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Poor sleep quality affects spatial orientation in virtual environments☆

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ABSTRACT

Sleep is well known to have a significant impact on learning and memory. Specifically, studies adopting an experimentally induced sleep loss protocol in healthy individuals have provided evidence that the consolidation of spatial memories, as acquired through navigating and orienteering in spatial surroundings, is negatively affected by total sleep loss. Here, we used both objective and subjective measures to characterize individuals' quality of sleep, and grouped participants into either a poor (insomnia-like) or normal (control) sleep quality group. We asked participants to solve a wayfinding task in a virtual environment, and scored their performance by measuring the time spent to reach a target location and the number of wayfinding errors made while navigating. We found that participants with poor sleep quality were slower and more error-prone than controls in solving the task. These findings provide novel evidence that pre-existing sleep deficiencies in otherwise healthy individuals affects negatively the ability to learn novel routes, and suggest that sleep quality should be accounted for among healthy individuals performing experimental spatial orientation tasks in virtual environments.

1. Introduction

Obtaining sufficient sleep is crucial for optimal cognitive performance. Sleep quantity and quality are, in fact, well-known to have a significant impact on alertness, vigilance, and attention, as well as high order cognitive functions such as mental flexibility, planning, and decision making [1]. In the context of learning and memory, sleep-dependent improvements have also been well-documented in both declarative (episodic and semantic) [2] and procedural [3] memory. While investigating the specific effects of sleep on spatial memory, a component of the declarative memory system [4], some studies have reported that hippocampus-dependent spatial memories respond favourably to sleep [2], with post-training sleep enhancing spatial knowledge and allowing for individuals to navigate and orient more efficiently through an environment [5]. Hippocampal activity during slow wave sleep (SWS) has been also associated with overnight improvements in route retrieval [6], and the performance of individuals with prior navigational experience has been shown to be improved following only a brief NREM nap (as measured by polysomnography) [7]. Finally, support for the importance of sleep on spatial memory has also been provided by behavioural sleep deprivation studies [8,9] showing that navigational accuracy in both real life and virtual environments is affected by sleep loss. In sum, although the research in the specific area of sleep and spatial memory is limited, the existing evidence suggests that spatial orientation skills are significantly related to sleep.

The majority of studies conducted on sleep and cognitive functioning have employed a total sleep deprivation protocol in which participants are typically deprived of one or more nights of sleep. An experimentally induced total sleep deprivation, however, may not accurately resemble the kind of sleep loss experienced by individuals in their daily life. To address this issue, some studies have examined the effects of chronic partial sleep deprivation [10], and showed a sleep dose-response effect on cognitive performance (e.g. behavioural alertness, working memory, and cognitive throughput). Other studies, adopting a similar chronic partial sleep deprivation protocol, revealed that restricting sleep to six hours or less per night, over a period of two weeks, results in cognitive performance deficits that are comparable to deficits experienced after two days of total sleep deprivation [11]. Altogether, these findings confirmed that sleep loss resulting from

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either total or chronic partial sleep deprivation has similar detrimental effects on cognitive performance [10].

Although partial sleep restriction and sleep deprivation studies have provided insights into the relationship between sleep and cognition, it remains difficult to generalize findings to individuals with chronic sleep disorders since experimental manipulations cannot fully replicate the long-term changes in sleep patterns that characterize those individuals [12]. This is the case for insomnia, a heterogeneous sleep disorder characterized by subjective poor sleep quality [13], difficulties in initiating and maintaining sleep, and impaired daytime functioning [14]. To date, findings from studies examining the relationship between cognitive functioning and insomnia have been inconsistent [15,16]. One study reported that people with insomnia rate their subjective performance on semantic memory tasks lower than controls despite the fact that their performance does not differ from control [17]; whereas, in another study, it has been shown that people with insomnia experience deficits when trying to retrieve semantic memories relative to healthy controls [18]. Despite the equivocal findings, it is suggested that mild to moderate cognitive deficits occur in the presence of insomnia [12,16,19].

Here, we used both objective and subjective measures to characterize individuals' sleep, and, based on these measures, we grouped participants into either a poor (insomnia-like) or normal (control) sleep quality group. We aimed to (1) investigate the effects of naturally occurring poor quality of sleep (as opposed to experimentally induced sleep deprivation) on wayfinding, and (2) contribute to clarify the effects of insomnia-like symptoms on spatial orientation and navigation. Based on prior literature, we hypothesized that individuals with relatively poorer sleep quality would not only take longer, but also make more errors while performing a wayfinding task in a virtual environment.

2. Material and methods

2.1. *Participants*

We recruited **24** healthy undergraduate students **(8 females, *M*=21.2 years old, *SD*=2.89)** who received course credits for participation in the study. **Participants did not report a history of medical, neurological or psychiatric disorders, and did not report the use of any psychoactive medications.** The study was reviewed and approved by the local research ethics board at the University of Calgary (CHREB-22847), and all participants provided written informed consent.

2.2. *Sessions*

We required participants to attend two sessions in the laboratory. Session one took place at 2 p.m. and session two occurred seven days later at 10 a.m. Both sessions lasted approximately one hour. During session one, participants were asked to complete a series of questionnaires (see below); afterwards, they were given an actigraph watch **(Ambulatory Monitoring Inc.)** measuring rest and activity during the night, and the Consensus Sleep Diary (CSD-E) [20], which they were required to fill out every night and return to the experimenter on session two. We asked participants to wear the actigraph on their non-dominant wrist at all times for seven days and nights (except while taking a shower or swimming). The actigraph contained a piezoelectric accelerometer that measures gross motor activity, which was used to indicate not only sleep-wake schedule, but also sleep quantity. When participants came back to the laboratory the following week for session two, they returned the actigraph and the sleep diary, and completed the virtual wayfinding task.

2.2.1. *Questionnaires (session one)*

Participants were brought to a quiet testing room for their first session. During this session, participants completed a battery of questionnaires. In addition to a brief demographic questionnaire, we obtained subjective sleep measures by asking participants to complete the Pittsburgh Sleep Quality Index (PSQI), which measured subjective sleep quality, sleep latency, duration, efficiency, sleep disturbance, use of sleep medications, and daytime dysfunction [21], and the Insomnia Severity Index (ISI) [22], which measured perceived day- and night-time symptoms related to insomnia for the two weeks preceding the study (scores less than eight indicated the absence of clinically significant symptoms). Participants who scored eight and higher were administered the Insomnia Interview Schedule (IIS) [23] in order to confirm and characterize sleep disturbances and obtain a better description of them. To assess participants' overall anxiety and depressive traits, we administered the State-Trait Anxiety Inventory (STAI) [24] in both state and trait forms, and the Beck Depression Inventory (BDI) [25], respectively. Participants were provided with the CSD-E after completing their questionnaires. The CSD-E provided with both objective and subjective measures of sleep quality. CSD-E objective measure consisted of the following items: (a) What time did you try to go to sleep? (b) How long did it take you to fall asleep? (c) How many times did you wake up? CSD-E subjective measures consisted of the following items: (a) How would you rate your quality of sleep? (b) How rested or refreshed did you feel when you woke up for the day? We instructed participants to log their entries before going to bed every night and upon waking up each morning. This entry logging started on the night of day one (session 1) and ended on the morning of day eight (session two) when they returned to the laboratory to perform the virtual wayfinding task.

2.2.2. *Virtual wayfinding task (session two)*

We constructed two virtual environments [26] using the Hammer map editor and Source Engine (Valve Software; www.valvesoftware.com). One environment was used as a practice environment in which participants were asked to first navigate through it in order to familiarize themselves with the movement controls. The other environment was used as the experimental environment. The experimental environment was composed of four defined areas. These areas (i.e. rooms) were connected to one another with a hallway network in such a manner that no area was visible from another. The hallways and rooms of the environment were all consistently illuminated through the use of overhead lights that were evenly spaced along the ceiling. The four rooms had unique names and contents, allowing them to be used as reference points for the task (i.e., the Storage Room, the Office, the Library, and the Elevators). Overhead and ground-level views of the experimental environment can be seen in Fig. 1.

The task was presented using a modified version of the game Half-Life 2 (Valve Software) on a PC with four 3.5 GHz processors, 8 GB of memory and a 24-in. LED monitor while running Windows 8. This program had a custom menu that offered the practice and experimental environment as the only selectable options. The participants' avatar moved at a maximum velocity of 150 map units per second, corresponding to 2.86 m/s. This velocity was accelerated to within 500 ms of initiating movement. Additionally, the avatar rotated at a rate of 60 degrees per second (therefore a full rotation required six seconds). The avatar had a horizontal field of view of 75 degrees and its viewpoint was situated at 64 map units from the ground, corresponding to a height of 1.2 m.

Before beginning the experimental task, participants completed the practice task in order to familiarize themselves with the controls for navigation. Participants used the left, right, and up arrow keys on a standard keyboard to make the avatar either turn left, turn right, and move forward, respectively. The practice task used a short maze environment with arrows directing participants down a single path. On-screen instructions prompted the participants to follow the arrows through the maze as quickly as possible while trying to avoid stopping or making contact with the walls. The practice trial ended when