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Original Article

Online assessment of sustained attention following sleep restriction

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ABSTRACT

Objective: To assess the feasibility of conducting home-based sleep restriction studies with actigraphic monitoring of sleep and a new online continuous performance test (OCPT).
Methods: Thirty-four university undergraduate students (24 females, 19–30 years old) underwent repeated home assessments using self-administered OCPT following a regular night of sleep (8 h or more) and following sleep restriction (4 h of sleep) in a within–between subjects counter-balanced design. Actigraphy was used to monitor sleep. OCPT sessions were scheduled in the morning and the evening of days following normal and restricted sleep.
Results: OCPT measures demonstrated acceptable test–retest reliability. Actigraphic monitoring revealed good compliance with sleep requirements, and reported alertness reflected significant effects of sleep manipulation ($p < .0001$). In comparison to performance following an 8-h sleep night, sleep restriction to 4 h was associated with a significant increase in omission errors in the high-target section of the test ($p < .0005$) and with a significant increase in omission errors in the low-target section of the test ($p < .01$).
Conclusions: These preliminary results support the feasibility of conducting home-based sleep restriction studies and the validity of the online version of the OCPT, suggesting that it may serve as a sensitive tool for assessment of sleep restriction/deprivation.

1. Introduction

The quest to unravel the function of sleep has led to numerous studies on the effect of sleep restriction/deprivation on cognitive performance [1–3]. Many studies have shown compromised neurobehavioral functioning following sleep loss, and a meta-analysis of sleep deprivation studies suggested that sleep deprived individuals function at a level that is equivalent to the ninth percentile of non-sleep-deprived individuals [1].

One domain of cognitive function that is particularly sensitive to sleep loss is sustained attention. Studies have repeatedly demonstrated that sleep loss in both children and adults leads to poor sustained attention as measured by different versions of the continuous performance test (CPT) and the psychomotor vigilance test (PVT) [3–9]. Furthermore, it has been shown that increase in sleep loss is associated with performance deterioration [4,5], and that these sustained attention tests are sensitive to circadian influences on alertness [10]. Finally, sustained attention tests are sensitive to intake of alertness promoting agents such as caffeine, amphetamines, and modafinil, reflected in improvements in cognitive function [11].

Traditionally, sleep restriction/deprivation studies have been conducted in laboratory settings to allow control over sleep schedule and cognitive testing. Recent research has shown the feasibility of conducting naturalistic sleep restriction studies using actigraphy to monitor compliance with prescribed sleep schedules [6,12,13]. Such studies are of great ecological value as they allow testing of sleep patterns in participants' natural settings. The ability to conduct studies on sleep deprivation outside the lab could be further enhanced by the development of reliable and valid Internet-based tests of cognitive function in general and of sustained attention in particular.

The goal of the present study was to assess the feasibility of conducting home-based sleep restriction study using actigraphy to monitor sleep and a new online continuous performance test (OCPT) to assess the effects of sleep restriction on cognitive function of young adults.

2. Methods

2.1. Procedure

Study design contrasted attentional capacities following two sleep-related conditions: (a) regular sleep – defined as a night of at least 8 h in bed; (b) restricted sleep – defined as a night of 4 h of sleep or less. To control for potential order effects, the

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participants were randomly assigned into two equal groups. One group was instructed to obtain 8 h of sleep during the first night of the protocol and to perform OCPT twice during the following day: (1) morning test, 30–60 min after their rise time and (2) evening test, between 18:00 and 21:00 h of the same day. These participants were instructed to sleep their regular sleep schedule on the following nights, and on the fourth night they were asked to sleep only 4 h and to perform the OCPT twice on the following day according to the same schedule (morning and evening tests). The other group received the same instruction with the only difference being that the first night was the restricted sleep night and the fourth night was an 8-h sleep night. All participants wore an actigraph to monitor their sleep–wake patterns. Participants were instructed to avoid any distractions including phone calls, TV, or other media or interpersonal stimulation while performing the OCPT. They were also instructed to shut down all other active windows or programs on the PC used to perform the test.

2.2. Participants

Forty undergraduate students enrolled and started the study. Participants received research credit hours according to their academic requirements. Four participants were excluded from the sample due to failure to complete all online tests. Two additional participants failed to comply with the sleep requirements as revealed through actigraphic monitoring. Thus, the final sample consisted of 34 participants (24 females), mean age = 23.67 years, SD = 1.99, range = 19–30. All participants reported good health and being free of prescription medications for health problems.

2.3. Measures

2.3.1. Online continuous performance test (OCPT)

The OCPT (eAgnosis Inc., Newark, DE) is a standard CPT designed and programmed for delivery over the Internet. The task is adapted for use with most Internet browsers (e.g., Internet Explorer, Fire Fox, Chrome, Apple-Safari) and can be operated from practically any computer connected to the Internet (for a demo see http://www.checkadhd.com/onlineCPTresearch.php). Millisecond accuracy in response time (RT) recording is achieved by using the end user's own CPU and transmitting the collected data back to a remote database at various points during task performance. Thus, the integrity of data collection does not depend on Internet speed or bandwidth. Furthermore, because the OCPT code for RT monitoring and recording is compact, the end user's computer characteristics and processor speed can rarely affect recording accuracy.

The task uses two geometric stimuli: equilateral triangles (5 cm sides) and circles (5 cm diameter), both presented in a light blue color delineated by a black one-pixel stroke contour. The geometric stimuli are presented in the middle of the screen against a gray background within a four-pixel stroke 7.5 cm $\times$ 11 cm black rectangle that is presented constantly throughout the task.

Each trial consists of a presentation of one geometric shape for 100 ms followed by a 1900 ms inter-trial interval. Participants are instructed to respond to the triangle shape as fast as possible without compromising accuracy by pressing the space bar on the computer's keyboard and to withhold responding to the circle shape. The task contains two conditions: low target frequency and high target frequency. The first half of the test (the low target frequency half) consists of 224 trials (56 targets, 168 non-targets) with a target to non-target ratio of 1:3. In this half, the task is boring and fatiguing. In the second half of the test (the high target frequency half), the target to non-target ratio is reversed and is set to 3:1 (168 targets, 56 non-targets). In this half of the test, the participant expects to respond most of the time but occasionally must inhibit the tendency to respond. These two conditions were chosen because they reflect a conceptual distinction in the attention/CPT literature between a condition that taxes sustained attention and attention focusing in a dull and boring environment (low target frequency) and a condition that taxes primarily the ability to inhibit a proponent response (high target frequency) [12]. Throughout the task the geometric shapes are presented in a fixed, pseudo-random sequence. To minimize practice effects, each half of the task is preceded by a 2-min practice phase reflecting the target to non-target ratios of the actual test to follow. Subjects are not informed about the practice nature of these 2 min sessions and consider these parts of the test. Total net test time (including the two practice sessions) is 19 min. Three breaks are allowed (following the first and second practice sessions and following the low target frequency session). Participants are instructed not to exceed 2 min of break time. Responses with RTs that are faster than 150 ms are considered anticipatory and are removed from analyses. When a participant presses the spacebar more than once per stimulus presentation, only the data from the first response is included in data analysis.

The software automatically records omission and commission errors as well as reaction times. Three primary measures were extracted for analyses: error of omission, errors of commission, and response times. These measures are extracted per condition (low and high target frequencies) and can also be extracted by test quartiles per condition. All data is stored offline and is available as a Microsoft Excel spreadsheet.

2.3.2. Sleep assessment

Actigraphy and sleep diaries were used to monitor sleep. The diary data was only used to detect and remove possible artifacts from the actigraphic data. Actigraphy has been established as a reliable and valid method to assess sleep–wake patterns in infants, children, and adults [13–15]. Participants were given actigraphs (Mini Motionlogger, Ambulatory Monitoring Inc.) and were instructed to wear these on their non-dominant wrist. The actigraph was set to collect data in 1-min epochs and amplifier setting 18 which is the standard mode for sleep–wake scoring. Actigraphic raw data were translated to sleep measures using the Actigraphic Scoring Analysis (ASA) program for an IBM-compatible PC. These sleep measures have been validated against polysomnography with agreement rates for minute-by-minute sleep–wake identification higher than 90% [16].

To monitor compliance with the study's sleep manipulation we analyzed true sleep time as derived from actigraphy. True sleep time is defined as sleep time excluding all periods of wakefulness during the sleep period. Daily sleep logs, completed by the participants, were used to corroborate the actigraphic data. The sleepiness visual analogue scale (VAS) was used to assess subjective perception of sleepiness in the evening on the daily sleep logs. The VAS measures sleepiness on a continuous scale ranging from wide awake (0%) to nearly being asleep (100%). Participants are required to mark their stage of sleepiness by placing a tick mark on a long line. The specific relative location on the line represents their subjective level of sleepiness [17,18].

3. Results

The data analysis plan was aimed at assessing: (a) compliance of the participants with the experimentally imposed sleep schedule; (b) test–retest reliability of the OCPT and (c) sensitivity of the OCPT in detecting the effects of sleep restriction on cognitive performance.

3.1. Compliance with experimental sleep schedule manipulation

To assess compliance with experimental sleep requirements we examined actual sleep time as monitored by actigraphy and

reported alertness level following the nights of prescribed 4 or 8 h of sleep (see Fig. 1).

On the "8-h" night, 24 participants slept at least 7 h, 12 participants slept less than 7 h (using actigraphic true sleep time), of whom 3 slept less than 6 h. Only one participant slept less than 5 h (4.6 h). On the "4-h" night, four participants slept slightly more than 4 h (up to 4.5 h). All the other participants obtained between 3 and 4 h of sleep.

Two MANOVAs with group and time (first or fourth night) as independent measures and either actigraphic true sleep time or subjective sleepiness as the dependent measures were computed. A significant group by time interaction effects were found for both true sleep time ($F = 565$; $p < .0001$) and subjective alertness ($F = 25$; $p < .0001$).

Participants slept more than 7 h on average when requested to sleep 8 h and slightly more than 3.5 h when requested to sleep 4 h. Their subjective alertness ratings reflected the effects of these differences in sleep time, showing that following 4-h sleep opportunity nights their alertness was significantly lower in comparison to nights with 8-h sleep opportunity.

3.2. Test–retest reliability

Each participant completed the OCPT four times (morning/evening, normal/restricted sleep). To assess the reliability of the OCPT we calculated test–retest reliability for the global measures in each measurement point. The correlations between all pairs of measurements are presented in Table 1. Most correlations were statistically significant in modest to good test–retest reliability range. Some correlations, however, were low and non-significant.

Table 1
Test–retest reliability of the online continuous performance test (OCPT) measures.

	Time 1 M Time 1 E	Time 1 M Time 2 M	Time 1 E Time 2 M	Time 2 M Time 2 E
OCPT measure				
HT – reaction time	.70***	.34*	.45**	.75***
HT – omission errors	.15	.34*	.09	.02
HT – commission errors	.38*	.54**	.42*	.25
LT – reaction time	.66***	.73***	.67***	.74***
LT – omission errors	.41*	.10	.48**	.72***
LT – commission errors	.35*	.51**	.48**	.63***

M = morning test; E = evening test; HT = high target frequency; LT = low target frequency.
* $p < .05$.
** $p < .005$.
*** $p < .0001$.

It should be noted that these correlations were between scores obtained under different testing conditions.

3.3. Effects of sleep restriction on sustained attention

MANCOVA with time-of-day (morning/evening) and condition (4 h/8 h of sleep) served as within-subject independent variables and OCPT measures as the dependent variables. Age and gender were used as covariates to control for their potential effects.

The MANCOVA revealed significant effects on omission errors in both the low and high target frequency sections of the OCPT (see Fig. 2). In the high target frequency section, a significant condition effect was found ($F = 14.84$; $p < .0005$). Performance following sleep restriction was significantly poorer than following regular

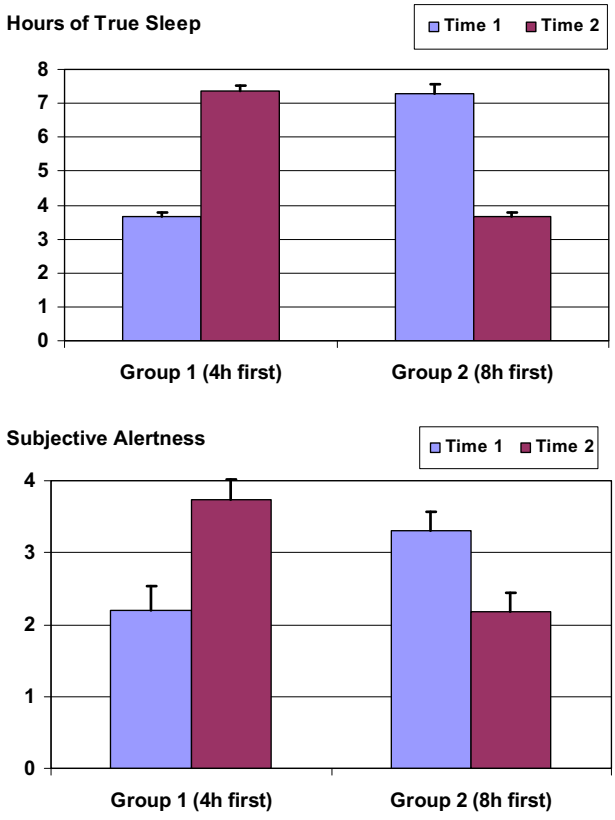

Fig. 1. Means and standard error bars for actigraphic true sleep time and subjective alertness in each group according to 8 and 4 h sleep requirements. Participants in group 1 were instructed to sleep 4 h on the first night and 8 h on the fourth night and those in group 2 were requested to follow the reverse order.

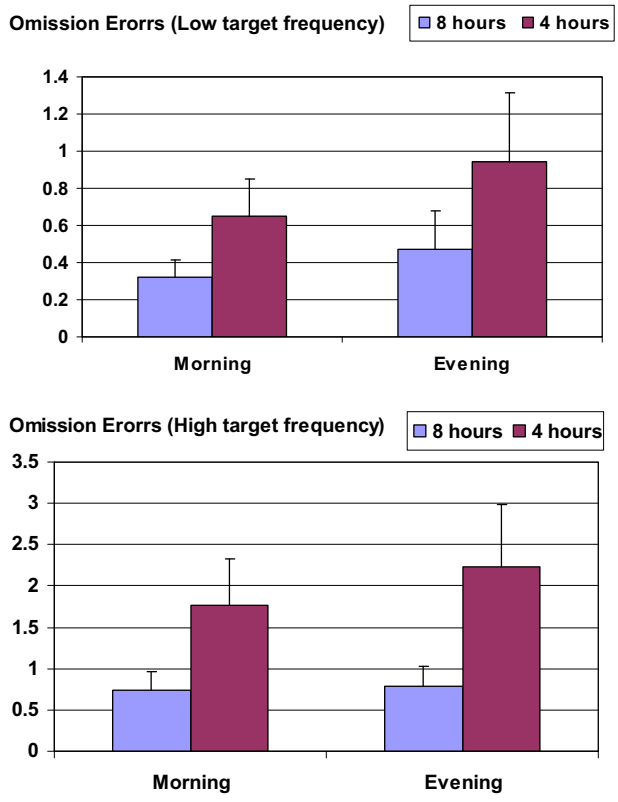

Fig. 2. Means and standard error bars for omission errors in the low and high target frequency sections of the online continuous performance test OCPT. Comparison of morning versus evening performance under sleep restriction and normal sleep conditions.

sleep. In addition, a significant time-of-day by condition interaction effect was found with higher number of omission errors recorded on the evening following sleep deprivation in comparison to the evening following regular sleep ($F = 10.46$; $p < .005$).

In the low target frequency section, a significant condition effect was found with a higher number of omission errors following sleep restriction than following regular sleep ($F = 9.01$; $p < .01$). Furthermore, a significant main effect of time-of-day was found with poorer evening performance in comparison to morning performance ($F = 16.54$; $p < .0005$).

No significant condition effects were found on response times in any of the analyses.

4. Discussion

To the best of our knowledge, the present study is the first home-based experimental sleep restriction study conducted via actigraphic monitoring of sleep and an Internet-based online sustained attention test. The results of the study provide preliminary support for the feasibility of conducting sleep restriction studies in the home setting using actigraphy for sleep monitoring and online testing of sustained attention.

Actigraphic sleep assessment indicated acceptable compliance with experimental sleep requirements. The significant order group by time interaction indicated that on the restricted night, participants slept significantly less than on the "8-h" night. Furthermore, following the restricted night, significantly higher sleepiness levels have been reported in comparison to those who reported following the "8-h" night. There was no significant main effect of order. These findings are in line with previous studies demonstrating the feasibility of conducting sleep restriction studies in natural settings in children and adolescents [6,19,20] that are now extended to young adults. The finding of significantly reduced subjective alertness ratings following restricted sleep further supports the validity of the sleep manipulation.

The test–retest reliability data of the OCPT provide reasonable psychometric support to this mode of testing, considering that the tests were conducted under substantially different conditions (morning/evening, normal/restricted sleep, and no control for environmental circumstances of test taking) with all their potential impact on the stability of the OCPT measures. It may be assumed that if an attempt was made to equate within-subject and between-subject testing conditions an even greater stability would have emerged.

The finding that sleep restriction significantly increases omission error rates in both the high and low target frequency sections of the test is consistent with multiple studies using the psychomotor vigilance test (PVT) reporting increase in lapses following sleep loss [4,5,11,21–23]. The fact that increase in lapses was more pronounced for the tests taken in the evening may suggest that the OCPT is also sensitive to circadian changes in vigilance, as demonstrated with the PVT [10,11], or to the cumulative effect of hours of sustained wakefulness [24,25].

The limitations of online assessment tools such as the OCPT should be highlighted. It requires Internet access and some computer skills or support. The outcomes of these tests could be distorted by environmental interferences or inappropriate testing environment. In our study, as well as is in future applications, lack of direct control over the use of alertness promoting agents (e.g., caffeine) may interfere with reliability. And, unlike laboratory-based studies there is little or no monitoring of participants' actual behavior, rendering the data provided by individuals who are motivated to cheat questionable. Finally, a critical question regarding the use of such an online tool (where the results of the tests are stored on a remote server) is related to data safety and confidentiality issues. In terms of data storage safety, in the system we have used, only authorized users can log in and back-up the data files at any point in time. For confidentiality, each user (i.e., patient or participant) receives a unique ID code and the data is stored only with ID codes. Access to the database is limited to the scientists or physicians responsible for the study, and only they can link between individuals and their personal CPT data.

Notwithstanding these limitations, the potential for repeated and easily collected reliable online CPT assessments of daytime sleepiness as well as remote monitoring of the effects of insufficient or disrupted sleep is of great value. In this era of growing applications for telemedicine in general [26–30], and for sleep disorders in particular [31,32], the ability to assess cognitive function at home or at the clinician's office with a validated task that is sensitive to sleep loss opens new possibilities for clinical research and for follow-up on clinical care. More research is needed to establish these tools for medical research and practice.

Conflict of interest

Orrie Dan and Yair Bar-Haim hold stocks in eAgnosis and serve on its scientific advisory board.

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