

THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

DEPARTMENT OF PSYCHOLOGY

THE EFFECTS OF CHRONIC SLEEP DEPRIVATION AND CIRCADIAN RHYTHM ON
CHANGE BLINDNESS AND GENERAL AROUSAL

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Spring 2015

A thesis
submitted in partial fulfillment
of the requirements
for a baccalaureate degree in Biology
with honors in Psychology

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ABSTRACT

Sleep deprivation continues to grow as a common problem across the country as people report often going extended periods of time without adequate sleep quality, or in some cases, none at all (Connor et al, 2002). Acute or *total sleep deprivation* (SD) is defined as “being awake for an extended of time” whereas *chronic partial sleep deprivation* (PSD) is defined as “extended reduction in sleep quality or duration”. Chronic PSD is more representative of the American population because individuals often report sacrificing an hour or two of sleep for some work or social related activity (Hershner & Chervin, 2014). *Change blindness* is defined as the inability to detect changes in details in a visual display or photograph (Rensink, 2001). This is common in our daily lives as our visual fields are often overloaded with a variety of stimuli. Related to this, the effects of SD and PSD can be highly variable, especially depending on the time of day and an individual’s circadian rhythm. Because of this, circadian rhythms can alter the effects of both acute and chronic PSD. There is no significant previous research that studies the interacting effect of sleep deprivation and its effects on change blindness. This present study focused on studying the effects of chronic PSD and specific circadian rhythm phase on change blindness and general arousal measurements. This study demonstrated significant performance differences on a visual attention task and general arousal measurements averaged across PSD and rested groups at day times 12 hours apart. These findings suggest that there are significant effects of chronic PSD similar those of total acute sleep deprivation. Also, there is a circadian rhythm effect on alertness and peak performance at different times of the day. Future research should focus on gathering a more representative sample and establishing strict guidelines and protocol for tracking the participant’s self-reported measures of sleep duration.

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ACKNOWLEDGEMENTS

I would like to first thank Dr. Frederick Brown for his support and advisement as my thesis supervisor for the past year and half. Throughout my tenure as a research assistant in his human performance rhythms lab, he has supported me in all my academic endeavors and assisted with my growth as a research professional. I have the highest respect for the dedication Dr. Brown has to his field, research and most importantly, his students.

I would also like to thank Dr. Cynthia LaJambe for her support and assistance in designing the experiment and analysis of the results. She provided me invaluable knowledge about statistics and various computer programs that were utilized to generate the results. She also helped me hone my research methods and designed the laboratory protocols necessary to successfully conduct the experiment.

Additionally, I would like to thank Dr. Jeffrey Love for his guidance as my honors advisor, for reviewing the entirety of my project and for providing invaluable advice and feedback.

Next, I would like to thank my fellow research laboratory assistants who provided me with support and guidance throughout my project. In particular, I would like to thank Jerry Bellettirie, who assisted with the development of the Eprime program and extraction of the results. His assistance was an integral part in the successful collection and analysis of the results.

Finally, I would like to thank my parents for their relentless support, emotionally, morally and fiscally, throughout my life. Their guidance has allowed me to accomplish everything in my life and become who I am today.

Chapter 1

Introduction

Sleep Deprivation

Sleep deprivation continues to grow as a common problem across the country as people report often going extended periods of time without adequate sleep quality, or in some cases, none at all (Connor et al, 2002). Acute or *total sleep deprivation* (SD) is defined as “being awake for an extended of time” whereas *chronic partial sleep deprivation* (PSD) is defined as “extended *reduction* in sleep quality or duration”. Chronic PSD is a growing problem in the United States, where insufficient sleep on a daily basis is reported by about 53% of adults in the U.S. (National Sleep Foundation 2013 International Bedroom Poll) and more than 70% of college student (Hershner & Chervin, 2014). One of the biggest problems associated with insufficient sleep is that people often don’t realize they are experiencing chronic sleep PSD and the associated deleterious effects.

People mistakenly believe that after sleeping for a sub-optimal duration of time for an extended period, their bodies will adapt to it. However, in a study of chronic PSD for 12 days conducted by Van Dongen, Maislin, Mullington & Dinges (2003), they found that impairment in visual reaction time, using a psychomotor vigilance task, and, in cognitive processing, using a symbol substitution, was very similar to that of a total SD group after 2 nights. This strongly demonstrates that while a couple of nights of sub-optimal sleep duration

may not necessarily be harmful, this continued PSD for a significant period of time can have small, yet additive effects that are significant (Van Dongen et. al, 2003).

One of the largest impacts of PSD on the body are neurocognitive effects: these include fatigue, reduced response time, impaired learning of cognitive tasks, errors with attention-intensive performance tasks, and several other broad cognitive performance effects (Durmer & Dinges, 2005). As anticipated, PSD groups in comparison to control groups, have demonstrated decreased performance on the Psychomotor Vigilance Test (PVT). The PVT is a test of alertness and response time that tracks the response time between different trials of being able to respond to a change to a stimuli. This performance measure has demonstrated that chronic PSD individuals perform worse on measures of reaction speed and attention on particular tasks (Dinges & Powell, 1985). Further, there has been a demonstrated decline in cognitive performance when “time on task” is increased; this demonstrates another sort of “fatigue” effect that is magnified by sleep deprivation (Kribbs & Dinges, 1994). That is, with “time on task”, while the performance may begin well, there is a notable deterioration over time as the task duration increases. Another significant effect of PSD is a growing neglect of activities deemed to be insignificant as individuals have demonstrated a systematic loss of situational awareness (Durmes & Dinges, 2005). This can have profound impacts in professions that require careful attention to detail, such as truck driving, medical professionals, and flight pilots. Chronic PSD as a whole, can have wide-ranging effects that are highly dependent on the specific individual, task and situation.

Change Blindness

Change blindness is defined as the inability to detect changes in details in a visual display or photograph (Rensink, 2001). The key differentiating characteristic of change blindness from other forms of visual inattention is that it commonly refers to rather large changes in natural scenes, such as a local stop light or park. This presents the argument that there is a limitation to human visual attention capacity and the ability to process changes in detail (Simons & Levin, 1998). In a practical scenario, this can have profound impacts if people are overestimating their ability to detect changes in daily activities, such as while driving or performing other delicate tasks. They might not be able to detect a pedestrian crossing the street or a change in the mechanisms of machinery they use daily, leading to profound consequences. In a study conducted by Simons and Levin (1998), they were able to demonstrate that a majority of people were unable to identify a difference in a scene that involved a pedestrian swap occurring subtly in front of them. As the pedestrians were talking to surrogates, a large distraction was walked between them and the surrogates swapped positions behind this large distraction. A majority failed to pick up on this surrogate swap and continued the conversation.

There are five main steps of being able to detect a change: 1) attention to the change location, 2) Encoding the original target location, 3) Encoding the target location after the change, 4) Comparisons of the two target locations and, 5) Consciously recognize the difference. A failure at any step can produce change blindness, demonstrating the sensitivity surrounding change blindness and its associated processes (Jensen, Yao, Street & Simons, 2011). There are three broad mechanisms that have been hypothesized to explain the process of change blindness. The first hypothesis, memory access problems, argues that the post-change stimulus (or visual field) can sometimes either overtake or interfere with access to the memory of the prechange

stimulus (Rensink et. al, 1997). This prevents an internal comparison between the two stimuli. The second hypothesis, lack of memory encodings, represents a similar argument, except that it assumes that the prechange stimulus was never encoded for by the brain. This argues that the brain does not store all visual stimuli; but rather, we are able to access this information from the external world as needed. Because of this, there is no basis for comparison between pre-change and post-change visual stimuli and, consequently, change blindness occurs (O'Regan, 1992). The third mechanism, non-comparisons, hypothesizes that while individuals may encode for both pre- and post- change stimuli, no internal active comparison occurs. That is, this is a comparison failure and not a representation failure (Hollingworth, 2003). In a study conducted by Angelone, Levein & Simons (2003), participants attempted to detect a change in experimental stimuli. Afterwards they were forced to choose between two objects and select which one had been displayed; they scored significantly higher than chance, demonstrating that while they were able to recognize the photos that were presented, they did not necessarily make the internal comparison between the two. This supports this comparison failure hypothesis because it demonstrates that the individuals were able to identify what they had seen, but were not actively making the internal comparisons necessary to prevent change blindness.

Change blindness is likely to occur more in certain situations and tasks than others. A situation filled with details and richness can affect the detection of the certain change in visual stimuli (Rensink et. al, 1997). The greater situational detail present, the greater chance of change blindness occurring, especially in specific area of lesser detail. Objects that are perceived of greater importance in a situation, such as stoplights while driving, will be detected faster and with a higher accuracy than objects of less importance. Consequently, in real-life scenarios, there is often an excess of details and distractions, which makes it more likely for change-blindness to

occur (Jensen et. al, 2011). As a result, change-blindness is a significant problem that people are likely to experience on a daily basis, without being aware of it.

Change Blindness and Sleep Deprivation

Because of the diverse and wide-ranging impacts of PSD on cognitive processes, there could be a connection between it and the occurrence of change blindness. The neurocognitive effects, particularly the ones that relate to attention on a task, alertness, and learning ability, could be significant factors in occurrence of change blindness in real-life situations (Durmer & Dinges, 2005). With the delicacy of some tasks we perform on a daily basis, such as driving, a subtle change in our cognitive processing could have widespread consequences leading to accidents and injuries. Decreased performance on attention-intensive tasks, which most people participate in daily, either at work or school, could increase the likelihood of change blindness occurrence. Not being able to focus and maintain attention can result in a poor mental representation of the details within our visual field, possibly leading to change blindness. Additionally, sleep deprivation-induced reduction in response time often demonstrates a decline in alertness, another factor that can contribute to change blindness. Being less alert can lead to constructing a poor mental representation of the visual field, as well as an inaccurate comparison of the two stimuli being presented, if that is what occurs. Lastly, with an overall decline in task performance over our daytime activity, this could induce change blindness in the latter half of tasks we perform on a daily basis, such as the end of a long drive or flight, or medical procedure. Regardless of the task, the neurocognitive effects of PSD could magnify the prevalence and extent of change blindness.

Literature Review

In a recent study conducted by Ball (2013), the researchers focused on inducing change blindness in photos they had manipulated to represent a color, position, or deletion change. The study consisted of five men and five women with a mean age of 26.9 years. The images were collected from natural scenes and manipulated using GIMP software. The images were presented in a trial that consisted of a cycle of the original image (600 ms), a blank screen (400ms), an altered image (600 ms), and a blank screen (400ms). The participants were given up to 60 trials before they had to choose where in the photo they thought the change occurred. The results indicated that each participant required between eight and 14 presentations of the image cycle to detect accurately where the change had occurred, indicating that the experimenters were able to induce change blindness through the photo manipulation (Ball et. al, 2013). They also found a main effect of the change type with color changes requiring the most presentations, followed by deletion and then position requiring the least amount of presentations. Additionally, response time significantly decreased with increasing size of the change. These data demonstrated that change blindness is indeed prevalent in natural scenarios and that there is a limited capacity of visual storage and representation in the human cognitive processes (Ball et. al, 2013). While the researchers were unable to propose a specific mechanism for the change blindness, they did hypothesize this probably results from a combination of a failure in visual representation memory of the stimuli and a failure in the comparison of the two stimuli.

Covariates and Confounding Variables

The effects of sleep deprivation can be highly variable, especially depending on the time of day and an individual's circadian rhythm. Circadian rhythms are physical, mental and behavioral activities that follow a near-24-hour cycle, controlled mainly by light and darkness periods in the environment. These circadian rhythms are controlled by a set of cells in the sub-cortical forebrain called the *suprachiasmatic nucleus*, which is a cluster of nerve cells used to regulate the timing all of the body's internal systems, including general arousal and fatigue. Naturally, our bodies are programmed to be more active in the late afternoon and less active during the early morning (Cassone, 2014). Because of this, circadian rhythms can alter the effects of both acute and PSD. Attention and alertness generally follow a circadian pattern, which has an interacting effect with sleep deprivation (Challet, 2008). The PVT is particularly sensitive to sleep loss and is inversely affected by the circadian pattern of activation and fatigue (Basner & Dinges, 2011). Due to these interacting effects, it can be difficult to separate the effects of sleep deprivation and natural circadian rhythms.

Present Study

While there is an abundance of studies on the effects of acute total sleep deprivation, there is limited literature on chronic PSD. Because of the greater prevalence of chronic PSD in the American population, it is imperative to study its effects in greater detail. Related to this, while many studies focus on change blindness, very few study it in sleep deprived individuals, and how circadian rhythms might be involved. Research in this area could be beneficial because PSD is wide-spread in the population, and people often fail to comprehend the serious

consequences associated with this, where change blindness can cause significant accidents and injuries.

This present study focused on the effects of chronic PSD and circadian patterns on the prevalence of change blindness, and general arousal measures. We hypothesized that the sleep deprived subjects would experience a greater degree of change blindness and experience lower general arousal measures in comparison to the rested persons. Additionally, we hypothesized that there would be a circadian rhythm effect on change blindness and general arousal measures. Both groups would perform better in a 12-hour later session that is closer to the circadian rhythm performance peak, in comparison to the morning session. A secondary hypothesis we also focused on was the effects of task on proportion correct and speed on the visual attention task.

Chapter 2

Methods

Participants

Pennsylvania State University students in an introductory psychology course voluntarily participated in this study as partial fulfillment of their course requirements. Participants who met the requirements of either being chronically PSD or non-sleep deprived were contacted directly through e-mail, and were explained the conditions and goals of the current research. The chronic PSD participant was characterized as averaging no more than 6.5 hours of sleep per night at least 3 times during Monday through Friday. The non-sleep deprived students were characterized as averaging at least 7 hours of sleep per night during Monday through Friday. This characterization of PSD was chosen because previous research demonstrated noticeable cognitive changes associated with this level of chronic partial sleep loss (Durmer & Dinges, 2008). Participants were also screened based on their daily rise and sleep times and how long and often they napped during the day. Participation who successfully completed the experiment were awarded two research participation credits for their Psych 100 course. All participants provided informed consent, approved by the Pennsylvania State University Institutional Review Board, for the behavioral testing of human participants.

Design

This study was a quasi-experimental repeated measures design, where subjects were grouped as sleep-deprived or well-rested, depending upon their self-determined habitual sleep-wake schedules. Subjects performed computer tasks twice in one day, once in the morning and once 12 hours later in the evening. The between-group condition is sleep group (PSD vs. non-sleep-deprived), and the within-subject repeated condition was time of day (AM and PM).

Materials

Participants completed the Pittsburgh Sleep Diary, Visual Attention Task, Psychomotor Vigilance Task, Mood Scale II, and Stanford Sleepiness Scale. The Pittsburgh Sleep Diary (Monk, et al., 1994) is a one-page self-report of bedtimes and wake times to verify sleep duration, sleep quality and daytime activities. The Visual Attention Task consists of local driving scenes that present two nearly identical photos. However, one has a single small change located in a certain quadrant of the picture that the subjects are told to identify in a fixed amount of time. The Psychomotor Vigilance Task (Dinges & Powell 1985) was a simple reaction-time task that measures response time in milliseconds. The Mood Scale II (Thorne, et al., 1985) is a three point scale that consists of different adjectives that describe anger, happiness, fear, depression, activity and fatigue. The Stanford Sleepiness Scale (Hoddes et al., 1973) is a task in which subjects select one of seven statements that describes their present state of alertness, ranging from a rating of one- being very active and wide awake, to a rating of seven- struggling to stay awake.

Visual Attention Task

The pictures for the task were first collected by photographing different driving scenes. Forty photos were selected in order to display 10 color changes, 10 position changes, 10 deletion changes, and 10 no-changes images. Each change picture was then altered in only one detail by using the image software, GNU Image Manipulation Software (GIMP 2014). Each photo was cropped to optimal dimensions for the Eprime computer software that was used to project the images on a screen. Each change image was altered with either a color change of picture detail, a detail deletion, or a position detail change of an object in a certain quadrant. The pictures were then inputted into the Eprime software program to project each image, both altered and unchanged, for a fixed period of 600 milliseconds 10 times. A blank screen was presented for 400 milliseconds between the altered and unchanged pictures. After 10 trials of each sequence, a response slide appeared with the original photo split into quadrants. Subjects selected one of the four quadrants for detecting a change, 1-4, or no change (0). The program was split into two different sets of 20 photos that continued until each photo was responded to.

Procedure

The experiment was divided into two test sessions, Session 1 was in the morning, within 90 minutes of each participant's habitual awakening time and Session 2 was 12 hours after Session 1. Session 1 began with unlimited time for the subjects to read and review the written informed consent form. One signed copy was given to the participants and another was kept for lab records.

Data collection proceeded in the following order. First, the participants were required to complete one section of the Pittsburgh Sleep Diary before proceeding to any of the computerized tasks. Then, the participants completed the Visual Attention Task Part 1 and Part 2. Each participant was randomly assigned an order of sequences of the photos to be displayed. Following this, the participants were required to complete the Psychomotor Vigilance Task (Dinges & Powell 1985) for a total of 100 trials. The subjects then completed the Mood Scale II (Thorne, et al., 1985) and Stanford Sleepiness Scale (Hoddes et al., 1973). Following completion of the first session, the subjects were given a reminder slip to return for Session 2 12 hours later, and were free to leave. Session 2 had an identical procedure to Session 1. Following completion of Session 2, the subjects were then debriefed and any questions regarding the study were answered. The total time for both sessions was just under two hours. The specific breakdown of the time was as follows: Pittsburgh Sleep Diary (< 5 minutes) + Visual Attention task (20 minutes) + Psychomotor Vigilance Task (10 minutes) + Mood Scale (3 minutes) + Stanford Sleepiness Scale (1 minute).

Analysis Methods

The data analysis started with the extraction of the raw data from the Eprime software into SPSS. The results were analyzed using a mixed model in SAS to accommodate for missing session data and run through the PROC GLIMMIX program using a doubly repeated method. Post-hoc analyses were utilized to determine specific effects revealed by the ANOVA analyses. One subject was switched from the PSD group to the control group while one subject was switched from control to PSD, based on post-screening self-reported behavior on the Pittsburgh

Sleep Diary. Even though there were proportional data, the values 0.3 to 0.7 allowed for no transformation of the raw data to be needed. The speed was calculated by transforming the inverse of the recorded response time on the visual attention task and PVT.

Chapter 3

Results

Ten PSD subjects and 13 rested subjects participated. A table of subject characteristics is include in the Appendix (Table 2), along with tables of means and standard deviations, and ANOVA tables for analyses discussed below. An ANOVA performance comparison revealed a significant effect of task on proportion correct on the visual attention task ($p < 0.001$). Post hoc analyses indicated that the proportion correct was significantly different among all tasks ($p < .01$).

Figure 1 illustrates the recorded proportion correct by both groups for all subjects on each specific task change. Color task changes demonstrated the lowest proportion correct ($M = 0.553$), followed by position task changes ($M = 0.784$) then deletion task changes ($M = 0.853$) and none task changes had the highest proportion correct ($M = 0.949$). Mean proportion correct for the PSD group ($M = 0.757$) tended to be lower across all conditions than the rested group ($M = 0.805$) although this effect showed only a trend towards significance ($p = 0.0822$)

Proportion Correct

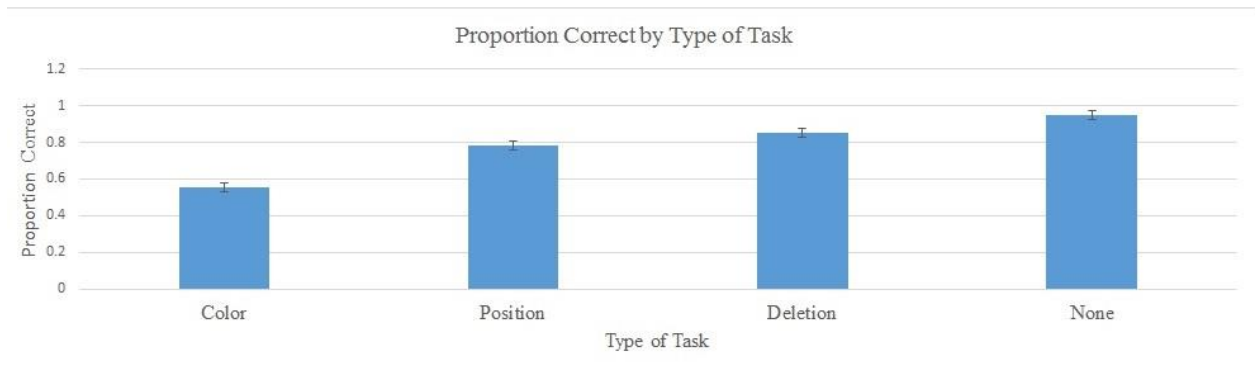


Figure 1. *The effect of type of task on overall proportion correct on the visual attention task across both groups.*

An ANOVA performance comparison revealed a significant effect of time on proportion correct on the visual attention task ($p=0.0043$). Figure 2 illustrates the recorded proportion correct on the visual attention task across both groups at each different time session. Time 1 session had an overall lower proportion correct ($M=0.754$) on the visual attention task in comparison to Time 2 session ($M=0.912$).

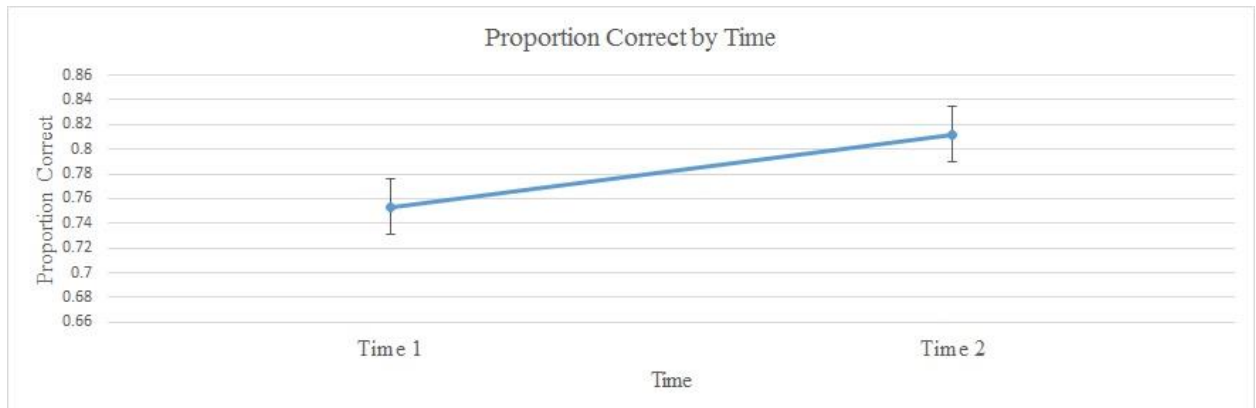


Figure 2. *The effect of time on the overall proportion correct on the visual attention task across both groups.*

Speed

Speed was measured by taking the inverse of the response time recorded for each picture task. An ANOVA comparison revealed a significant effects on speed of time ($p=.0016$), task ($p<.0001$), Task x Time ($p=.0115$), and Group x Task x Time ($p=.0300$). Differences in speed at time 1 were found for both the PSD group ($p<.0001$) and the rested group ($p=.0014$) but not at time 2 for either group ($p>.05$). Specifically, at time 1 the PSD group was significantly slower to respond to position changes than to color ($p<.0001$), deletion ($p=.0034$), and no ($p=.0046$) changes. Also, at time 1 the rested group was significantly slower to respond to position changes than color ($p=.0018$), deletion ($p=.00006$), and no ($p=.0180$) changes. Furthermore, speed of response increased from time 1 to time 2 for both PSD ($p=.0291$) and rested ($p=.0092$) subjects. In particular, for PSD subjects there was a significant improvement in change detection from time 1 to time 2 for deletion ($p=.0074$) and for position ($p=.0001$) conditions, and for the rested subjects there was a significant improvement in change detection over time for color ($p=.00293$) and for position ($p=.00009$) conditions. No other significant changes were found ($p>.05$). Figure 3 illustrates the recorded speed of the chronic PSD subjects on the different task types at the two different time sessions.

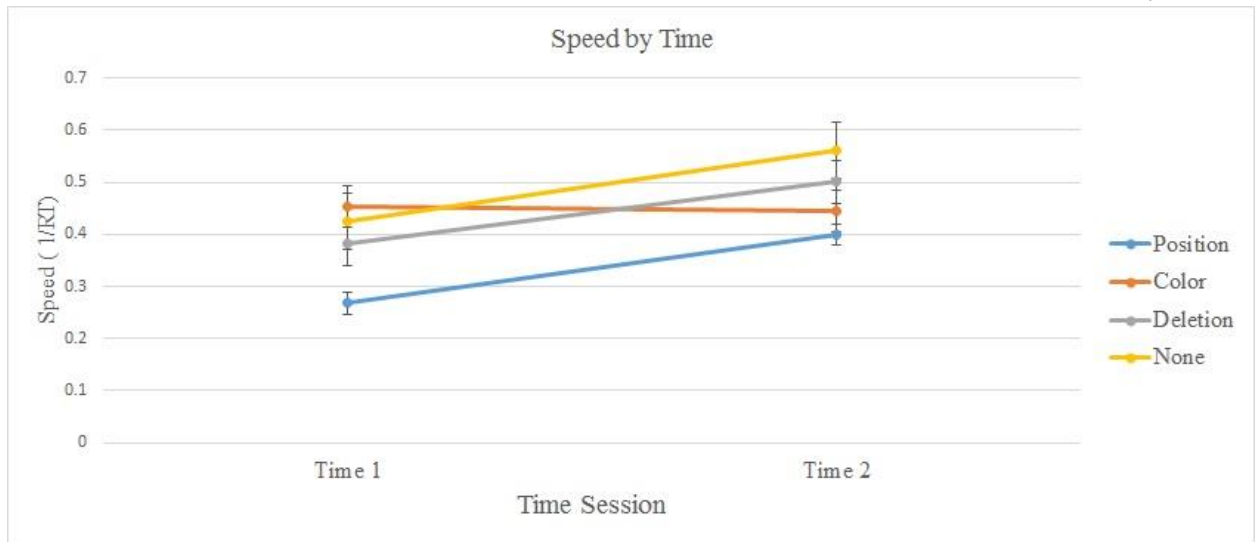


Figure 3. The effect of time on the speed of the chronic PSD subjects on the different task types of the visual attention task.



Figure 4. The effect of time on the speed of the rested subjects on the different task types of the visual attention task.

Figure 4 illustrates the recorded speed of the rested subjects on the different task types at the two different time sessions.

General Arousal

Table 1 illustrates the averaged scores on the Mood Subscales, SSS and PVT. An ANOVA comparison revealed a significant effect of time on the fatigue subscale ($p=0.0022$), SSS ($p=0.0021$), PVT scores ($p<0.0001$) and a marginally significant effect on activation ($p=0.0948$). Additionally, there was a significant group effect on the fatigue subscale ($p=0.0172$).

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

Group	Activation	Fatigue	SSS	PVT
PSD-1	1.48±0.547	2.26±0.611	4.90±0.674	3.53±0.310
Ctrl-1	1.78±0.632	1.74±0.378	4.15±1.14	3.53±0.239
PSD-2	1.85±0.687	1.70±0.492	2.90±0.314	3.67±0.396
Ctrl-2	1.91±0.470	1.45±0.367	3.23±1.54	3.80±0.248

Analysis Methods

The data analysis started with the extraction of the raw data from the Eprime software into SPSS. The results were analyzed using a mixed model in sass to accommodate for missing session data and run through the PROC GLIMMIX program using a doubly repeated method. Post-hoc analyses were utilized to determine specific effects revealed by the ANOVA analyses. Under some conditions, one subject was switched from PSD to control and one subject was switched from control to PSD based on self-reported behavior on the Pittsburgh Sleep Diary. Even though there was proportional data, the values 0.3 to 0.7 allowed for no transformation of

the raw data to be needed. The speed was calculated by taking the inverse of the recorded response time on the visual attention task and PVT.

Chapter 4

Discussion

This study examined the effects of chronic partial sleep deprivation (PSD) and the circadian pattern rhythm on change blindness and general arousal. Based on previous studies, we hypothesized that chronic PSD individuals would experience a greater degree of change blindness and experience lower general arousal measures in comparison to the rested subjects. Additionally, we hypothesized that there would be a circadian rhythm effect on the prevalence of change blindness and general arousal measures, with both groups performing better in a 12-hour later session that is closer to their daily circadian peak performance, in comparison to the morning session. A secondary hypothesis was that there would be an effect of task type on proportion correct and speed, with color being least correct, and none being most correct.

The first measure analyzed was the overall proportion correct on the visual attention task by the two sets of groups across both time periods. The ANOVA analysis (Appendix Table 5) demonstrates the marginally significant effect of group, and the significant effect of time on proportion correct on the visual attention task. As a whole, the PSD group performed worse than the rested group across both time sessions but the means were not statistically different (Appendix Table 3). These results partially support our initial hypothesis regarding a decrease in performance in the chronic PSD group. This marginally significant difference in performance can be attributed to the studied cognitive impairments in chronic PSD individuals, as explained by Durmer and Dinges (2005). That is, chronically PSD individuals are likely to experience

declined performance on attention-intensive tasks, loss of situational awareness, and decline in short-term and working memory. The task required careful attention to detail and accurate memory re-call in order for a correct answer. These chronic PSD subjects may have experienced any of these symptoms to a degree, which would explain the declined performance on the visual attention task. Additionally, loss of situational awareness is an important aspect in regards to change blindness, because if people neglect smaller or secondary objects in their visual field, they are much less likely to detect a change in that area. Further, a one-way ANOVA comparison (Appendix Table 7) revealed a significant group effect on fatigue measurements averaged across both time sessions. The chronic PSD individuals reported significantly greater fatigue than the rested individuals (Table 1). This further supports the generalization that chronic PSD causes significant fatigue in comparison to rested individuals and can ultimately hinder cognitive functioning. Consequently, the data demonstrates that there could have been a decline in performance in chronic PSD due to declined ability to maintain attention and performance on tasks over time, something not been present in the rested individuals.

The second measure analyzed was the total proportion correct by both groups, based on the specific task change of the image. An ANOVA comparison (Appendix Table 5) revealed a very significant effect of task on proportion correct for both groups. Color task changes had lowest proportion correct followed by position task changes then deletion task changes, with the non-change task changes having the highest proportion correct (Figure 1). These results support the initial hypothesis that color task changes would be the most difficult while non-change task changes would be the easiest to detect among both groups. This highly significant difference in performance across the different task changes demonstrates the sensitivity of change blindness to the visual field being presented (Ball et. al, 2013). Some of the changes may be easier to spot due

to the specific nature of the scene while others may be more difficult. In the Ball et. al study (2013), the researchers demonstrated that there was a significant difference in number of required presentations before detecting a change in the images. Color changes (M= 13.91) required the most number of presentations, followed by deletion changes (M=12.31), with position changes (M=8.00) requiring the least number (Ball et. al, 2013). These researchers also demonstrated that certain changes in our visual field are more likely to be detected than others, depending on the size and saliency. With this, the color task changes were often more difficult to detect because they were a simple color object change, something people are often unaccustomed to looking for in their visual field. On the other hand, none-change tasks can be an accurate representation of our daily lives because as we are examining a natural scene, there often is no significant change in the visual field. Consequently, this could explain the high accuracy in response to none task changes in the visual attention task. In regards to position and deletion changes, these results actually were opposite of what was found in the Ball et. al 2013 study. Again, this can be attributed to the sensitivity of the images displayed, and how significant the changes were to the subjects. Additionally, the introduced effects of chronic PSD could have differential impacts on the response accuracy to certain task type changes. For example, chronic PSD could hinder the detection of position task changes to a greater degree than deletion task changes, possibly explaining the observed data in this study. Nonetheless, the data significantly supports the hypothesized task effect on proportion correct across all the task types.

The next three measures focused on the time-of-day effect of the circadian rhythm on proportion correct, response speed, and general arousal at the different time sessions. A one-way ANOVA (Appendix Table 7) revealed a significant time effect on proportion correct. At morning time 1, both groups performed worse than at evening time 2 (Figure 2). Additionally, one-way

ANOVA comparisons revealed a significant time effect significant task effect and significant group*task*time effect on response speed (Appendix Table 6). The first time session had a slower speed among both groups in comparison to the second time session (Appendix Table 4). Lastly, a one-way ANOVA comparison revealed a significant time effect on PVT speed fatigue, SSS and a marginally significant effect on activation (Appendix Table 7). At morning time 1, both groups also reported lower levels of activation than at evening time 2 while reporting higher levels of fatigue and sleepiness at time 1 than at time 2 (Table 3).

All of these results support the original hypothesis of a time-of-day circadian rhythm effect on change blindness and general arousal measurements. With the general rise in alertness and activity at later times in the day, this can explain the increased proportion correct among the variables at evening time 2 in comparison to morning time 1 (Cassone, 2014). Because the visual attention task requires a high degree of attentiveness, this increase in alertness could explain the significantly improved accuracy at evening time 2. Additionally, this circadian rhythm effect can also explain the time effect on PVT speed, response time, and also the fatigue and activation measures. All of these measures are connected by the general wakefulness of the individual which is directly controlled by the circadian rhythm pattern (Ballet, 2008). The rise in general alertness with the peaking of the circadian rhythm in the later afternoon can explain the improved performance on the PVT, visual attention task, fatigue and activation measures (Cassone, 2014). Conversely, the decrease in level of alertness early in the morning can explain the decreased performance on the visual attention task, PVT, fatigue and activation measures. As a whole, the effects of the time-of-day circadian rhythm pattern are demonstrated through the comparison of both groups at the different time sessions.

The findings from this study, combined with previous literature, can have profound impacts on the health and safety of individuals all around the world. The goal was to demonstrate that these are visual stimuli that these individuals could be exposed to while they are driving a vehicle or riding their bike. The fact that there were significant visual mistakes demonstrates that change blindness apparently occurs often and most people don't realize the danger of missing a small change in their visual field. This could be the difference between missing a traffic light switching from green to red or a pedestrian crossing the street which could result in serious consequences. Change blindness is apparently enhanced by increasing chronic PSD, which is a rising concern in America as people become busier with work and other activities and often sacrifice sleep in the process (Connor et. al, 2002).

This phenomenon of change blindness being enhanced by sleep deprivation is closely correlated with driver drowsiness being reported as the main cause of car accidents around the world (Eoh et al., 2004). Fatigued drivers have difficulty focusing and their processing speed and memory capacity are decreased (Wylie et al., 1996). These cognitive changes can have profound consequences in delicate tasks, such as driving and biking, as an even one-second lapse in attention can lead to a possible accident. This study has demonstrated that both rested and chronic PSD individuals are unable to completely spot all changes that occur in normal driving scenarios, with chronic PSD individuals at a higher risk for making a mistake. This presents a serious problem because individuals often perform these sorts of delicate tasks while being chronically PSD, and do not realize the magnitude of the effects associated with PSD.

Limitations

The present study has strengths and limitations that should be taken into account while reviewing the analysis of the data collected. First and most importantly, the visual attention task is a fairly accurate representation of change blindness in natural scenes, as it followed previous literature that was also able to demonstrate change blindness (Ball et al., 2013). Additionally, the general arousal measurements demonstrated the expected differences between the chronic PSD and control groups. The chronic PSD individuals reported being more fatigued, less active, and more sleepy at both times in comparison to the control group. Those results demonstrated that the initial categorization of the individuals was accurate. Lastly, the visual attention task appeared to be sensitive to chronic PSDs, which was necessary to represent a realistic real-life scenario.

The biggest limitation of this study was the limited sample size that was available. The entire population was a restricted age cohort between 18-21 years old. Additionally, the sample size was rather small with only 8 sleep deprived individuals and 15 control individuals which made the sample size rather small. A skewed gender distribution amongst the two groups included 75% male in the chronic PSD while the control group was 73.3% female. This greatly limited the generalizability of the results produced. Further, the basis of categorizing the individuals as chronic PSD and rested relied on self-reported measures and the expectation that there was no significant change in sleep-wake behavior prior to the testing sessions. This was an unreliable amount of variability in the actual sleep-wake patterns of the individuals, making the generalizability of the results difficult. Lastly, there could have been learning effect present at time 2 which could possibly account for the improved performance by both groups. The photos

were very similar so it's possible the subjects retained some prior information by time session 1.

This might negate the hypothesized effect of circadian rhythm patterns.

Further Studies

Further studies should seek to replicate the results of this study by utilizing a greater, more representative sample size by incorporating a wider age range and more equal gender distribution between the groups. These studies should also maintain a strict sleep-wake behavior tracking of individuals of each group to minimize the effect of fluctuating sleep quality and duration. The visual attention task should also consist of two completely unique photo sets at the different time sessions to minimize the learning effect associated with the time 2. Further research in this area is warranted because as the prevalence of chronic PSD grows, it's imperative that future literature demonstrates the apparent effects on neurocognitive ability and general arousal measures. This future research can also help establish a link between chronic PSD and how this interacts with change blindness.

Appendix

Tables

Table 2. General Demographics and Characteristics of Participants

Sleep Duration						
Group	Size	Mean	SD	Range	SE	T-value
PSD	10	6.55	0.841	2.6	0.266	0
Control	13	8.67	0.845	2.75	0.234	
Age						
PSD	10	19	1.05	3	0.333	0.0873
Control	13	19.1	1.19	3	0.329	
Gender						
	Male	Female	Male Proportion	Female Proportion		
PSD	6	4	0.400	0.600		
Control	2	11	0.154	0.846		

Table 3. Proportion Correct on Visual Attention Task at Time 1 and Time 2

Group	Color		Position		Deletion		None	
	M	SD	M	SD	M	SD	M	SD
PSD-1	0.425	0.139	0.7738	0.106	0.812	0.135	0.912	0.146
Control-1	0.583	0.175	0.767	0.0888	0.825	0.0964	0.925	0.176
PSD-2	0.540	0.178	0.780	0.132	0.860	0.126	0.960	0.0697
Control-2	0.615	0.134	0.831	0.111	0.900	0.0911	0.984	0.0374

Table 4. Speed on the Visual Attention Task at Time 1 and Time 2

Group	Color		Position		Deletion		None	
	M	SD	M	SD	M	SD	M	SD
PSD-1	0.453	0.112	0.268	0.0583	0.383	0.119	0.425	0.0153
Control-1	0.378	0.0862	0.300	0.0579	0.406	0.078	0.409	0.178
PSD-1	0.445	0.174	0.399	0.0813	0.501	0.130	0.561	0.318
Control-1	0.472	0.128	0.389	0.116	0.472	0.080	0.541	0.161

Table 5. ANOVA of Proportion Correct on Visual Attention Task

Effect	Num DF	Den DF	F-value	Pr>F
Group	1	21	3.33	0.0822
Task	3	63	46.3	0.0001
Group * Task	3	63	0.86	0.466
Time	1	18	10.6	0.0043
Group * Time	1	18	0.01	0.9114
Task * Time	3	54	0.10	0.9586
Group * Task * Time	3	54	.72	0.5438

Table 6. ANOVA of Speed on Visual Attention Task

Effect	Num DF	Den DF	F-value	Pr>F
Group	1	21	0.09	0.7701
Task	3	63	12.1	<0.0001
Group * Task	3	63	0.300	0.8269
Time	1	18	13.7	0.0016
Group * Time	1	18	0.01	0.9341
Task * Time	3	54	4.04	0.0115
Group * Task * Time	3	54	3.21	0.0300

Table 7. 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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