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An examination of the association between chronic sleep restriction and electrocortical arousal in college students

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HIGHLIGHTS

- Chronic sleep deficits across an academic semester impair vigilant attention.
- Changes in circadian rhythm activity and average daily sleep are each associated with changes in cortical arousal.
- Very small changes in sleep have a profound effect on neurocortical functioning.

ABSTRACT

Objective: The deleterious neurocognitive effects of laboratory-controlled short-term sleep deprivation are well-known. The present study investigated neurocognitive changes arising from chronic sleep restriction outside the laboratory.
Methods: Sleep patterns of 24 undergraduates were tracked via actigraphy across a 15-week semester. At the semester beginning, at a midpoint, and a week before finals, students performed the Psychomotor Vigilance Test (PVT) and cortical arousal was measured via event-related potentials (ERP) and resting state electroencephalography (EEG).
Results: Average daily sleep decreased between Session 1 and Sessions 2 and 3. Calculated circadian rhythm measures indicated nighttime movement increased and sleep quality decreased from Sessions 1 and 2 to Session 3. Parallel to the sleep/activity measures, PVT reaction time increased between Session 1 and Sessions 2 and 3 and resting state alpha EEG reactivity magnitude and PVT-evoked P3 ERP amplitude decreased between Session 1 and Sessions 2 and 3. Cross-sectional regressions showed PVT reaction time was negatively associated with average daily sleep, alpha reactivity, and P3 changes; sleep/circadian measures were associated with alpha reactivity and/or P3 changes.
Conclusions: Small, but persistent sleep deficits reduced cortical arousal and impaired vigilant attention.
Significance: Chronic sleep restriction impacts neurocognition in a manner similar to laboratory controlled sleep deprivation.

1. Introduction

Sleep plays an essential role in supporting effective cognitive processing (Doran et al., 2001; Fallone et al., 2001; Taras and Potts-Datema, 2005; Kong et al., 2012), yet sleep deprivation and sleep restriction are very common conditions for the general populace (Centers for Disease Control and Prevention, 2013). In fact, thirty percent of adults report getting less than the recommended 7–8 h of sleep per night according to a 2007–2008 survey by the Center for Disease Control (CDC).

Considerable research has examined the effects of total sleep deprivation (TSD) on cognitive processes such as working memory, executive functioning, learning, and selective attention (Harrison

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and Horne, 2000; Smith et al., 2002; Trujillo et al., 2009; Tucker et al., 2010; Maddox et al., 2011). Of particular importance, and a domain of considerable research, is the effect of TSD on vigilance – defined as "the ability of organisms to maintain their focus of attention and to remain alert to stimuli over prolonged periods of time" (Warm et al., 2008, p. 433) – because attentional deficits reliably impact many high-level aspects of cognition (Lim and Dinges, 2008; Jung et al., 2011; Jugovac and Cavallero, 2012). Multiple controlled studies have shown that TSD is fundamentally related to a decrease in the ability to sustain attention, as demonstrated by changes in performance on the psychomotor vigilance task (PVT; Lim and Dinges, 2008; Franzen et al., 2008; Hoedlmoser et al., 2011). In addition to its use in studies of TSD, the PVT has also been used in monitoring effects of sleep restriction in controlled laboratory settings (Dinges et al., 1997; Drake et al., 2001; Vgontzas et al., 2004). For example, in a study by Belenky et al. (2003) participants were split into four different cohorts who experienced various levels of sleep restriction over a 7-day period followed by a 3-night recovery period. Participants were tested using the PVT four times each day and the cohort with the greatest sleep restriction (3 h a night) showed the greatest increases in response time. The less restrictive cohorts of 5 and 7 h a night showed an initial decrease in their performance, which eventually leveled out below their initial speed. During the recovery period, the 5-h and 7-h cohorts did not return to baseline. While the 3-h cohort did improve their reaction times, they also did not show a full rebound, with performance leveling off at the same speed of the 5- and 7-h recovery scores. Therefore, the PVT has been shown to serve as an accurate and reliable measure of vigilance and is the measure most often used in sleep research studies (Dinges and Powell, 1985; Balkin et al., 2004).

Despite its widespread use in sleep research, less is known about the neural basis of performance changes in the PVT. One previous study (Hoedlmoser et al., 2011) found TSD-related PVT performance impairments to be accompanied by decreased activation of event-related electroencephalographic (EEG)-based responses including the early visual event-related potential (ERP) P1 component and delta/theta-band intertrial EEG phase variability. This finding of decreased ERP responses during PVT performance under conditions of TSD is consistent with the results of several previous electrophysiological studies of the effects of sleep deprivation on attention, cognition, and perception (see Trujillo et al., 2009, for a brief review).

Sleep research to date has rarely combined examinations of sleep restriction with neurocognitive measures over extended periods of time in real-world settings. Hence it is unknown the degree to which individuals can adapt to more chronic forms of sleep restriction and whether performance measures such as the PVT and scalp recorded EEG can be sensitive to variations in real-world sleep patterns. This was the primary goal of the present study – to examine the neurocognitive effects of chronic sleep restriction using the PVT in conjunction with EEG measures in a group of normally functioning college students over a period of approximately 15 weeks. Aside from being a convenience sample, college students, and young adults in general, suffer some of the worst sleep restriction (Bonnet and Arand, 1995; Carpenter, 2001; Buboltz et al., 2001). A study by Coren (1994) showed that only about one-third of young adults do not suffer from some sort of sleep disturbance. Lack (1986) observed 'difficulty falling asleep' as the most-often reported sleep issue of approximately 18 percent of the college student sample. Fifty percent of this same group also reported getting insufficient sleep and needing at least 30 additional minutes of sleep time in order to feel rested (Lack, 1986). Clearly, student populations are not receiving ample rest and are thus a good cohort to use when examining the neurocognitive effects of sleep patterns across extended periods of time.

In the present study, student sleep patterns throughout a single school semester were assessed via actigraphy to provide a quantitative continuous measure of sleep/wake activity (Littner et al., 2003). At three intervals throughout a semester (beginning, middle, end), participants performed the PVT while scalp ERPs were recorded. Additionally, we investigated changes in general cortical arousal using a measure of resting state alpha reactivity of the EEG that has previously been shown to be sensitive to sleep loss (Kornguth et al., 2013).

2. Methods

2.1. Participants

Twenty-eight undergraduate students at the University of Texas at Austin were paid for participating in our study (10 males, $M = 20.2 \pm .4$ years). One participant opted to drop out during the first third of the study and so was not included in the analyses. Three participants were excluded from the analyses due to missing large portions of actigraph data. Thus, a total of twenty-four participants were used for all analyses. All participants were right-handed and had no history of neurological or psychological disorders, including sleep disorders. Criteria for participation in this study included a GPA (grade point average) cut-off of above 3.0 and at least 1 year as an undergraduate, attended at the University of Texas. The reason for these criteria was to insure that the primary determinant of the pattern of sleep behavior was successful functioning as an undergraduate student. All participants gave informed consent before testing. This study was approved by the institutional review board at the University of Texas.

2.2. Procedure

Participants were recruited at the beginning of the academic school semester, and after an initial phone screening, attended their first session. At this session, questionnaires including the PANAS (Positive and Negative Affect Schedule), ERQ (Emotion Regulation Questionnaire), CES-D (Center for Epidemiologic Studies Depression Scale), PSQI (Pittsburgh Sleep Quality Index), and a health and demographics questionnaire were completed. We have previously used these questionnaires in normal functioning college students (Vanderlind et al., 2014) and they are widely accepted for use in a non-clinical setting (Crawford and Henry, 2004). None of these measures were used as rejection criteria, as participants had already been screened using a phone survey.

The participants then underwent 10 min of resting state EEG recording while sitting quietly in a comfortable padded chair (5 min eyes open and 5 min eyes closed interleaved in 1-min intervals; eyes open/closed order was balanced across participants). Next, the participants underwent an approximate ten-minute session of EEG recording during performance of the psychomotor vigilance task (PVT; Dinges and Powell, 1985). The PVT is a high-signal load reaction time test in which participants attended to a small fixation cross at the center of a computer screen. At random intervals (2–10 s inter-trial intervals), a bright millisecond timer appeared at the center of the screen. The timer stimulus subtended ~2.35° (w) × .75° (h) of visual angle at a viewing distance of 100 cm. Upon detection of the counter stimulus, participants responded as rapidly as possible via button press with their dominant hand. A participant's response stopped the counter from updating and the final counter value, corresponding to the participant's RT in milliseconds, provided performance feedback for that particular trial. After a one-second exposure duration, the final counter value was replaced by a new fixation cross. Participants were given 30 s to make a response before the computer automatically aborted a trial.