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THE EFFECTS OF CHRONIC PARTIAL SLEEP DEPRIVATION AND CIRCADIAN RHYTHMS ON SEMANTIC MEMORY AND GENERAL AROUSAL

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ABSTRACT

Sleep deprivation is a rampant phenomenon that affects millions of people around the world. *Acute* or *total sleep deprivation* (TSD) refers to the "elimination of sleep for a period of time (at least one night)," whereas *chronic partial sleep deprivation* (PSD) refers to persistent "... reduction in sleep time below an individual's usual baseline" (Reynolds & Banks, 2010, p. 91). Chronic PSD occurs far more frequently than TSD, and constitutes a growing public health epidemic (U.S. Centers for Disease Control and Prevention, 2014). *Semantic memory* refers to our conceptual knowledge about the world, including people, objects, facts, relations, rules, ideas, and beliefs (Saumier & Chertkow, 2002). Past studies have found that TSD leads to impaired semantic memory (Harrison & Horne, 1997; Harrison & Horne, 1998; Tilley, Horne, & Allison, 1985). We extended this research, by investigating the effects of chronic PSD and circadian rhythms on semantic memory. Twenty-three participants (8 males, 15 females, mean age 19 years) who were either chronic PSD (n = 10) or well-rested (n = 13) performed an immediate serial recall (ISR) task involving three word classes that differed according to their semantic representations: concrete content words, abstract content words, and function words. We observed a previously undocumented pattern of semantic impairment in the chronic PSD group, such that function words were the most frequently impaired word class. Additionally, there were significant performance differences on the Psychomotor Vigilance Task (PVT), Mood Scale II, and Stanford Sleepiness Scale (SSS) averaged across the chronic PSD and well-rested groups at two different test sessions 12 hours apart. These findings suggest that the assessment of semantic memory is relevant in the evaluation of individuals suspected of being chronic PSD. Furthermore, they suggest that the systematically cycling rhythms of circadian arousal affect alertness and peak performance at different times of the day. Future research requires data from a more representative sample, as well as the use of actigraphy to confirm participants' self-reported measures of sleep duration.

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Chapter 1

Introduction

Sleep Deprivation

Sleep deprivation is the condition of not getting enough sleep, and occurs in two common forms: *acute* or *total sleep deprivation* (TSD) and *chronic partial sleep deprivation* (PSD). For adults, this generally refers to sleeping less than the average basal need of 7 to 8 hours per night (Dinges, Rogers, & Baynard 2005). TSD is the “elimination of sleep for a period of time (at least one night),” while chronic PSD is a persistent “…reduction in sleep time below an individual’s usual baseline” (Reynolds & Banks, 2010, p. 91).Compared to TSD, chronic PSD is much more widespread and affects an increasing number of people.

Nearly 30 % of adults report sleeping less than 6 hours per night (Schoenborn & Adams, 2010). Insufficient sleep is even higher among college students, with approximately 70 % reporting feeling sleep-deprived and receiving less than 8 hours of nightly sleep (Lund, Reider, Whiting, & Prichard, 2010).

The U.S. Centers for Disease Control and Prevention (2014) reports chronic PSD as a growing public health epidemic. Sleep-loss fatigue accounts for the greatest cause of transportation accidents, nearly 20 % (Connor, Norton, Ameratunga, Robinson, Civil, Dunn, Bailey, & Jackson, 2002). They have fatality rates and injury levels similar to alcohol-related crashes (A.I. Pack, A.M. Pack, Rodgman, Cucchiara, Dinges, & Schwab, 1995). In the workplace, sleep loss is responsible for 274,000 occupational accidents and errors each year in the U.S. (Shahly, 2012). Moreover, sleep loss is cited as contributory to several large-scale human disasters. These include the nuclear reactor catastrophes at Three Mile Island and Chernobyl, the explosion of the Challenger space shuttle, the chemical factory poisoning in Bhopal, India, and the grounding of the Exxon Valdez oil tanker (Colten & Altevogt, 2006). Thus, it is crucial that researchers and public health officials alike understand the cognitive mechanisms involved in performance deficits caused by sleep deprivation. Failure to do so precludes the possibility of preventing such severe public health consequences.

An extensive body of research demonstrates that sleep deprivation degrades cognitive performance across the following domains. The list includes selective attention (Chee, Tan, Parimal, & Zagorodnov, 2010), psychomotor vigilance, visuospatial perception, emotional perception, learning, convergent thinking, divergent thinking, logical deduction, (Killgore, 2010), response inhibition (Anderson & Platten, 2011; Drummond, Paulus, & Tapert, 2006), working memory (Hagewoud, Havekes, Novati, Keijser, Van der Zee, & Meerlo, 2010), long-term memory (Alvarenga, Patti, Anderson, Silva, Calzavara, Lopez, Frussa-Fillho, & Tufik, 2008; Gais, Albouy, Boly, Dang-Vu, Darsaud, Desseilles, Rauchs, Schabus, Sterpenich, Vandewalle, Maquet, & Peigneux, 2007; Rauchs, Bertran, Guillery-Girard, Desgranges, Kerrouche, Denise, Foret, & Eustache, 2004), decision making (Alhola & Polo-Kantola, 2007; Harrison & Horne, 1999), and psychomotor skills (Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002; Williamson & Feyer, 2000).

One area rarely reported is the effects of sleep deprivation on language skills and language-based tasks, both verbally and orally. These are necessary for successful daily functioning in areas such as public transportation, industry, medicine, and in healthy child development. Increasingly in our society, people are forced to use these skills while they suffer from chronic-fatigue stressor effects. If sleep deprivation affects language skills, then this knowledge can help researchers and public health officials design speaking-ability screening tests to detect its symptoms on the job and in the classroom, and to develop interventions to address these problems. Thus, understanding the effects of sleep deprivation on language can potentially serve to help develop interventions to address these problems and reduce the error-related accidents that result in human and financial costs.

Some studies have claimed that sleep deprivation has little or no effect on language skills (Ryman, Naitoh, & Englund, 1985; Swann, Yelland, Redman, & Rajaratnam., 2006; Webb, 1986). Ryman et al. (1985) monitored US Marine corps enlisted subjects throughout two continuous workdays. Percent correct answers to sentence types involving different voice (active vs passive), use of negatives, and outcome (true vs false) were analyzed across three rest conditions: no rest, 3 or 4-hr. naps, and 8-hrs of sleep (Ryman et al., 1985). Ryman et al. found no significant differences between groups on comprehension for any of the sentences. Webb (1986) administered a college level reading comprehension test to subjects before and after two continuous nights without sleep. No significant performance decrements were found across the two nights for reading speed or reading accuracy (Webb, 1986). Swann et al. (2006) used a masked word priming task to investigate the impact of PSD on word recognition and lexical access. Subjects were restricted to 60 percent of their normal sleep duration for two consecutive nights (Swann et al., 2006). No significant effect of PSD was found for response time or error rate (Swann et al., 2006).

In contrast, other studies have reported negative effects of sleep deprivation on a range of different language skills, for both comprehension and production (Babkoff, Zukerman, Fostick, Ben-Artzi, 2005; Harrison & Horne, 1997; Moris, Williams, & Lubin, 1960; Mu, Nahas, Johnson, Yamanaka, Mishory, Koola, Hill, Horner, Bohning, & George, 2005; Vogel, Janet, & Paul, 2010; Whitmore & Fisher, 1996). Moris et al. (1960) observed qualitative differences in speech articulation following 72-98 hours of sustained wakefulness. Subjects' speech "became slower, softer, and contained more unexpected breaks in rhythm. Slurring and softening were often sufficiently marked that the listener could not understand the subject's statements" (Moris et al., 1960, p. 252). Whitmore and Fisher (1996) monitored four-man bomber crews throughout 36-hr exercises. Every three hours the subjects spoke two sentences: "Futility Magellan, this is xxx yyy. The time is zz:zz, Zulu," where "xxx" was the subject's rank, "yyy" was the subject's name, and "zz:zz" was the current time (Whitmore & Fisher, 1996, p. 62). Voice recordings showed reduced intonation and speaking rate following TSD (Whitmore & Fisher, 1996). Harrison and Horne (1997) used a reading-aloud task to investigate the impact of sleep loss on speech. Subjects read aloud sections from a dramatic story (Harrison & Horne, 1997). After 36 hours of TSD, subjects' voices were judged to be more flat and monotonic (Harrison & Horne, 1997). Vogel et al. (2010) found a similar effect of sleep loss on speech after only 24 hours of TSD. Babkoff et al. (2005) investigated the impact of sleep deprivation on auditory temporal resolution, which is integral to speech comprehension. A temporal order judgement (TOJ) task was used to measure auditory temporal resolution following 24 hours of TSD. They found that TOJ accuracy was significantly reduced compared to a baseline condition (normal nocturnal sleep). Mu et al. (2005) investigated the impact of sleep deprivation on verbal working memory using functional magnetic resonance imaging (fMRI) during a verbal working memory task. They found a significant decrease in brain activation in the left dorsolateral prefrontal cortex, Broca's area, and the bilateral posterior parietal cortexes after 30 hours of TSD. Task performance also significantly declined. Thus, in light of these findings, it would seem premature to conclude that sleep deprivation has little or no effect on language skills.

Semantic Memory

Semantic memory is the part of memory responsible for the representation and retrieval of conceptual knowledge about the world, including people, objects, facts, relations, rules, ideas, and beliefs (Saumier & Chertkow, 2002). The cognitive act of accessing semantic knowledge via semantic memory underlies the linguistic ability to impute meaning to words and sentences (Binder, Desai, Graves, & Conant, 2009; Saumier & Chertkow, 2002). Semantic memory contrasts with episodic memory, which refers to knowledge about autobiographical events and experiences (Tulving, 2002). For example, knowing that dogs have four legs, a tail, and bark would be considered part of semantic memory; whereas knowing where you were the last time you petted a particular dog would be considered part of episodic memory.

The neural organization of semantic memory has been explored by cognitive neuroscientists using neuroimaging techniques of positron emission tomography (PET) and fMRI. Evidence suggests dissociations in performance between tasks that use words and those that use object pictures to elicit semantic memory retrieval (Yee, Chrysikou, & Thompson-Schill, 2013). For example, patients with optic aphasia are unable to name objects presented pictorially, yet their word comprehension remains relatively intact (Davidoff & De Bleser, 1994; Hillis & Caramazza, 1995; Riddoch & Humphreys, 1987). Moreover, functional neuroimaging studies of healthy participants show different patterns of brain activation between matched word and picture recognition tasks (Bright, Moss, & Tyler, 2004; Chee, Weekes, Lee, Soon, Schreiber, Hoon, & Chee, 2000; Gates & Yoon, 2005; Moore & Price, 1999; Reinholz & Pollmann, 2005). This supports the view that while the semantic knowledge systems underlying both word comprehension and object recognition may overlap, they are not identical. Binder et al. (2009) performed a meta-analysis of 120 functional neuroimaging studies that used word-based tasks (either written or spoken) to elicit semantic memory retrieval. They found evidence for a distinct semantic knowledge system for word comprehension comprised of seven neural regions: the posterior inferior parietal lobe, the middle temporal gyrus, the fusiform and parahippocampal gyri, the dorsomedial prefrontal cortex, the inferior frontal gyrus, the ventromedial prefrontal cortex, and the posterior cingulate gyrus.

Semantic memory impairments can profoundly affect a person's ability to function normally in daily life, including potential loss of ability to understand or communicate effectively with others. Semantic impairments are observed in neurological disorders such as semantic dementia (SD) and Alzheimer's disease (AD) (Henry, Crawford, & Phillips, 2004; Jefferies, Hoffman, Jones, & Ralph, 2008; Marczinski & Kertesz, 2006; Rogers & Friedman, 2008).

Two main theories have been proposed to explain the process of semantic impairment. The first is that they result from degradation of the semantic knowledge system itself (Rogers & Friedman, 2008). The second, proposed by Rogers and Friedman (2008), is that such impairments result from degradation in the ability to retrieve consciously words from the semantic knowledge system. They investigated these competing theories in patients with semantic dementia (SD) and Alzheimer's disease (AD), using a semantic fluency task to test explicit semantic processing, and a word-word lexical decision-priming task to test implicit semantic processing. They predicted that while both types of impairments would affect the semantic fluency task, only degraded semantic knowledge would affect the priming task. They found no significant difference between SD patients and AD patients on the semantic fluency task. However, SD patients demonstrated significantly worse performance than AD patients on the priming task. Thus, they concluded that the impairments observed in SD do indeed result from degraded semantic knowledge, while those observed in AD result from degraded retrieval and partially degraded semantic knowledge.

Semantic Memory and Sleep Deprivation

A number of studies have found that that sleep deprivation impairs semantic memory (Harrison & Horne, 1997; Harrison & Horne, 1998; Tilley, Horne, & Allison, 1985). Harrison and Horne (1997) investigated the impact of sleep deprivation on verbal fluency. They used a phonemic fluency task for word generation. After 36 hours of TSD, the number of words generated by subjects in response to letter prompts significantly declined. Additionally, subjects tended to perseverate within a semantic category and demonstrated less mental flexibility. Similar results were found earlier by them (1998), in which a version of a semantic fluency task was used. Subjects were given a noun prompt and instructed to generate as many verbs associated with that noun within 60 seconds. Compared to controls, subjects who underwent 36 hours of TSD generated significantly fewer words, had slower response latencies, and made more incorrect responses (i.e. unrelated or non-verb responses). Tilly et al. (1985) investigated the impact of sleep deprivation on a word-word category verification task. Subjects were presented with a category word (e.g. Fruit) followed by a test word (e.g. Apple) and had to decide whether the test word belonged to the given category. After one night without sleep, decision latencies were significantly slower. Furthermore, they were significantly slower in the morning than at midday, providing evidence for a circadian arousal rhythm.

In short, impaired lexical retrieval from semantic memory might be one feature of language decrement that occurs during sleep deprivation. However, because all studies to date have been conducted using either verbal fluency or category verification tasks, this confounds our understanding of the impact that sleep deprivation has on uniquely linguistic abilities. For example, although verbal fluency tasks are thought to measure lexical retrieval, there is evidence that they engage a variety of extralinguistic processes. Shao, Janse, Visser, and Meyer (2014) showed that both semantic and phonemic fluency tasks engage aspects of executive control such as updating and response inhibition. Therefore, they cannot be regarded as pure measures of lexical retrieval. Verbal fluency tasks are also affected by vocabulary size. Sauzéon, Raboutet, Rodrigues, Langevin, Schelstraete, Feyereisen, Hupet, and N'Kaoua (2011) found that subjects with smaller vocabularies tended to generate fewer words than those with larger vocabularies. Category verification tasks, on the other hand, have been shown to produce unreliable results (Cantor, Smith, French, & Mezzich, 1980; Kempton, 1978; McCloskey & Glucksberg, 1978). That is, a particular word may be categorized differently by different subjects or by the same subject at two different times.

In contrast, verbal short-term memory (STM) might provide a better framework to explore the relationship between sleep deprivation and impaired lexical retrieval. Verbal STM is supported by multiple levels of linguistic representations, including lexical and semantic representations. The research of Caza and Belleville (1999) shows that cognitively normal individuals have better immediate serial recall (ISR) for words over nonwords, thus confirming a lexical contribution to verbal STM. They also have better immediate serial recall for content words over function words, thus confirming a semantic contribution. Studies involving SD patients have demonstrated the efficacy of using ISR tasks to investigate semantic impairment in verbal STM (Jefferies, Jones, Bateman, & Ralph, 2004; Jefferies et al., 2008). Thus, ISR could potentially be relevant to the study of semantic impairments during sleep deprivation.

Literature Review

Caza and Belleville (1999) investigated the contributions of lexical and semantic levels of representations to verbal STM, by testing subjects on an ISR task involving three classes of words: content words, function words, and nonwords. Twelve females and nine males with a mean age of 21.67 years participated in this study. All three word classes were matched for number of syllables, phonemes, and letters. Content and function words were also matched for word frequency. A total of 24 pseudorandom lists of five-word sequences were generated. The order of presentation of the different word classes was balanced using a Latin Square design. All subjects underwent 24 trials of ISR. During each trial, the five-word sequence was presented visually at a rate of one word every 1500 milliseconds. Individual words remained on screen for 1250 milliseconds. At the end of the sequence, the subjects tried to recall the words in the order they were presented. Additionally, articulatory suppression of the test words was performed during word presentation and recall. This consisted of the subjects counting out loud repeatedly from one to eight between the presentation of the cue and the recall of the last word. The researchers found that both content and function words were better recalled than nonwords. Furthermore, content words were better recalled than function words. There was no effect of position in the Latin Square design. These results indicate that: (a) lexical representations contribute to the recall advantage of content and function words over nonwords; and (b) semantic representations contribute to the recall advantage of content words over function words. ISR is therefore a sensitive measure of semantic effects on verbal STM.

Covariates and Confounding Variables

The normal sleep/wake cycle is governed by endogenous circadian rhythms. Consequently, the effects of sleep deprivation can vary according to the time of day. *Circadian rhythms* are neurobiological and behavioral activity patterns that predictably follow an approximately 24-hour cycle (Bernard, Gonze, Cajavec, Herzel, & Kramer, 2007). They are controlled by the suprachiasmatic nucleus (SCN), which is a distinct group of nerve cells located in the hypothalamus (Bernard et al., 2007). The SCN responds to the external environment's natural light/dark cycle and produces signals that regulate the timing of hormone secretion, urine production, changes in blood pressure, changes in body temperature, and changes in arousal (Purves, Augustine, Fitzpatrick, Hall, LaMantia, & White, 2001; Wright, McHill, Birks, Griffin, Rusterholz, & Chinoy, 2013). Circadian arousal is lowest in the early morning and highest in the late afternoon (Dijk & Czeisler, 1994; Dijk & Edgar, 1999). As a result, both TSD and chronic PSD involve circadian variation in performance. For example, Tilley et al. (1985) found that time of day modulated the effects of TSD on a category verification task, whereby decision latencies were significantly slower at 08.00 hours than at 12.00 hours, indicating a circadian arousal pattern. Thus, it is necessary to adopt experimental procedures that disentangle the effects of sleep deprivation and circadian rhythms.

Present Study

While previous research has used immediate serial recall to examine semantic impairments, a literature search found no studies in the context of sleep deprivation or circadian rhythms. Furthermore, in contrast to the abundant literature focusing on the effects of total sleep deprivation, few studies have focused on the effects of chronic PSD (Durmer & Dinges, 2005). This research gap is significant given that in real-life situations, chronic PSD occurs far more frequently than TSD. The present study thus makes a unique contribution to the literature by investigating the effects of chronic PSD and circadian rhythms on semantic memory using immediate serial recall.

In order to test ISR, recall performance was compared across three word classes that differ according to their semantic representations: concrete content words, abstract content words, and function words. Concrete content words are open-class words that have direct sensory referents, such as objects, places, or living things (e.g., chair, street, cat). Their meanings are readily imageable and have the strongest semantic representations (Jefferies, Patterson, Jones, & Ralph, 2009). Abstract content words are open-class words that do not have direct sensory referents, such as ideas, qualities, or mental states (e.g., hope, beauty, love). Their meanings are less readily imageable and have weaker semantic representations (Jefferies et al., 2009). Function words are closed-class words that convey grammatical relationships, such as articles, prepositions, or conjunctions (e.g., the, for, and). Their meanings are not imageable at all and have the weakest semantic representations (Pulvermuller, 2002).

Cognitively normal individuals typically demonstrate a recall advantage for concrete words over abstract words (Walker & Hulme, 1999). This word concreteness effect has been shown to be exaggerated in semantic dementia (SD) patients; that is, they have significantly worse recall for abstract than concrete words (Hoffman, Jones, Ralph, 2013; Jefferies et al., 2009; Reilly & Peelle, 2008). Concrete words are considered as less impaired due to their stronger semantic representations, which facilitate their recall (Hoffman et. al., 2013). Accordingly, if the effects of sleep deprivation parallel those observed in SD, impairment should be more severe for words that have weaker rather than stronger semantic representations. Thus, we hypothesized that chronic PSD individuals, as compared to well-rested controls, would have: (a) lower recall for function words than abstract or concrete content words, and (b) lower recall for abstract than concrete content words. In addition, we hypothesized that there would be a circadian rhythms effect on immediate serial recall and general arousal measures. Both groups would perform worse during the lower circadian rhythm phase of the early morning session as compared to a 12-hour later session that was closer to the circadian arousal peak phase.

Chapter 2

Methods

Participants

Twenty-three Pennsylvania State University students (8 males, 15 females, mean age 19 years) from an introductory psychology course participated voluntarily in this study as partial fulfillment of their course requirements. A table of participant characteristics is included in the Appendix (Table 2). Participants who met the inclusion criteria for either the chronic PSD group or the well-rested control group were recruited directly by e-mail. For the chronic PSD group, 10 participants were selected who averaged 6.5 hours or less of sleep per night at least 3 times during Monday through Friday as part of their weekly routine. For the well-rested control group, 13 participants were selected who averaged at least 7 hours of sleep per night during Monday through Friday as part of their weekly routine. These inclusion criteria were selected based on previous studies that found significant performance decrements on various tasks at this level of chronic PSD (Dinges, Pack, Williams, Gillen, Powell, Ott, Aptowicz, Pack, 1997; Drake, Roehrs, Burduvali, Bonahoom, Rosekind, & Roth, 2001; Van Dongen, Maislin, Mullington, & Dinges, 2003). The participants were additionally screened for their daily rise and sleep times as well as for the frequency and duration of their daily napping. Upon successful completion of the study, the participants were granted two research participation credits that counted toward their psychology course. Informed consent was obtained from all of the participants, in compliance with the Pennsylvania State University Institutional Review Board for behavioral testing on human participants.

Design

This study utilized a quasi-experimental repeated measures design. Participants performed a series of computer tasks twice in one day: once in the morning within 1 hour of their wake-up time, and once 12 hours later in the evening. The between-group condition was sleep group (PSD vs. well-rested), and the within-group repeated condition was time of day (AM vs. PM). ANOVAS were used to evaluate the effects of sleep group and time of day on the dependent measures: rate of recall for concrete content words, abstract content words, and function words.

Materials

The following tasks were administered to the participants at time of testing in the laboratory: the Pittsburgh Sleep Diary, ISR Task, Psychomotor Vigilance Task, Mood Scale II, and Stanford Sleepiness Scale. The Pittsburgh Sleep Diary is a comprehensive self-report questionnaire of sleep and wake times that assesses sleep duration and sleep quality (Smith & Wegener, 2003). The ISR task consisted of five-word sequences of concrete content words, abstract content words, and function words presented visually to the participants that were to be recalled in serial order. Additionally, a distractor task required participants to count the number of seconds that had passed during the time the words were presented. The Psychomotor Vigilance task (PVT) is a response-time test that measures fatigue-related changes in alertness and attention performance (Basner & Dinges, 2011). The Mood Scale II is a subjective assessment of six mood dimensions – activation, happiness, depression, anger, fear, and fatigue – based on a Likert scale ranging from 1 (not at all) to 3 (mostly/generally) (Paterson, Dorrian, Furguson, Jay, & Dawson., 2013). The Stanford Sleepiness Scale (SSS) is a subjective assessment of sleepiness based on a Likert scale ranging from 1 (being very active and wide awake) to 7 (struggling to stay awake) (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973).

Immediate Serial Recall Task

The words for this task were first selected from a corpus of the 60,000 most frequent words in American English (Davies, 2012). Forty concrete content words, forty abstract content words, and forty function words that were all monosyllabic were selected. One-hundred-twenty pseudorandom lists of five-word sequences were then generated by an SPSS computer program. The order of presentation of the three word classes was balanced according to the following six sequences (C = concrete content word; A = abstract content word; F = function word): C-C-A-F-F; C-C-F-A-A; A-A-F-C-C; A-A-C-F-F; F-F-C-A-A; F-F-A-C-C. The five-word sequences were then transferred to the E-Prime software program and were presented visually at a rate of one word every 1500 milliseconds. Individual words remained on screen for 1250 milliseconds, with an inter-stimulus interval of 250 milliseconds. At the end of each five-word sequence, the participants were instructed to recall the words in the order that they were presented. A secondary time production task was used while the word sequences were presented. The participants were instructed to count silently from the beginning of each trial, when a red ‘X’ appeared, until the end of the trial, when a green ‘X’ appeared. The participants were then instructed to type on a computer keyboard the number of seconds they had counted. The purpose of this secondary task was to prevent rehearsal. Participants underwent a total of 25 trials of ISR.

Procedure

The two separate test sessions occurred in the morning within 60 minutes of the participants' habitual wake time and in the evening 12 hours after Session 1 began. During test Session 1, participants reported to the Human Performance Rhythms Laboratory. They were escorted to assigned computers. After all participant questions were answered, consent forms were signed. The participants were allowed unlimited time to read and sign the written consent forms. One signed copy of the consent forms was given to the participants, and another was kept for lab records. At the beginning of each testing session, the participants completed the appropriate part of the Pittsburgh Sleep Diary. Then, the four computer tasks were administered in the following order. First were the 25 trials of the five-word sequence ISR task, followed by the Psychomotor Vigilance task across 100 total trials. Then, participants rated their mood, ending with their sleepiness rating. Then, participants were given reminder slips of their time to return for Session 2, and were free to leave the laboratory. Except for the informed consent signing, Session 2 was conducted identically 12 hours later from the beginning of the first session. Upon completion of Session 2, the participants were debriefed and were given answers to any remaining questions. The total duration of both test sessions (Session 1 and Session 2) was less than 2 hours, apportioned approximately as follows: Pittsburgh Sleep Diary (< 5 minutes) + ISR task (20 minutes) + Psychomotor Vigilance Task (10 minutes) + Mood Scale (3 minutes) + Stanford Sleepiness Scale (1 minute).

Analysis

The data were transferred from the E-Prime files into SPSS, and were analyzed using a linear mixed model (ANOVA) to accommodate for missing data from a single session. ANOVA was conducted to evaluate the effects of sleep group (PSD vs. well-rested) and time of day (AM vs. PM) on rate of recall by collapsing across all word types. Then the effect of word class (concrete content words, abstract content words, and function words) was added to the model. Post-hoc analyses were performed to determine specific effects revealed by the ANOVA analyses. Means (M) and standard deviations (SD) or standard errors (SE) are reported. Following analysis of the participants' Pittsburgh Sleep Diary responses to verify hours of sleep and sleep schedule at the time of testing, one participant was switched from the PSD group to the control group, while another was switched from control to PSD. Initial screening had been done two months earlier, with subsequent changes in their sleep regimen, but not of their chronotype.

Chapter 3

Results

Mean Number and Proportion Correct

Tables of means and standard deviations, as well as ANOVA tables for analyses, are included in the Appendix and discussed below. Figure 1 illustrates the mean (± SE) number of words correctly recalled across both groups at each different test session. An ANOVA performance comparison revealed a significant effect of time of day (p=0.0010) upon the mean of total number correct. Morning Session 1 had an overall lower mean number correct (M=3.21, SD=0.89) compared with the evening Session 2 (M=3.52, SD=0.91), regardless of sleep group or word class.

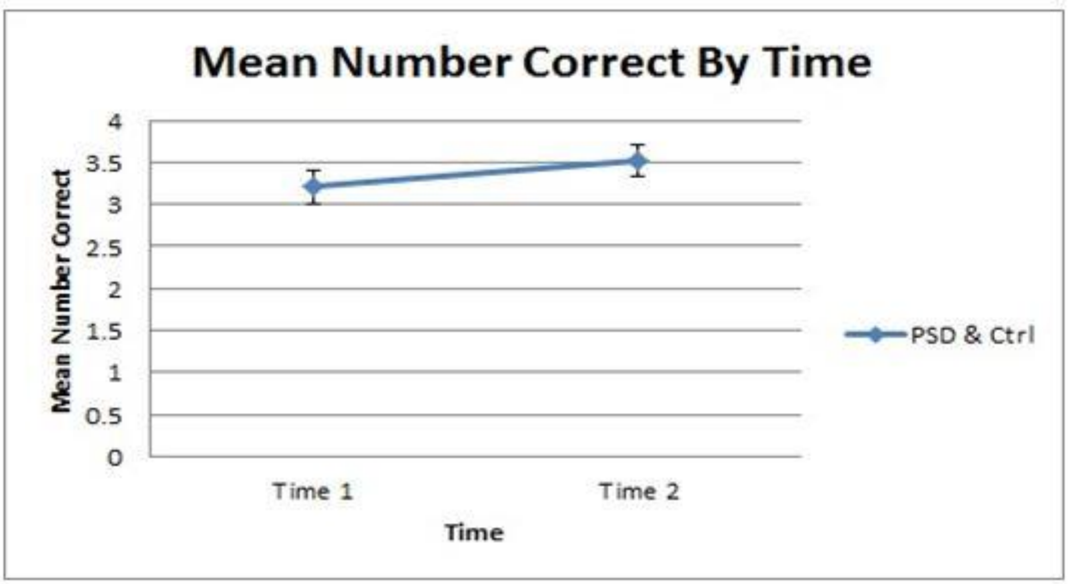

Figure 1. The effect of time on mean number correct on ISR Task across both Groups

Figure 2 illustrates the mean proportion of words correctly recalled (±SE) by the PSD and control groups for each specific word class. An ANOVA performance comparison revealed a significant effect of group x word class (p=0.0354) on the mean proportion correct. Although the well-rested control group had similar mean proportion correct for all word classes (p=0.343), proportion correct for the PSD group varied by word class (p=0.025). Specifically, the chronic PSD group demonstrated a significantly lower mean proportion correct for function words (M=0.61, SD=0.23) than for either concrete content words (M=0.68, SD=0.18; p= 0.009) or abstract content words (M=0.67, SD=0.15; p=0.025). The PSD group showed no difference between mean proportion correct for abstract content words and concrete content words (p=0.814). Furthermore, a marginally significant difference (p=0.059) in mean proportion correct for function words was found between the PSD group (M=0.61) and the well-rested group (M=0.73). No other significant effects were found.

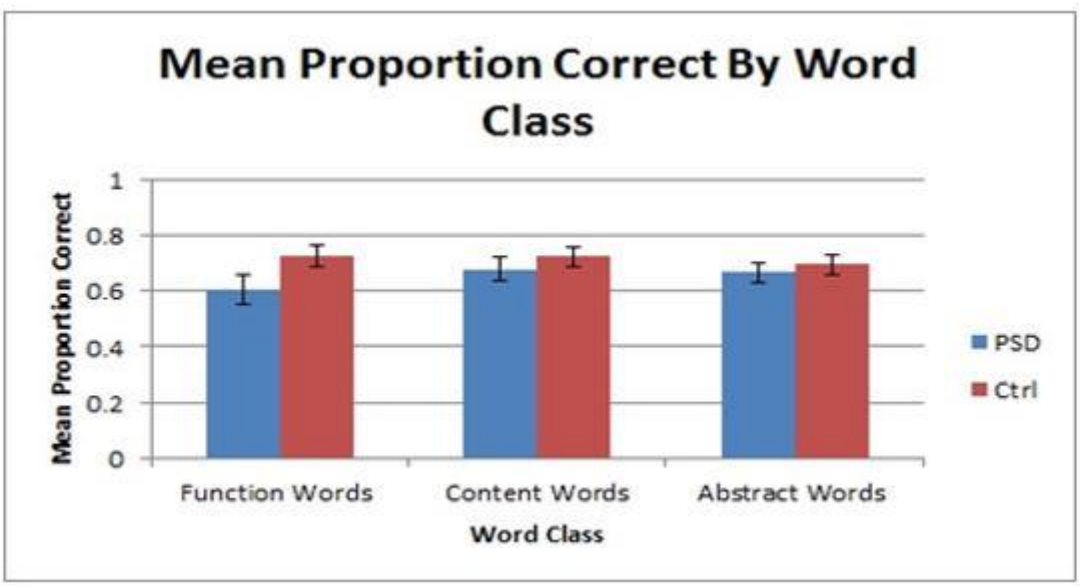

Figure 2. The effect of word class on proportion correct on ISR Task for either Group

General Arousal

Table 1 illustrates the mean scores on the Mood Subscales, SSS and PVT. An ANOVA comparison revealed a significant effect of time of day on the fatigue subscale (p=0.0022), SSS (p=0.0021), PVT scores (p<0.0001), and a marginally significant effect on activation (p=0.0948). Overall, Session 1 mean scores were lower as compared with Session 2. Additionally, there was a significant effect of sleep group on the fatigue subscale (p=0.0172), with the PSD mean fatigue scores lower across both test sessions as compared to well-rested participants.

Table 1. The recorded mean values of the different general arousal measurements

Group	**Activation**	**Fatigue**	**SSS**	**PVT**
PSD-1	1.48±0.55	2.26±0.61	4.90±0.67	3.53±0.31
Ctrl-1	1.78±0.63	1.74±0.38	4.15±1.14	3.53±0.24
PSD-2	1.85±0.69	1.70±0.49	2.90±0.31	3.67±0.40
Ctrl-2	1.91±0.47	1.45±0.37	3.23±1.54	3.80±0.25

Chapter 4

Discussion

The effect of sleep deprivation on language is a contentious issue, as was earlier mentioned. Some argue that it has little to no effect, while others argue that it affects a wide range of language skills. We tested participants on an ISR task involving three word classes that differed according to their semantic representations: concrete content words, abstract content words, and function words.

As hypothesized, we found that both sleep groups tended to recall fewer words on the ISR task during test Session 1 as compared with test Session 2. This is consistent with previous research on time of day effects and semantic memory (Tilley & Warren, 1984; Tilley et al., 1985). The lower recall during Session 1 can be explained by the lower level of circadian arousal in the morning. Conversely, the significant improvement in recall during Session 2 can be explained by the higher level of circadian arousal in the evening. Also, as hypothesized, we found that the PSD group had significantly worse recall on function words than on either type of content word. This was not the case for the well-rested group. The latter finding differs from those of Caza and Belleville (1999), who found that cognitively normal participants had a recall advantage for content over function words. A crucial difference between our experiment and Caza and Belleville's is that they did not screen participants for their sleep-wake behavior. This raises the question whether some of their participants were sleep deprived, which might have led to worse recall of function words than would be expected by well-rested participants. Our finding that the PSD group showed the greatest impairment on function words could be explained by the fact that content words, unlike function words, have sensory referents. Therefore, visual/sensory information might help contribute to semantic knowledge of content words, resulting in stronger semantic representations (Jefferies et al., 2009). In contrast, semantic knowledge of function words is much more heavily dependent on purely verbal information (Jefferies et al., 2009). Thus, greater impairment of function words due to chronic PSD might arise because of their relatively weaker semantic representations compared to concrete or abstract content words. Conversely, both types of content words might be spared because of their relatively stronger semantic representations. Lastly, as hypothesized, we found that both sleep groups were more impaired on vigilance (PVT) and general arousal (fatigue, activation, and SSS) during test Session 1 as compared with test Session 2, indicating a clear circadian rhythms effect. This is consistent with previous research on fatigue, alertness, and performance measures (Blatter & Cajochen, 2007; Dongen & Dinges, 2010; Valdez & Garcia, 2012; Van Dongen & Dinges, 2010). Furthermore, the fact that we did not find a significant 3-way interaction (group x task x time) or a significant 2-way interaction of group x time indicates that the impairment from sleep deprivation remained similar during both test sessions (i.e., it was not worse in the AM for the PSD group). This suggests that impairment in vigilance and general arousal were likely not the primary reasons that the PSD group performed worse than the well-rested group on word recall. Thus, it provides further evidence of a uniquely semantic impairment.

In conclusion, the most important contributions of this study are to demonstrate that chronic PSD gives rise to impaired semantic memory; and, furthermore, that immediate serial recall (ISR) is sensitive to this impairment. Our goal was to determine whether there are certain types of words that are more susceptible to semantic impairment as a result of chronic

PSD. That significantly lower recall of function words by the PSD group occurred on the ISR task indicates that these words are particularly susceptible to the effects of chronic PSD. Taken altogether, the results of this study might have helpful implications for the health and safety of individuals suffering from the growing phenomenon of chronic PSD. The knowledge that function words are particularly impaired due to chronic PSD, along with the knowledge that such impairment is detectable by means of immediate serial recall, could potentially provide the basis for screening tests in the workplace, thereby preventing error-related accidents that are associated with chronic PSD.

Limitations

This study had a number of limitations, which are noted. First, the order of presentation of the different word classes was not completely balanced. Therefore, the participants were not presented with an equal number of each word class. This prevented us from analyzing potential primacy and recency serial position effects. A primacy effect occurs when better recall is for earlier words in a word list, while the recency recall effect is for later words. Past studies have shown mixed results regarding serial position effects on immediate serial recall. Second, our sample size and composition were rather limited, with only 10 sleep-deprived and 13 well-rested individuals, all drawn from a restricted age cohort of 18-21 years. There was also skewed gender distribution, with the chronic PSD group 75 % male and the well-rested group 73.3 % female. Third, categorization of the participants as chronic PSD or well-rested relied on self-report measures, as well as the expectation of no significant changes in sleep-wake behavior prior to testing. Considerable variability occurred in the actual sleep-wake patterns of the participants. Last, the improved performance by both groups during test Session 2 could alternatively be accounted for by a practice effect, as well as the greater circadian arousal. Research suggests that participants tend to perform initial trials of a task poorly, because the task is novel to them, then, later perform better with greater familiarity (Heiman, 2002). If this was the case here, then it might reduce the effect of circadian rhythms. This also could be controlled for by counterbalancing the sessions, running half the participants for their first time during the evening session, followed by their second session the following morning. All of these factors limited the generalizability of the results.

Further Studies

Given the limited nature of our results, future studies will be needed to strengthen our hypotheses. They should utilize a larger, more representative sample size, with a wider age range and a more equal gender distribution between groups. A stricter accounting of the participants' sleep-wake behavior will also be needed to minimize the confounding effect of variable sleep quality and duration. For the ISR task, the order of word class presentation should be balanced using a Latin Square design, to ensure an equal number of each word class presentations. This will allow for the analysis of potential serial position effects. Future research in this area is warranted because, as the prevalence of chronic PSD continues to increase, it is imperative that researchers and public health officials understand its effects on language skills and general arousal. Such understanding might have the potential to reduce human-error related disasters that arise from chronic PSD.

Appendix

Tables

Table 2. General Demographics and Characteristics of Participants

Sleep Duration* Group	Size	Mean	SD	Range	SE	
PSD	10	6.55	0.841	5.0-7.6	0.266	**$t_{(21)}$=5.98**
Control	13	8.67	0.845	7.75-10.5	0.234	**p=.000**

Age	Size	Mean Years	SD	Range	SE	
PSD	10	19.00	1.054	18-21	0.333	**$t_{(21)}$=0.16**
Control	13	19.08	1.188	18-21	0.329	**p=.836**

Gender

	Male	Female	Male Proportion	Female Proportion	
PSD	6	4	0.400	0.600	**$\chi_{(1)}$=4.96**
Control	2	11	0.154	0.846	**p=.026**

* Note: Sleep duration calculations were based on hours of sleep during the week of testing. Although some PSD subjects had $\geq$ 6.5 h sleep that week, overall semester weekly averages were $\leq$ 6.5 h.

Table 3. Number Correct on ISR Task at Time 1 and Time 2 by either Group

Group	Words Correctly Recalled	
	M	**SD**
PSD-1	3.12	0.94
Control-1	3.27	0.886
PSD-2	3.23	0.97
Control-2	3.73	0.0.831

Table 4. Number Correct on ISR Task at Time 1 and Time 2 by both Groups

Group	Words Correctly Recalled	
	M	**SD**
Both PSD and Control-1	3.21	0.889
Both PSD and Control-2	3.52	0.913

Table 5. Proportion Correct on ISR Task at Time 1 and Time 2 by either Group

Group	Function Words		Concrete Content Words		Abstract Content Words	
	M	**SD**	**M**	**SD**	**M**	**SD**
PSD-1	0.547	0.239	0.676	0.174	0.651	0.161
Control-1	0.672	0.197	0.672	0.166	0.650	0.191
PSD-2	0.656	0.222	0.678	0.201	0.681	0.141
Control-2	0.777	0.166	0.7706	0.165	0.735	0.165

Table 6. Total Proportion Correct on ISR Task by either Group

Group	Function Words		Concrete Content Words		Abstract Content Words	
	M	**SD**	**M**	**SD**	**M**	**SD**
PSD	0.607	0.230	0.677	0.184	0.668	0.146
Control	0.726	0.185	0.723	0.169	0.694	0.179

Table 7. ANOVA of Proportion Correct on ISR Task

Effect	**Num DF**	**Den DF**	**F-value**	**Pr>F**
Group	1	21	1.46	0.2411
Task	2	42	1.97	0.1525
Group * Task	2	42	3.62	0.0354
Time	1	18	3.81	0.0666
Group * Time	1	18	0.25	0.6214
Task * Time	2	36	2.40	0.1047
Group * Task * Time	2	36	1.96	0.1555

Table 8. ANOVA of General Arousal Measurements

Effect	Num DF	Den DF	F Value	PR > F
PVT				
Group	1	21	0.90	0.352
Time	1	21	30.3	<0.0001
Group* Time	1	21	0.09	0.7735
Activation				
Group	1	21	0.79	0.3821
Time	1	21	3.06	0.0948
Group * Time	1	21	0.71	0.4087
Fatigue				
Group	1	21	6.69	0.0172
Time	1	21	12.19	0.0022
Group*Time	1	21	1.20	0.2852
SSS				
Group	1	21	0.20	0.6628
Time	1	21	12.21	0.0021
Group*Time	1	21	1.66	0.2116

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