Online assessment of sustained attention following sleep restriction

Avi Sadeh,*, Orrie Dan, Yair Bar-Haim

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 < 0.001). 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 < 0.005) and with a significant increase in omission errors in the low-target section of the test (p < 0.01).

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.

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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 performance 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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2.3. Measures

2.3.1. Online continuous performance test (OCPT)

The OCPT (eAgnosis Inc., Newark, DE) is a standard CPT designed and adapted for use with most Internet browsers (e.g., Internet Explorer, Firefox, Chrome, Apple Safari). The task is displayed using Java applets on a computer connected to the Internet. Any computer connected to the Internet can be used to complete the task (the computer used for the CPT is not used for any other work during the study). The OCPT is unique in that it can be completed at different times and places. The OCPT can be completed at the time that is most convenient for the participant, and in different places, which is convenient for the participant.

The task 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 shape presented 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) consists of 224 trials (56 targets; 168 non-targets) with a target to non-target ratio of 1:4. In this half of the test, the target is the fist and the non-target is the circle. In the second half of the test (the high target frequency), the target to non-target ratio is reversed and is set to 3:1.

The task consists of 100 trials (33 targets; 67 non-targets) with a target to non-target ratio of 1:3. In this half of the task, the target is the circle and the non-target is the fist. The target is presented for 100 ms followed by a 1900 ms inter-trial interval. Participants are instructed to respond to the circle presented by pressing the space bar on the computer's keyboard and to withhold responding to the fist shape.

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

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...
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 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 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 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 eAgnose and serve on its scientific advisory board.

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References