustained attention, response inhibition, and vigilance. The outcome measures are: (1) hit response time (RT), which is the time (in milliseconds) that it takes the participant to respond to a non-X signal; (2) hit RT standard error (SE), which is the consistency in response time; (3) hit RT SE variability, which is the variability of the consistency in response time; (4) commission errors, where the participant responds even though the target signal (X) is presented; (5) omissions, where the participant fails to respond when a non-X signal is presented; (6) *detectability or perceptual sensitivity*, which is defined as the standardized distance between signal and noise distribution; and (7) response style, which reflects whether a participant responds more or less than expected (90%, lower scores indicate a higher-risk style). The internal reliabilities for all of the CPT performance measures range between 0.73 and 0.95, and the test-retest correlation for a 3-month interval ranges between 0.55 and 0.84.[9]

Actigraphy

Actiwatch 2 (Philips Respironics) actigraphs are widely used to objectively assess sleep parameters. In young adults examined at the threshold sensitivity used in the present study, agreement rates between actigraphy and polysomnography for epoch-by-epoch sleep-wake identification were 87.7%.[10] Actigraphy also has considerable test-retest reliability, with intrasubject correlations over

1 year of 0.76 for total sleep time, 0.93 for sleep onset latency, and 0.90 for sleep efficiency.[11] Bedtimes and wake times were reported by each participant using sleep logs, and these times were used as the start and end times for the analyses. One-minute epochs were used to analyze actigraphic sleep data. For each 1-minute epoch, the total sum of activity counts was computed. If this sum exceeded a threshold (threshold sensitivity value = mean score in active period/45), then the epoch was considered waking. If it fell below that threshold, then it was considered sleep.

Actigraphic data were analyzed using sleep software (Actiware Sleep 6.1, Respironics). Means were determined for the following parameters: (1) bedtime, which was the time the participant got in bed; (2) sleep start; (3) sleep end; (4) get-up time, which was the time the participant got out of bed; (5) time in bed, which was the amount of time (in minutes) between bedtime and the get-up time; (6) assumed sleep time, which was the amount of time (in minutes) between the sleep start and sleep end times; (7) actual sleep time, which was the amount of time (in minutes) between the sleep start and sleep end times that was scored as "sleep" according to the Actiware-Sleep algorithm; and (8) sleep efficiency, which was the percentage of time spent asleep between bedtime and get-up time.

A minimum of 4 nights of actigraphic data was required per week (baseline or experimental sleep manipulation) for analysis. If fewer than 4 nights of actigraphic data were collected, participants were asked to repeat the week; if such a participant refused to repeat the week, they were excluded.

Sleep log

Participants completed a sleep log every morning and evening during the weeks their sleep was measured. Each morning, participants reported their bedtimes and wake times for the previous night; this information was used to score the actigraphic data. Each evening, participants reported whether they had taken a nap during the day and, if so, the duration of the nap(s).

VAS–Sleepiness

A VAS consists of a 10-cm line that is anchored at both ends with words describing the minimum and maximum extremes of sleepiness, in this case, from "not sleepy at all" to "extremely sleepy." Participants mark the place on the line that describes their subjective feeling, and the distance is measured to the nearest millimeter. This produces a continuous scale that describes subjective sleepiness. The strengths of a VAS are that it is suitable for repeated use, it is very sensitive, it has a high discriminating capacity, it requires little motivation by the participants to answer, and it produces values that are suitable for statistical analysis.[12]

Statistical analyses

To detect between-group differences at baseline, demographic variables were analyzed using χ^2 tests for categorical variables, Mann-Whitney *U* tests for ordinal variables, and 1-way analysis of variance (ANOVA) for continuous variables, with condition (cumulative partial sleep deprivation or placebo) as the independent variable. For each week, participants were dichotomously categorized as having taken at least 1 nap or having taken no nap. Between-group differences in self-reported napping were subjected to χ^2 analysis for the baseline and experimental weeks.

To determine the effects of the experimental manipulations on sleep and sleepiness, we conducted analyses of variance (MANOVA or ANOVA depending on the number of dependent measures) with condition (sleep restriction or placebo) as the between-subject variable; time (baseline vs experimental) as the within-subject independent variable; and actigraphic sleep measures, subjective sleepiness, or performance on a cognitive task (CPT, CGT, or SPS score) as the dependent variable. A Bonferroni correction was applied to control for multiple (3) comparisons of cognitive measures by condition and time. To examine the potential association between a change in subjective sleepiness and performance, we conducted linear regression analyses with performance on cognitive tasks during the experimental session as the dependent variable and the change in subjective sleepiness (sleepiness during the experimental session minus sleepiness at baseline) as the independent variable, with baseline performance on the same cognitive tasks as a covariate. Inferences for significant differences in cognitive variables by condition and time were set at a threshold of $P = .017$, whereas significant differences for all other variables were accepted at $P < .05$. Sensitivity power analyses also were conducted (see below). SPSS version 22 was used for all statistical analyses.

Power analyses

A sensitivity power analysis was conducted using the GPower software package.[13] The sample size was 93, the α significance level was set as .017, power was set as 0.80, and the following parameters were used: 2 groups and 2 measurements, an assumed correlation of 0.50 between repeated measures, and a nonsphericity correction (ε) of 1. The minimum detectable effect size (f) was 0.17, which corresponded to a small effect size.

Table 1
Demographic characteristics of sample

	Mean (SD)
Education level (y)	16.12 (2.14)
Munich Chronotype Questionnaire	04:57 (1:11)
	n (%)
Age category (y)	
18-20	22 (23.7%)
21-25	47 (50.5%)
30-34	24 (25.8%)
Sex	
Male	46 (49.5%)
Female	47 (50.5%)
Race/ethnicity	
White	67 (72.0%)
Chinese	1 (1.1%)
Black	9 (9.7%)
Latin American	3 (3.2%)
Arab	3 (2.2%)
Southeast Asian	2 (2.2%)
Other	8 (8.6%)
Income ($)	
None	5 (5.4%)
1-11,999	50 (53.8%)
12,000-29,999	20 (21.5%)
30,000-39,999	8 (8.6%)
40,000-49,999	5 (5.4%)
≥50,000	5 (5.4%)
Occupation	
Work and study	56 (60.2%)
Study	11 (11.8%)
Work	21 (22.6%)
Unemployed	1 (1.1%)
Unstable	4 (4.3%)
Marital status	
Single	74 (79.6%)
Married	16 (17.2%)
Divorced	3 (3.2%)

Table 2
Means (*M*) and standard deviations (SD) for sleep measures for placebo and sleep restriction conditions at baseline and intervention sessions

	Placebo		Sleep restriction	
	Baseline *M* (SD)	Intervention *M* (SD)	Baseline *M* (SD)	Intervention *M* (SD)
Time in bed (min)*	488 (70)	487 (61)	487 (61)	399 (54)
Sleep duration (min)*	387 (66)	384 (61)	391 (51)	322 (46)
Sleep start (h:min)**	00:46 (1:18)	00:55 (1:31)	00:51 (1:11)	01:25 (1:18)
Sleep end (h:min)*	08:10 (1:22)	08:17 (1:20)	08:16 (1:09)	07:27 (1:05)
Sleep efficiency (%)	76.8 (9.9)	78.0 (9.5)	79.2 (7.0)	78.9 (8.0)
Sleepiness	28 (20)	49 (29)	32 (22)	51 (23)

* Time by condition interactions significant at the $P < .001$ level.
** Time by condition interaction significant at the $P = .03$ level.

Results

Demographic characteristics

Table 1 presents the demographic characteristics of the participants in the placebo and cumulative partial sleep deprivation groups. There was no significant between-group difference in income, education, race, occupation, marital status, or chronotype. The sample included a high proportion of students (72%), and 80.7% of the sample had incomes lower than the average in Quebec.[14] Of the participants, 31% reported napping during the experimental week. Participants in both conditions were equally likely to report napping during the baseline ($\chi^2_{[1,93]} = 0.01$, $P = .94$) or experimental ($\chi^2_{[1,93]} = 0.00$, $P = .99$) weeks.

Sleep

Table 2 shows the means and standard deviations of the sleep measures for each group during the baseline and experimental weeks. At baseline, the participants allocated to the sleep-restriction or placebo conditions did not significantly differ on any actigraphic sleep measurement.

Significant time-by-condition interactions were found when actigraphic sleep measures were examined ($F_{[5,85]} = 15.53$, $P = .000$, $\eta^2_p = 0.48$). Univariate analysis revealed that, after intervention, the sleep duration was shorter in the sleep-restriction group but unaltered in the placebo group compared with baseline values, both when measured as time in bed ($F_{[1,89]} = 53.71$, $P < .000$) and as actual sleep duration ($F_{[1,89]} = 45.99$, $P < .000$). This finding indicates that sleep was significantly shorter (by averages of 88 and 69 minutes for time in bed and actual sleep duration, respectively) in the sleep-restriction group but was unchanged in the placebo group (an average of 3 minutes shorter for both time in bed and actual sleep duration, which was a statistically and clinically insignificant difference). In addition, the sleep start time was significantly delayed in the sleep-restriction group ($F_{[1,89]} = 4.64$, $P = .03$) but unaltered in the placebo group. The sleep end time was significantly earlier in the sleep-restriction group ($F_{[1,89]} = 17.67$, $P < .000$) but unaltered in the placebo group. When sleep efficiency was examined, there was no significant interaction between time and condition, nor were there any main effects of time or condition.

Sleepiness

Means and standard deviations for the sleepiness measure are presented in Table 2. Mixed design ANOVA was conducted to determine whether the sleepiness measure differed between baseline and during the experimental period. The results revealed a significant time main effect, with differences in sleepiness found relative to the baseline in the experimental group ($F_{[1,91]} = 49.13$, $P = .000$). Participants in both groups reported a 67% increase in their subjective sleepiness during the experimental week. The change in subjective sleepiness in the placebo group was not associated with performance on any cognitive task during the experimental session.

Table 3
Means (*M*) and standard deviations (SD) for cognitive tasks

	Placebo		Sleep restriction	
	Baseline *M* (SD)	Intervention *M* (SD)	Baseline *M* (SD)	Intervention *M* (SD)
CPT				
Hit RT	322 (41)	325 (43)	332 (42)	337 (52)
Hit RT SE	4.18 (1.32)	4.47 (2.11)	4.96 (3.29)	5.20 (2.94)
Hit RT SE variability	5.95 (4.00)	7.25 (9.01)	8.07 (9.40)	8.65 (8.83)
Omission errors	2.25 (3.39)	2.44 (4.21)	1.89 (3.91)	3.80 (7.50)
Commission errors	15.10 (7.59)	14.19 (8.53)	14.82 (7.67)	14.24 (8.70)
Detectability	0.60 (0.40)	0.75 (0.54)	0.66 (0.42)	0.75 (0.50)
Response style	0.47 (0.38)	0.48 (0.55)	0.37 (0.41)	0.58 (0.74)
SSP*	7.19 (1.50)	7.77 (1.08)	7.47 (1.33)	7.38 (1.40)
CGT				
Deliberation time	1908 (585)	1485 (417)	1900 (677)	1439 (554)
Delay aversion	0.28 (0.18)	0.28 (0.16)	0.30 (0.14)	0.28 (0.18)
Quality of decision making	0.92 (0.09)	0.95 (0.07)	0.93 (0.08)	0.96 (0.07)
Overall proportion of bet	0.47 (0.13)	0.54 (0.11)	0.51 (0.13)	0.55 (0.12)
Risk taking	0.52 (0.14)	0.59 (0.12)	0.56 (0.12)	0.60 (0.12)
Risk adjustment	1.55 (1.21)	1.62 (0.99)	1.70 (1.13)	1.91 (1.19)

* Time-by-condition interaction significant ($P = .01$).

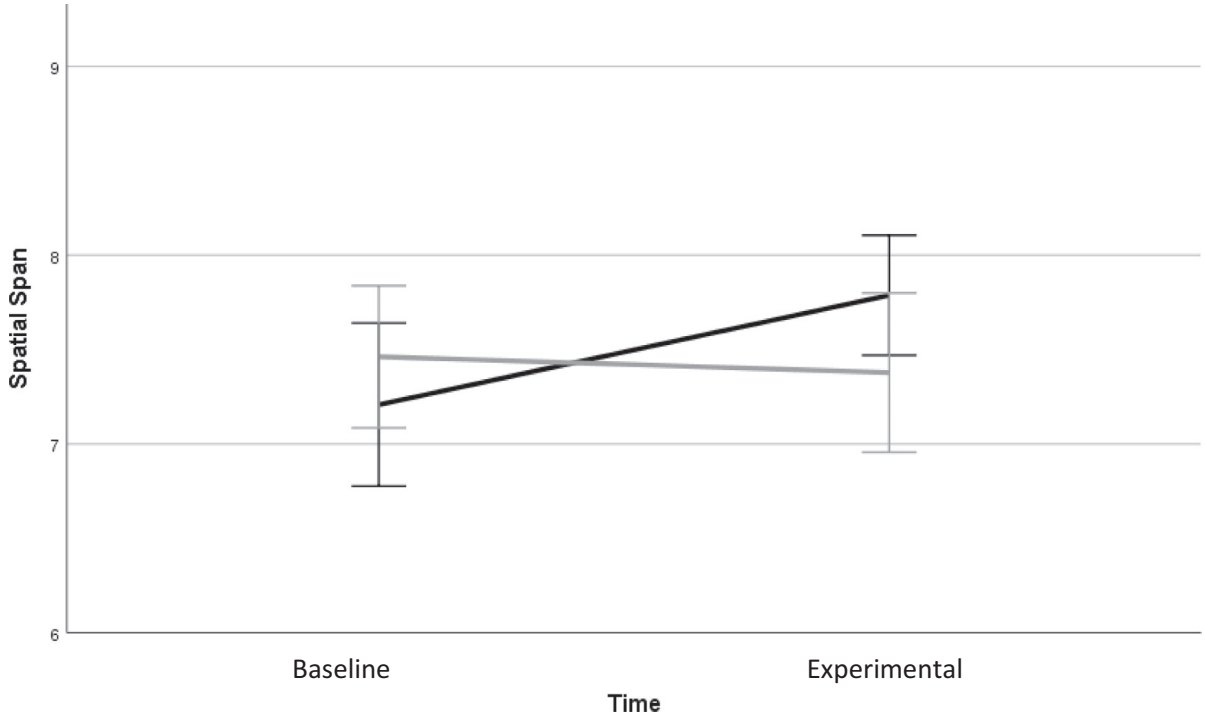

Fig. 2. Spatial span for sleep restriction (gray line) and placebo (black line) conditions at baseline and after the experimental week. There was significant improvement in spatial span length between baseline and experimental weeks in the placebo condition, whereas no change was found between baseline and experimental weeks in the sleep restriction condition. Error bars represent 95% confidence interval.

Cognitive measures

Table 3 presents the means and standard deviations of the outcome measures for the SSP task, CPT, and CGT. No significant between-group difference was found on any cognitive measure at baseline.

Working memory capacity

A significant time-by-condition interaction was found when performance on the working memory task was examined ($F_{[1,91]} = 6.86$, $P = .01$, $\eta^2_p = 0.07$). Post hoc analyses showed that the spatial span length increased between the baseline and experimental sessions in the placebo group ($P = .002$) but not in the cumulative partial sleep deprivation group. Thus, performance on the working memory task improved under the placebo condition but not under the sleep-restriction condition. Fig. 2 graphically presents this data.

Continuous Performance Test

No significant time-by-condition interaction was found when performance on sustained attention and response inhibition measures was examined ($F_{[7,85]} = 0.89$, $P = .52$, Wilks' $\Lambda = 0.93$). A significant main effect of time was found ($F_{[7,85]} = 2.68$, $P = .015$, Wilks $\Lambda = 0.82$), and detectability increased between the baseline and experimental sessions ($F_{[1,91]} = 10.13$, $P = .002$).

Decision making

No significant time-by-condition interaction was found when measures of performance on decision making under known risk were examined ($F_{[6,86]} = 0.98$, $P = .45$, Wilks $\Lambda = 0.94$). A significant main effect of time was found ($F_{[6,86]} = 23.55$, $P = .000$, Wilks $\Lambda = 0.38$). The deliberation time decreased between the baseline and experimental sessions ($F_{[1,91]} = 86.08$, $P = .000$), whereas the overall proportion of bet, risk taking, and quality of decision making increased between the baseline and experimental sessions ($F_{[1,91]} = 25.66$, $P = .000$; $F_{[1,91]} = 26.37$, $P = .000$; $F_{[1,91]} = 8.62$, $P = .004$, respectively).

Analyses for the cognitive tests were repeated after exclusion of participants who reported taking at least 1 nap during the experimental week. As when the full sample was analyzed, a significant interaction for time and condition was found for working memory capacity ($F_{[1,62]} = 6.44$, $P = .01$, $\eta^2_p = 0.09$) but not for the CPT ($F_{[7,56]} = 0.91$, $P = .50$, Wilks $\Lambda = 0.90$) or CGT ($F_{[6,57]} = 0.98$, $P = .45$, Wilks $\Lambda = 0.90$).

Discussion

The goals of this study were to examine the effect of cumulative partial sleep deprivation and the subjective perception of sleepiness on performance on tests of various cognitive functions (specifically working memory, sustained attention, response inhibition, and decision making under known risk).

This is the first report to study the effect of sleep deprivation on cognitive functions using a 1-hour per night sleep reduction in adults, as well as the first to use a placebo control group.

The experimental manipulation of sleep duration was successful. The actual sleep duration of participants in the sleep-restriction group, but not in the placebo group, was reduced by 69 minutes. Therefore, those under the sleep-restriction condition were objectively sleep deprived, whereas those under the placebo condition were not.

Subjective sleepiness increased equally in both groups between the baseline and experimental sessions even though the sleep duration had not changed in the placebo group. Participants subjected to both conditions had the same subjective perception of sleepiness at the tested time points.

Performance on the working memory capacity task, CPT, and CGT improved between the baseline and experimental sessions in the placebo group. Notably, there was no between-session change in

performance on the working memory capacity task in the sleep-restriction group. This suggests that eliminating 1 hour of sleep per night relative to the habitual sleep duration for 6 nights may have prevented improvement on the working memory task between the baseline and experimental sessions. This is consistent with findings showing that performance on working memory tasks improves with practice[15,16] and that partial sleep deprivation may prevent this improvement.[17,18]

In contrast with the findings obtained using the working memory task, performance on the CPT and CGT improved similarly under both conditions, suggesting that the studied level of cumulative partial sleep deprivation does not negatively impact performance on these tasks. Studies with more severe sleep deprivation found impairment in cognitive functions, with greater reductions of sleep leading to greater cognitive impairment.[4] Because the present study examined a smaller reduction in sleep than those tested in the previous reports, a smaller effect was expected. Indeed, it is possible that the level of sleep deprivation tested herein has no negative effect on sustained attention, response inhibition, or decision making or that any negative effect(s) would only become apparent over a longer period of observation. It could also be that such effects have been masked by the impact of other sources of variability, such as between-individual differences in sleep need, activity level, and/or food consumption. Future studies should examine different levels of sleep deprivation, including mild sleep deprivation, to determine the threshold at which negative effects begin to occur and elucidate dosage effects.

Subjective sleepiness increased equally in both groups between the baseline and experimental sessions even though the sleep duration was unchanged in the placebo group. This finding is similar to that of a previous study in which a placebo treatment for sleep apnea was found to reduce subjective sleepiness without altering the objective sleep duration, whereas the active treatment reduced subjective sleepiness and increased the objective sleep duration.[19] This suggests that one of the manifestations of sleep deprivation, sleepiness, can be induced with a deception protocol. By comparing the sleep-restriction group with a placebo group that presented similar levels of sleepiness, the present study was able to examine differences in objective sleep duration and not in subjective sleepiness. Therefore, the negative effect of sleep deprivation on performance on the working memory task is not attributable to reported, subjective, sleepiness. In addition, the change in subjective sleepiness among participants in the placebo group was not associated with performance on cognitive tasks, suggesting that subjective sleepiness does not impair performance.

No previous study of sleep deprivation has used a placebo control. Trials without a placebo control tend to overestimate the size of the effect compared to trials with a placebo control.[20,21] In the present study, the use of a placebo control decreased the likelihood that an effect will be overestimated. Future studies should consider including a placebo control condition because it improves blinding and allows subjective sleepiness to be separated from changes in objective sleep duration. Future studies should consider studying a group of participants with healthy sleep and no intervention, in addition to the placebo and sleep-restriction groups. This would illuminate how much of the change in cognitive performance should be attributed to the reduction in sleep vs a placebo effect.

Limitations

Partial sleep deprivation changes sleep architecture, and these changes in sleep architecture may modulate the effect of sleep deprivation on cognitive functions.[4] As actigraphy does not measure sleep architecture, the present study could not test for the presence of a compensatory change in sleep architecture that might have reduced the effect of partial sleep deprivation. Noncompliance with sleep instructions (eg, daytime napping) may have resulted in the sleep-deprivation group experiencing a smaller reduction of sleep duration compared to the objectively measured duration, potentially reducing the between-group difference in sleep duration. However, the results of the study did not change when participants that reported napping during the experimental week were excluded from the analyses. This suggests that the level of noncompliance present in the study did not affect the conclusions. Information regarding daytime napping was based on self-reports, which might be of limited accuracy. Future studies should use actigraphy to document daytime napping. Practice effects were found for the working memory task, CPT, and CGT. This may have masked the true effect of cumulative mild partial sleep deprivation. The presence of practice effects prevents the dissociation between an effect of sleep restriction on working memory and on learning. Future studies could include practice sessions to reach a ceiling effect, allowing the effect of sleep deprivation to be determined independent of practice effects. Practice effects could be reduced by using different tests that measure the same construct.[22] Participants' sleep was measured in their home environment. This increased the ecological validity and feasibility of the study but did not allow us to monitor compliance or control for participants' light exposure, exercise, or caffeine consumption. Future studies could benefit from being conducted as a clinical trial in a controlled environment, such as in a sleep laboratory. The present study did not evaluate participants' sleep status at the time of the baseline cognitive testing. In addition, the participants included in this study may have had low sleep quality, as evidenced by an average sleep efficiency at baseline lower than 80%. As a result, the negative effects of sleep restriction on performance on the CPT and CGT might have been masked by participants' carrying a sleep debt acquired prior to their participation in this study. However, because previous studies have found a dose effect for sleep deprivation,[4] even with previous sleep deprivation, further restriction of sleep could have had an additive effect on cognitive functions. Finally, the generalizability of these results may be limited, as a large proportion of the sampled individuals were students with low incomes.

Conclusion

The sleep restriction and placebo groups differed in their change of working memory capacity between the baseline and experimental sessions even though subjective sleepiness increased similarly under both conditions. In the placebo group, the working memory capacity improved between the baseline and experimental sessions. In contrast, no between-session change in working memory capacity was seen in the sleep-restriction group. The changes in sustained attention, response inhibition, and decision making under known risk between baseline and experimental sessions were similar in both groups. Therefore, the tested cumulative mild partial sleep deprivation negatively affected performance on a test of working memory capacity but did not affect sustained attention, response inhibition, or decision making.

In addition, this study showed that although subjective sleepiness was induced with a deception protocol, it did not impair performance. This suggests that the negative effect of sleep deprivation in performance on the working memory task is not attributable to a placebo effect.

Disclosure

The authors have nothing to disclose.

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