

Towards a Novel Measure to Determine Improvement of Cognitive Functioning Following Cognitive Behavioral Therapy for Insomnia

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Received date: July 22, 2016; Accepted date: September 12, 2016; Published date: September 19, 2016

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Abstract

Background: Cognitive impairments are often reported by individuals with insomnia. Yet, objective performance-based measures of cognitive functioning have yielded inconsistent results. The present study aims to investigate sustained attention and vigilance in individuals with insomnia by employing a novel task based on the Schröger and Wolff paradigm. This innovative auditory distraction task measures two different cognitive processes: 1) the ability to sustain attention in order to detect the duration of auditory stimuli; and 2) the ability to detect auditory stimulus change, which requires a switch of attention. A standard psychomotor vigilance test (PVT) was also employed for comparison purposes.

Methods: Cognitive behavioral therapy for insomnia was delivered to 5 participants. Performance on the psychomotor vigilance test and the novel auditory distraction task were examined prior to and following treatment.

Results: Accuracy of detection in the psychomotor vigilance test significantly improved following treatment. Similarly, the novel distraction task led to a significant improvement of accuracy of detection of auditory stimulus duration following treatment. However, processes related to the switching of attention upon presentation of auditory stimulus change were not altered following treatment.

Conclusion: Insomnia seems to affect sustained attention and vigilance. Such processes do appear to be responsive to therapy, unlike the ability to switch attention when relevant. The novel auditory distraction task examined in this study seems to be a promising clinical outcome measure of sustained attention and vigilance for insomnia, as it was observed to have the benefit of being devoid of a ceiling effect, which was found with the psychomotor vigilance test. Further investigation of this novel application is warranted.

Keywords: Insomnia; Cognitive behavioral therapy for insomnia; Cognitive impairment; Sustained attention; Vigilance

Introduction

Insomnia is the most prevalent sleep disorder, affecting an estimated 6% to 15% of the general population [1,2]. Insomnia is characterized by persistent difficulties in initiating or maintaining sleep with significant distress or impairment in daytime functioning that occur despite adequate opportunities for sleep [3,4]. Substantial societal and personal costs are associated with insomnia. High rates of motor-vehicle accidents, increased health care use, and economic burden linked to work absenteeism or reduced productivity have been documented [5-8]. At an individual level, fatigue, reduced motivation and initiative, as well as mood disturbance are frequently reported by individuals with insomnia [9]. Cognitive impairments typically involving attention, memory, and/or executive functions also represent a significant number of the complaints shared by individuals with insomnia. These subjective complaints have not however always been found to be correlated with objective performance-based measures. Indeed, different meta-analyses have highlighted a lack of consistency in the performance data. Riedel and Lichstein [10] reviewed 13 different studies using various cognitive measures and concluded that

only a few of them confirmed the presence of significant cognitive impairments, and these were mainly related to psychomotor functions. Fulda and Schulz [11] arrived at a similar conclusion. In their review of 18 studies, they also noted a lack of consistent evidence of objective cognitive deficits associated with insomnia. Fulda and Schulz [11] however indicated that cognitive tasks that required vigilance were the most likely to be compromised by insomnia. More recently, Shekleton et al. [12] evaluated 18 other studies and suggested that the effect of insomnia on cognitive functions was small and subtle. In addition, the results from the various studies were inconsistent: some studies reported an effect, while others did not using essentially identical tasks. The authors did however note that tasks having a high cognitive load, presumably involving complex, higher cognitive processes, appeared to be the most sensitive to insomnia. Fortier-Brochu et al. [13] reviewed 24 studies and also indicated that insomnia had only small or moderate effects on cognitive functions, in particular on cognitively demanding tasks involving processes such as working and episodic memory, and problem solving. However, no significant differences were observed for less-demanding, simpler tasks. In brief, the findings from the different meta-analyses highlight that studies to date have failed to find a consistent effect of insomnia on various cognitive functions. These reviews do point out a failure to employ identical methodological procedures. Small changes in the methodology of very

similar tasks can have a large effect, thus perhaps accounting for some of the inconsistency of results. Moreover, many studies employ standardized neuropsychological measures and these may not be optimal for revealing the small and subtle cognitive deficits identified by the above-mentioned studies. Buysse et al. [14] and Shekleton et al. [12] also point to another limitation of the use of neuropsychological batteries: they are clinical tools used for the screening of individuals likely to meet the criteria of a specific population on basis of a comparison to normative sample data.

Because of the inconsistencies in the insomnia literature, the extensive sleep deprivation body of research might be used as a starting point for the study of cognitive impairments induced by insomnia. Indeed, although the mechanisms responsible for cognitive deficits in insomnia remain to be elucidated, sleep loss can be considered as a factor contributing to performance decrements. Multiple studies have confirmed the deleterious effect of sleep deprivation on cognitive functioning [15]. These impairments have been hypothesized to be the result of either a frontal central executive dysfunction [16], or a more general inability to sustain attention and maintain vigilance [17]. The cognitive correlates resulting from insomnia and their underlying mechanisms could of course differ from those generated by experimental sleep deprivation [10]. Nevertheless, this is the approach used in the present study because the effects of sleep deprivation could at least point to certain aspects of cognition that might be consistent with insomnia [12]. The present study thus employs a novel task that our lab has found to have strong effects obtained in both total and partial sleep deprivation studies.

Many studies have now found that sleep deprivation mainly affects cognitive tasks that are dependent on the maintenance of active, sustained attention, particularly for monotonous tasks [15,18]. A task that is frequently used in sleep deprivation studies is the psychomotor vigilance test (PVT) [19]. In this task, participants are asked to detect a visual stimulus, presented at random intervals ranging from 2 s to 10 s. As its name implies, the PVT requires the participant to remain vigilant and sustain attention for the entire testing period. Accuracy of detection and speed of responding have repeatedly been shown to be affected by sleep loss [20]. Another advantage to the use of the PVT is that it shows little effects of practice or learning, apart from a slight improvement after the first few trials [21]. It can thus be used in pre-post designs. Unfortunately, in the insomnia field, numerous and different tasks requiring sustained attention and vigilance have been used, making comparisons difficult, and thus possibly contributing to the inconsistency of the results. The PVT has not often been used. This might be because of the relative ease of the PVT. Most individuals with insomnia will rarely fail to detect the target stimulus and as a result, the rate of detection will be very high.

Our lab has carried out an initial sleep deprivation study testing a task developed by Schröger and Wolff [22]. It was designed to examine the automatic switching of attention from an ongoing task and towards a potentially more relevant novel stimulus. However, part of the interest of this task to the study of sleep deprivation and insomnia is that the “primary” task, like the PVT, does require sustained attention and vigilance for its successful completion and thus might be susceptible to the effects of insomnia. However, unlike the PVT, it also measures the extent to which individuals can detect acoustic change and subsequently take action, when appropriate. In the classic paradigm, participants are presented with a sequence of equally probable short and long duration auditory tones and asked to discriminate the duration of the stimuli. As mentioned, this does

require sustained attention. An advantage of this task is that the difficulty of the task and thus, the accuracy of detection, can be manipulated by varying the difference in the duration of the two stimuli. In pilot studies carried out in our lab on the effects of sleep deprivation, we have found that tones having duration of 190 ms and 310 ms resulted in detection rates varying from 0.70 to 0.85. Decreasing the difference in duration between the tones produced a task that was too difficult, resulting in participants “giving up”. Increasing the difference in duration between the tones produced a task that was too easy, resulting in participants no longer needing to be vigilant to successfully carry out the task. Another feature of the Schröger and Wolff [22] task is that it also examines another cognitive function, the switching of attention to a potentially more relevant event. Thus, at rare and unpredictable times, a feature of the auditory stimulus (for example, its pitch) changes. This deviant feature is however irrelevant to the duration detection task, participants still needing to determine whether its duration is short or long. Evidence of the switch of attention away from the processing of the relevant feature of the stimulus, its duration, and towards the processing of the irrelevant feature is provided by performance on the task. Accuracy of detection of the duration of the deviant deteriorates and speed of responding slows. Such switching of attention has both advantages and disadvantages. On the positive side, detection of change (or novelty) in the environment is crucial for survival. While the driving of a car requires sustained attention and vigilance, it is also critical that the driver is made aware of an environmental event occurring outside of the focus of attention, the honking of a horn. On the negative side, the large majority of potentially highly relevant input turns out to be irrelevant. Thus the switching of attention to these events results in distraction and deterioration in performance. Our initial study indicated that total sleep deprivation was associated with an overall decrease in performance compared to normal sleep, probably because of an inability to sustain attention. After normal sleep, when the deviant stimulus was presented, performance did deteriorate. However, after sleep deprivation, deterioration in performance was less marked. Thus, the sleep-deprived seem to be less able to switch attention to potentially highly relevant stimulus input. Partial sleep deprivation also resulted in an overall deterioration in performance. Its effects on the processing of the deviant stimulus were not however significant. Thus, while partial sleep deprivation does affect the ability to sustain attention, there was little evidence that the ability to switch attention to novel input was compromised.

The present study will examine the use of this Schröger and Wolff [22] distraction task to determine the effects of insomnia on cognitive processing. This task will be used to provide an objective measure of cognitive processing prior to and following cognitive behavioral therapy for insomnia (CBT-I). The PVT was also administered because it is considered to be the gold standard for the assessment of the effects of sleep loss on cognition. Performance on these tasks was thus examined prior to and following CBT-I. Various sleep questionnaires and inventories were also used to determine if treatment altered the subjective reports of the quantity and quality of sleep.

Method

Participants

Five participants (4 women, 1 man) aged between 22 and 59 ($M=39.8$, $SD=16.7$) volunteered to participate in this exploratory study. It is recognized that this sample is small but it was reasoned that for

any task to be useful in a clinical setting, effects need to be highly consistent across most individuals and therefore be evident even in small samples.

All participants met the inclusion and exclusion criteria described in the Procedure section. For diagnostic purposes, 4 of the participants

had mixed insomnia (combination of 2 or 3 of sleep onset, middle and late insomnia). The fifth one had middle insomnia only. Additional sociodemographic and clinical characteristics of the sample are shown in Table 1.

Participant	Sociodemographic characteristics				Clinical characteristics		
	Age (years)	Marital status	Education completed	Occupation	Type of insomnia	Insomnia duration (years)	Sleep medication, type (daily dosage)
1	29	Living with partner	University	Employed	Mixed	4	---
2	56	Married	University	Retired	Mixed	3	---
3	22	Living with partner	University	Employed	Mixed	8	Trazodone (50 mg)
4	33	Married	High-School	Employed	Mixed	23	---
5	59	Divorced	University	Retired	Middle	8	Zopiclone (10 mg)
Mean (SD)	39.8 (16.7)	---	---	---	---	9.2 (8.0)	---

Table 1: Sociodemographic and clinical characteristics of participants.

This study was approved by University of Ottawa and Montfort Hospital (Ottawa, Canada) research ethics boards following the guidelines of the Canadian Tri-Council (Medical, Natural and Social sciences) on ethical conduct involving human subjects. In accordance with these guidelines, all participants provided a written informed consent prior to beginning pre-treatment assessment procedures. Data collection was part of a larger study assessing the efficacy of CBT-I delivered by videoconference.

Procedure

Recruitment: Participants were recruited through referrals from general practitioners in Eastern Ontario (Canada). Twenty individuals indicated they were interested in participating in this study. All potential participants were contacted by telephone and given a brief screening interview to determine eligibility. The inclusion criteria included: 1) between 18 and 65 years of age; and 2) having a diagnosis of persistent insomnia as defined by a combination of criteria deriving from the diagnostic and statistical manual of mental disorders (DSM-5) [3], the international classification of sleep disorders (ICSD-3) [4], and those recommended to be used in insomnia research [9,23]. More precisely, the combination of the insomnia criteria included: a) difficulties initiating and/or maintaining sleep. This was defined as a sleep onset latency and/or wake after sleep onset greater than 30 min; b) poor sleep efficiency. This was defined as a percentage of time asleep while in bed lower than 85%; c) sleep difficulties occurring at least 3 nights a week, for at least 6 months; and d) sleep difficulties causing significant distress or deterioration in daytime functioning. Exclusion criteria were: 1) presence of a sleep disorder other than insomnia (e.g. sleep apnea, narcolepsy, periodic limb movement); 2) presence of a severe psychiatric disorder (e.g. major depression, psychosis, neurocognitive disorders); 3) presence of a medical illness potentially related to disturbances in sleep (e.g. anemia, thyroid disorder); 4) use of medication having a proven impact on sleep (e.g. beta blockers); 5) shift work; and 6) currently participating in or having received a psychological treatment for insomnia within

the past 2 years. Current use of sleep medication (stable for at least 2 months) was not an exclusion criterion.

Individual clinical interview: Of the 20 individuals who were interviewed, 5 were deemed to be eligible for the study and were invited to complete a second-stage screening consisting of an individual clinical interview. This interview aimed to confirm the diagnosis of insomnia and to assure the absence of exclusion criteria determined for this study. Three diagnostic tools were administered to prospective participants: 1) insomnia interview schedule (IIS) [24] to confirm the presence of persistent insomnia; 2) the mini international neuropsychiatric interview (MINI) [25] to rule out any psychiatric disorders; and 3) the montreal cognitive assessment (MoCA) [26] to rule out any cognitive impairment. All 5 individuals were considered eligible to participate in the study. They were then asked to complete the insomnia severity index (ISI) [24], the PVT and the distraction task. An appointment for the first treatment session was then scheduled. Participants were asked to complete a daily sleep diary over 2-weeks prior to treatment initiation.

Treatment: Each participant individually underwent CBT-I. CBT-I has long been established as a first-line treatment of insomnia and its efficacy is supported by strong empirical evidence [27,28]. Protocol used in the present study was based on Morin's [24] clinical procedures; an exhaustive description can be found in Morin's [24] book. In brief, CBT-I combines three main components: educational, behavioral, and cognitive. The educational component involves basic education about insomnia including sleep architecture, circadian rhythms, sleep hygiene, and its cognitive behavioral conceptualization. The behavioral intervention includes stimulus control and sleep restriction, which respectively aim to: 1) reinforce the association between the bed and bedroom with sleep, and establish a regular sleep-wake schedule; and 2) restrict time spent in bed as close as possible to the actual sleep time in order to induce a more consolidated and efficient sleep. The third component, the cognitive intervention, involves reframing faulty beliefs and attitudes that interfere with sleep. All sessions were delivered by a clinical psychologist (JG) with

extensive training and experience in CBT-I. Structured guidelines were followed during treatment sessions in order to enhance treatment fidelity. Treatment consisted of 6 weekly sessions lasting 60 min and was delivered by videoconference within Montfort Hospital (Ottawa, Canada). Throughout treatment, participants were again instructed to complete a daily sleep diary. Following treatment, participants were also asked to continue to complete the daily sleep diary for an additional 2-week period.

All 5 participants completed all 6 CBT-I sessions. They also fully complied with treatment protocol and sleep diary procedures at all stages.

Individual post-treatment session: Two weeks following the end of treatment, participants completed the ISI, the PVT and the distraction task. The pre and post-treatment outcome measures were administered by an independent researcher who had no role in the provision of treatment.

Measures

Diagnostic measures

Insomnia interview schedule (IIS): The IIS is a semi-structured interview that includes several questions designed to clarify the nature, characteristics, history, and impact of sleep disturbances [24]. It provides a functional analysis and allows establishing an insomnia diagnosis.

Mini international neuropsychiatric interview (MINI): The MINI is a brief structured diagnostic interview that covers all major axis I psychiatric disorders of the DSM-IV. The MINI has a high reliability with other structured interviews [25,29], and has shown good inter-rater and test-retest reliabilities [30].

Montreal cognitive assessment (MoCA): The MoCA is an instrument aiming to screen mild cognitive impairment, by assessing the following eight cognitive domains: attention and concentration, executive functions, memory, language, visuospatial skills, abstraction, calculation, and orientation. The MoCA has a total possible score of 30; a score equivalent to or greater than 26 indicates the absence of cognitive deficit. This measure of global cognitive function has excellent psychometric properties as evidenced by high internal consistency and test-retest reliability, and demonstrates strong sensitivity and specificity to neurocognitive impairment [26].

Subjective outcome measures

Sleep diary: The sleep diary is completed daily upon arising. This diary provides a subjective measure of sleep parameters such as bedtime hour, number and duration of awakenings during the night, and time of arising from bed [24]. The daily sleep diary data is then used to calculate sleep variables useful for clinical and treatment outcome analysis. In the present study, the following sleep measures were derived from the diary: sleep onset latency (SOL: min between lights off and first sleep episode), wake after sleep onset (WASO: min awake between sleep onset and wake time), and sleep efficiency (SE: percentage of time asleep while in bed). These variables were selected because they represent outcome indicators commonly used in insomnia research [31,32]. They also have specific normative thresholds - directly drawn from the diagnostic criteria defining insomnia that allow measuring the clinical significance of participant's outcomes. The sleep diary is the gold standard of subjective sleep

measures, and data derived from it have proven to be reliable and valid [31].

Insomnia severity index (ISI): The ISI is a 7-item self-report questionnaire inquiring about insomnia symptoms and related distress over the last 2 weeks [24]. The following dimensions are assessed: 1) perceived severity of problems with sleep onset, sleep maintenance, and early morning awakenings; 2) current satisfaction with sleep; 3) degree of interference of sleep difficulties with daytime functioning; 4) noticeability of quality of life impairments due to sleep disturbances; and 5) degree of distress caused by sleep difficulties. A 5-point likert scale (0=no problem; 4=very severe problem) is used for each item and their sum yields a total score ranging from 0 to 28. Four categories of symptom severity based on total score have been defined: scores 0 to 7=no clinically significant insomnia; 8-14=sub threshold insomnia; 15-21=clinical insomnia of moderate severity; 21-28=severe clinical insomnia. For clinical trials, a minimum threshold score of 11 is recommended [33]. The ISI has strong psychometric properties and has been validated as an outcome measure in treatment research [34]. It also permits the measurement of the success of treatment using well-defined parameters: a 7-point reduction in baseline score is considered to be minimal evidence of moderate improvement, while a 9-point or larger reduction corresponds to a marked improvement [33]. A post-treatment reduction to a score equal or lower than 7 has also been used as an index of remission [35]. These indicators were thus selected as outcome measures for the current study.

Objective cognitive outcome measures

Two different cognitive tasks were run. Stimulus presentation, response monitoring and timing were controlled by E-prime software (Psychology Software Tools Inc., Sharpsburg, Pennsylvania).

Psychomotor vigilance test (PVT) [17]. In this task, participants were asked to detect a visual stimulus, presented at random times. Because this is a visual task, participants were seated approximately 50 cm from a computer monitor. All stimuli were presented in black against a white background. A trial began with a fixation point (“+”) presented in the center of the monitor. This was replaced by a 15 mm diameter circle lasting 1 s. The onset of the circle varied randomly between 2 s and 10 s (on average, every 6 s) after the onset of the fixation point. The participant was asked to press the left mouse button as quickly as possible after presentation of the circle. Feedback then informed the participant that a correct response had occurred and the actual reaction time (RT; in ms) was displayed. If participants failed to respond, a feedback message “no response was detected” was displayed. The feedback message also lasted 1 s after which the next trial was initiated with the presentation of the fixation point. The task lasted 10 min. Performance was measured according to: 1a) accuracy of responding; 1b) number of lapses (response occurring with a RT greater than 500 ms); and 2) mean and median RTs, and variability in individual participant's RTs.

Because it is known that performance improves after the first few trials, it is possible that improvements following therapy might be a confound of prior exposure to the task (participants had already been exposed to the task prior to therapy). Practice trials lasting about 1 min were therefore initially run at both pre and post-treatment sessions. This served two purposes. It assured that the participants did understand the instructions and nature of the task. Also, the practice sessions should have removed any improvement that might have been experienced during the actual testing.

Distraction task: This task also lasted about 10 min. Participants were presented with short and long duration auditory tones and asked to determine their duration. A total of 500 moderate intensity (70 dB SPL) auditory pure tones (1000 Hz) were presented binaurally through Sony MDR-V6 headphones. The duration of half the stimuli was 190 ms and for the other half, 310 ms. The short and long stimuli were presented in random order. A stimulus occurred every 1400 ms. Participants were asked to press one mouse button for short duration stimuli and a second button for long duration stimuli. A response had to occur within 1200 ms. This 1000 Hz “standard” stimulus was presented on 84% of trials. A small frequency change was however introduced on the remaining trials. A 950 Hz “deviant” was thus presented on 16% of trials. Standards and deviants occurred in random order with the restriction that a deviant be followed by at least three presentations of the standard. Performance was measured by accuracy of and speed of responding (RT). Accuracy and RT were collapsed across short and long duration trials because accuracy of detection of specific stimulus duration was not a concern in this study. Importantly, accuracy and RT were however measured separately for standard and deviant trials. Performance should deteriorate following presentation of the deviant if participants do switch attention to the processing of its irrelevant feature, its pitch.

Practice trials lasting about 1 min were also run in both pre and post-treatment sessions. Again, this served to assure that the participants did understand the nature of the task and should have removed any possible improvement after the first few trials.

Data Analyses

Subjective outcome measures

The effectiveness of treatment on the various measures was determined by using a one-tailed t-test, $\alpha=0.05$, because the interest was focused only on improvement with CBT-I. Thus, treatment was considered to be successful if post-treatment measures significantly improved from pre-treatment measures. Treatment was not considered to be successful if measures failed to change or if they were worse, regardless of whether they were statistically significant or not.

Total scores obtained on the ISI were analyzed using a paired-sample t-test to compare pre and post-treatment conditions. For the sleep diary data, means for the 2-week pre and post-treatment periods were computed for the SOL, WASO, and SE of each participant. Paired-sample t-tests were then run to compare pre and post-treatment conditions.

Objective cognitive outcome measures

Performance was measured in two ways, accuracy of responding and RT. These were analyzed separately. For each of the tasks, RTs were computed only on correct trials. There were too few errors to reliably analyze the error data. The participant’s mean RT was computed for the PVT and the distraction task in the pre and post-treatment conditions. A problem with the use of the mean RT is that it can be skewed by extremely fast or low RTs [36]. For this reason, the participant’s median RT was also computed. Some studies have indicated that sleep deprivation also increases variability of single participant RTs within a task [15]. For this reason, the standard deviation (SD) of individual participant’s RT distribution was also used as a dependent measure.

For the PVT, the same dependent measures (accuracy and RT) were used. In addition, researchers often examine “lapses” in performance. The number of lapses, defined as RTs greater than 500 ms, was thus computed. Sleep deprivation is associated with a deterioration in PVT measures [20]. It was expected therefore that successful outcome would be associated with an improvement on the measures at post-treatment. This was tested statistically using paired-sample one-tailed t-tests, $\alpha=0.05$, on the various performance measures.

The distraction task is unusual in that it measures two different cognitive processes: 1) the ability to sustain attention in order to detect the duration of the stimuli; and 2) the ability to automatically detect potentially highly relevant stimulus change. Our initial total sleep deprivation study indicated that both processes were affected, whereas partial sleep deprivation did not affect the ability to detect the deviant stimulus. It was therefore expected that: 1) performance on the relevant duration detection, requiring sustained attention, would improve following treatment; and 2) individuals with insomnia would be less able to detect the deviant, and thus show less deterioration in performance prior to treatment and more deterioration following treatment. This was tested statistically using a two-way ANOVA, $\alpha=0.05$, with repeated measures on treatment (pre, post) and type of stimulus (standard, deviant) on each of the performance measures.

Results

Subjective outcome measures

Table 2 presents sleep diary data and ISI scores at pre and post-treatment.

Sleep diary

Sleep onset latency (SOL). The SOL group mean at pre-treatment was 35.3 min (SD=28.7 min) and decreased to 10.6 min (SD=4.0 min) at post-treatment. This reduction was not statistically significant, $t(4)=1.80$, $p=0.15$. It did however reflect a clinically significant gain as the post-treatment mean was below the recommended diagnostic threshold of >30 min. The lack of statistical significance was probably due to the fact that there was wide variability in SOL prior to treatment. Three of the individuals had a pre-treatment SOL score that would be considered within normal range, thus limiting the extent to which treatment could result in an improvement.

Wake after sleep onset (WASO). Pre-treatment WASO was above the threshold diagnostic criteria of >30 min for all participants. At post-treatment, 4 of the 5 participants had a WASO score lower than this threshold. The WASO group mean at pre-treatment was 87.2 min (SD=39.0 min) and significantly decreased to 36.8 min (SD=31.3 min) at post-treatment, $t(4)=4.55$, $p=0.01$; $d=2.03$. The post-treatment WASO mean was however above the threshold criteria, thus remaining in the clinical range.

Sleep efficiency (SE). Pre-treatment SE met the threshold diagnostic criteria of <85% for all participants. At post-treatment, the SE score improved and no longer met this threshold for 4 of the participants. The SE mean at pre-treatment was 73.3% (SD=12.1%) and significantly increased to 89.4% (SD=5.9%) at post-treatment, $t(4)=2.99$, $p=0.04$; $d=1.34$. This increase suggested a significant clinical gain as the post-treatment SE mean was above the threshold diagnostic criteria.

Insomnia severity index

Pre-treatment ISI score was above the suggested threshold score for clinical insomnia trials (threshold of 11) for all participants. At post-treatment, 3 of the 5 participants had achieved remission (ISI scores lower than 7) and the 2 remaining participants showed a marked improvement (ISI mean change score between pre and post-treatment equal or greater than 9 points). The mean ISI score at pre-treatment

was 18.8 (SD=5.1) and significantly decreased to 5.0 (SD=4.4) at post-treatment, $t(4)=5.36$, $p=0.006$; $d=2.4$. This reduction also suggested a significant clinical gain; ISI pre-treatment mean scores fell in the “clinical insomnia of moderate severity” category (scores of 15 to 21) and declined to join the “no insomnia” category (scores 0 to 7) at post-treatment.

Participant	Sleep Diary Data						ISI	
	SOL		WASO		SE		Total score	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	85	9.3	123.9	30.4	53	89	25	2
2	15.7	15.5	134.7	90.8	72.5	80	18	9
3	18.2	12.9	55.7	24.3	83.5	92.5	23	10
4	33.9	4.9	54	9.4	77	95.8	13	4
5	23.8	10.4	67.5	29.3	80.5	89.5	15	0
Mean (SD)	35.3 (28.7)	10.6 (4.0)	87.2 (39.0)	36.8 (31.3)	73.3 (12.1)	89.4 (5.9)	18.8 (5.1)	5.0 (4.4)

Table 2: Individual participant pre and post-treatment sleep diary data and ISI scores.

Objective cognitive outcome measures

Psychomotor vigilance test

Table 3 presents the effects of treatment on accuracy and speed of responding during the PVT.

Accuracy

Accuracy improved for all 5 participants following treatment. A significant effect of treatment was found for accuracy of responding, $t(4)=2.45$, $p=0.04$; $d=1.1$. Accuracy increased by 1.8% at post-treatment.

Speed of responding

RT improved for all 5 participants following treatment. A significant effect of treatment was again observed. Post-treatment was associated with a significant 53 ms decrease in the mean speed of responding, $t(4)=3.87$, $p=0.009$; $d=1.73$. This could however be a reflection of a reduction in the number of extremely long RTs. Post-treatment was associated with a significant 7% decrease of number of lapses (i.e., response occurring within a $RT > 500$ ms), $t(4)=2.36$, $p=0.04$; $d=1.06$. The variance around individual participant RTs was also smaller after treatment than prior to it, $t(4)=2.28$, $p=0.04$; $d=1.02$. However, pre and post-treatment median RTs (not affected by extremely long RTs) were also significantly reduced, $t(4)=4.02$, $p=0.008$; $d=1.80$.

Accuracy (in %)		Lapses (in %)		RT (in ms)					
Pre	Post	Pre	Post	Pre			Post		
M	M	M	M	M	Med	SD	M	Med	SD
0.98 (0.03)	0.99 (0.01)	0.13 (0.14)	0.06 (0.09)	390 (91)	376 (90)	95 (23)	337 (71)	320 (69)	77 (27)

M: Mean; Med: Median; SD: Standard Deviation; Pre: Pre-treatment; Post: Post-treatment

Table 3: PVT: Accuracy, lapses and RT (SD in parentheses) at pre and post-treatment.

Distraction task

For this task, data is based only on 4 of the 5 participants. One participant did not complete the task and was therefore excluded from the analysis.

Table 4A presents the effects of treatment on the accuracy of and speed of responding to detection of the duration of the standard and deviant stimuli. In this analysis, only the standards occurring before the deviant were analyzed. The two standards occurring after the deviant were analyzed subsequently.

Accuracy

Accuracy improved for all 5 participants following treatment. An overall significant main effect of treatment was also found, $F(1,3)=9.91$, $p=0.05$; $\eta^2=0.77$. Accuracy of detection of stimulus duration significantly increased by 5.9% at post-treatment, regardless of the type of stimulus (standard or deviant). Although accuracy of detection decreased following presentation of the deviant, the main effect of type of stimulus did not attain significance, $F(1,3)=3.45$, $p=0.16$. The extent of the decrease in accuracy following presentation of the deviant was

however similar to that observed in other studies with larger sample sizes. Importantly, the interaction between treatment and type of stimulus was also not found to be significant, $F < 1$. There was thus little evidence that treatment had an effect on the switching of attention following the presentation of the deviant.

Participants at times failed to respond to the stimuli. Treatment did not however significantly alter the number of failures to respond, $F < 1$. The main effect of type of auditory stimulus and the interaction between treatment and type of stimulus were also not significant, $F(1,3)=1.57$, $p=0.30$, and $F(1,3)=0.58$, $p=0.50$, respectively.

Speed of responding

RT improved for all 5 participants following treatment. However, there was no evidence of an increase in the speed of responding

following treatment, the main effect of treatment not being significant for either the mean or median RT, $F < 1$ in both cases, or the standard deviation of the individual mean RT, $F(1,3)=5.34$, $p=0.10$. Slower RTs to the deviant stimuli can be used as evidence that the presentation of the irrelevant feature distracted resources away from the processing of the relevant feature (duration). Speed of responding did not however differ between the standard and the deviant. The main effect of type of auditory stimulus did not attain significance for the mean, $F < 1$, or the median, $F(1,3)=5.05$, $p=0.11$, or the standard deviation of the individual mean RT, $F < 1$. Again, the interaction between treatment and type of stimulus was also not significant for the 3 measures of speed of responding, $F < 1$ in all cases.

Type of auditory stimulus	Accuracy (%)		Failures to respond (in %)		RT (in ms)					
	Pre	Post	Pre	Post	Pre			Post		
	M	M	M	M	M	Med	SD	M	Med	SD
Standard before deviant	0.81 (0.17)	0.85 (0.13)	0.06 (0.05)	0.06 (0.07)	634 (84)	64 (83)	14 (64)	64 (71)	63 (79)	11 (50)
Deviant	0.72 (0.10)	0.79 (0.13)	0.08 (0.05)	0.06 (0.07)	646 (101)	64 (99)	13 (53)	64 (62)	65 (76)	11 (43)

M: Mean; Med: Median; SD: Standard Deviation; Pre: Pre-treatment; Post: Post-treatment

Table 4A: Distraction task: Accuracy, failures to respond and RT (SD in parentheses) for standard and deviant stimuli at pre and post-treatment.

The deterioration in performance following presentation of the deviant can be used as evidence of a switching of attention and distraction. Recovery from distraction was therefore also examined. It was quantified by examining performance on the two standards occurring after the presentation of the deviant. The standard occurring immediately after the deviant can also be considered a “deviant” because its features are different from the preceding deviant. The features of the second subsequent standard however match those of the standard immediately preceding it. Recovery from distraction should thus result in an improvement in performance upon presentation of the standards following the deviant. Therefore, performance measures were compared for the deviant stimulus and the two subsequent standards. Table 4B presents the effects of treatment on the accuracy of detection and speed of responding to the stimuli (standard and deviant).

Type of auditory stimulus	Mean accuracy (in %)	
	Pre-treatment	Post-treatment
Deviant	0.72 (0.10)	0.79 (0.13)
Standard after deviant 1	0.82 (0.12)	0.84 (0.14)
Standard after deviant 2	0.65 (0.35)	0.80 (0.17)

Table 4B: Distraction task; Mean (SD in parentheses) accuracy measure of recovery from distraction at pre and post-treatment.

Accuracy

Accuracy improved for all 5 participants following treatment. An overall significant main effect of treatment was also observed, $F(1,3)=10.59$, $p=0.05$; $\eta^2=0.78$. Accuracy of detection of the stimulus

duration significantly increased by 8.3% at post-treatment, regardless of the type of stimulus (i.e., whether a deviant or subsequent standard was presented). The main effect of stimulus type (standard vs deviant) approached significance, but was not found to be significant, $F(2,6)=1.25$, $p=0.35$, nor was the interaction between treatment and type of stimulus, $F < 1$. Recovery from distraction was thus not affected by treatment.

In the initial RT analyses, there was little evidence that speed of responding to the deviant was different than that to the standard. Similarly, there was no significant difference in the number of failure to respond to the deviants compared to the standards. There was thus little evidence of distraction for these measures. For this reason, recovery from distraction was not subsequently analyzed for these failures to respond and for speed of responding.

Discussion

Subjective outcome measures

The present findings suggest that CBT-I was successful in improving the overall quantity and quality of sleep in the 5 participants, as assessed by the 3 sleep diary variables (SOL, WASO, SE) and the ISI score at post-treatment. Of note, some of the analyses on the subjective treatment outcome variables were not found to be significant, either statistically or clinically. This lack of significance should however be interpreted in a clinical and qualitative context. First, the type of insomnia experienced by participants was not homogenous, resulting in a relatively large amount of variability in the sleep diary data, and particularly for the SOL variable. Second, the extreme scores recorded for one participant may have skewed the results: underlying anxiety issues were revealed for this participant during treatment, and this

comorbidity may have had an impact on the effects of the treatment. Nevertheless, subjective outcome sleep data indicated that the overall participant's level of functioning following CBT-I fell within or close to the normative range. Such individuals would thus no longer have been diagnosed as having insomnia.

It should of course be mentioned that whatever benefits of treatment were obtained might be due to a placebo effect. In this initial study, a placebo condition was not run. Again, the purpose of this study was to determine if the apparent beneficial effects of CBT-I on subjective sleep measures would also carry over to objective measures of performance on cognitive tasks.

Objective cognitive outcome measures

Changes were indeed observed between pre and post-treatment measures of cognitive performance. Two cognitive tasks were employed, both requiring sustained attention and vigilance for successful performance. The frequently employed PVT did reveal a lower accuracy of target detection, a slower RT to these targets, and more frequent lapses compared to post-treatment scores in our participants. Although the PVT results are statistically significant, caution should be heeded in its application as a clinical assessment tool. For an outcome tool to be meaningful, it must accurately measure the full spectrum of the construct, including its extremes [37]. This consideration is particularly relevant in the field of insomnia in which inter-individual variability associated with the effects of insomnia on cognitive functioning is suspected [38]. RT measures did reveal a wide range of individual scores and thus met this criterion. In addition, a rather substantial decrease in RT (53 ms) was also found at post-treatment. On the other hand, a high level of accuracy (mean=0.98) was apparent in all participants before treatment. This may lead to a ceiling effect. Thus, although accuracy did significantly improve with treatment, the difference (0.018) was small. The restricted range of possible scores on outcome measures may therefore overestimate the individual's cognitive functioning. In this context, a wider range of task difficulty may be required in order to accurately detect different levels of cognitive functioning, and to discern any meaningful change that has occurred as a result of treatment. The distraction task, although infrequently used in the sleep literature, did appear to meet this criterion. The initial level of accuracy was far from a ceiling level. Post-treatment accuracy on this task increased by almost 6%. A second purpose of this task was to examine changes in cognitive processing as a result of changing a feature of the frequently presented standard stimulus. Prior to treatment, the presentation of the deviant did result in a decrease in accuracy of detection of the duration of the stimulus. Although the effect was not statistically significant, the trend was similar to that found in many studies. Again, this deterioration in performance has been interpreted as a result of a switching of attention away from the task-at-hand (the detection of the duration of the stimulus), and towards the processing of a novel feature (the frequency of the deviant). This is beneficial in that a potentially highly relevant change, one that might be critical for survival, has been detected. On the other hand, it does lead to a deterioration in performance (i.e., as result of distraction). Regardless of the outcome of the switch of attention, treatment did not significantly affect this cognitive process. The present findings mirror those obtained with our initial partial sleep deprivation study. Processes related to the detection of stimulus duration were affected by sleep loss, while processes related to the switching of attention upon presentation of a novel stimulus were not affected. Thus insomnia does not seem to alter the ability to switch attention to a potentially more relevant stimulus.

There are however problems with the use of the distraction task. It does have the benefit of being sufficiently difficult to result in levels of accuracy well below a ceiling level. However, many cognitive tasks could be designed to meet this criterion. In addition, in the present study, although the extent of improvement with treatment was significant, the effect size, as measured by Cohen's *d*, was actually lower compared to the results of the PVT. The real advantage of the distraction task was that it was designed to examine additional cognitive processes, those associated with the switching of attention upon presentation of a novel stimulus. Such switching of attention was not affected by treatment. It is possible that the extent of stimulus change (only a 50 Hz difference between the deviant and the standard) was too small to result in a large switch of attention. A larger extent of change might be considered in future studies.

In summary, the findings from the present study employing a relatively small number of individuals with insomnia indicate that these individuals appear to be unable to sustain attention on two different vigilance tasks to allow for an optimal level of performance. The use of CBT-I appears to be able to alleviate many of the symptoms of insomnia, and also results in an improvement on these vigilance tasks. This study did, of course, have several limitations. Similar to other exploratory studies, the sample size was small and homogenous, and it was not a randomized control design, thus limiting the generalization of the results. Still, the effects of treatment must have been quite consistent because even with a small sample size, these effects were statistically significant. Future research should however attempt to replicate the present findings by using a randomized experimental design including a placebo group. Obviously, a larger sample size presenting a diversity of clinical and sociodemographic characteristics should be tested.

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