Eye Movement in Correlation to Sleep Quantity

Saccadic Eye Movement and Search Time in Correlation to Sleep Quantity

Bishop Armstrong
College of Engineering
Clemson University
Clemson, SC, USA
bishopa@clemson.edu

Dylan DuBay
College of Engineering
Clemson University
Clemson, SC, USA
ddubay@clemson.edu

Michael Furlong
College of Engineering
Clemson University
Clemson, SC, USA
mjfurlo@clemson.edu

1 ABSTRACT

This study aims to determine the effects of sleep deprivation on attention, arousal, and alertness, using saccadic eye movements measured via Gazepoint GP3 eye tracker. Eleven participants performed the experiment trying to locate and identify a target letter while spending most of their time focused on a stationary fixation point at the center of the screen.

KEYWORDS

Eye tracking, Gazepoint, Sleep Deprivation

2 INTRODUCTION

The goal of this study is to determine the link between the quantity of sleep and various quantitative characteristics of eye movement. The experiment measures response time, saccadic velocity, and saccadic latencies. All of these characteristics have been linked to attention and arousal [2].

We hypothesize that participants with lower amounts of sleep will have significantly impaired eye movements compared to participants with a standard or longer amount of sleep recorded. Meaning that the sleep deprived participant's attention, arousal, and alertness are all lowered.

Attention and arousal may be a significant factor in regards to reaction times and processing speeds, which directly impacts performance in common, potentially life-threatening tasks such as driving and operating heavy machinery. Driving specifically is one of the most dangerous activities most people regularly participate in, with an average of 38,000 deaths per year on U.S. roadways [10]. Many of these deaths are attributed to impaired drivers, influenced by factors such as alcohol or lack of sleep, accounting for over a third of all car accident fatalities [1].

2.1 Background

Attention is defined as the allocation of processing resources to relevant stimuli and arousal is defined as the state of physiological reactivity of the subject according to J. T. Coull (1997). In the early 1990's Wilkinson concluded that "sleep deprivation reduces the non-specific arousal level of the body, but has no special effect" [18]. Multiple recent studies disagree with Wilkinson's conclusion and argue that sleep deprivation decreases function in certain parts of the brain including the prefrontal cortex (PFC)[9][11]. The PFC plays a critical role in cognitive control functions, as well as controlling dopamine levels, influencing attention, impulse inhibition, and cognitive flexibility. This information aligns with Wilikson's conclusion about sleep deprivation directly affecting the arousal level of the body. More recent studies have observed that sleep deprivation is linked to a decreased glucose metabolism in the frontal and parietal cortices [5][6][14]. Glucose metabolism in this part of the brain is responsible for higher executive functions including emotional regulation, planning, problem-solving, arithmetic working memory tasks, and most significant to this study, visuospatial attention. "Visuospatial attention is the capacity of someone to attend to and to process stimuli in his surrounding space" [15]. This relates to the motivation for the experiment that doing dangerous tasks such as driving, operating heavy machinery, or other life-endangering tasks (whether to self or others) is increasingly dangerous with the less amount of sleep that person has. The best way to test this according to Fischer (1987), Fischer and Weber (1993) and Crommelinck and Roucoux, 1976; Ron et al., (1972) is testing for saccadic latency and saccadic peak velocity. There are two generally accepted methods for measuring saccadic eye movements referred to as gap and overlap. For each method, a fixation point is displayed in a central location, and then another target is added somewhere on the screen, causing the attention of the participant to switch from the first object to the second. The first method is known as the gap method, in which the original fixation point disappears once the second fixation point appears. In the second method known as overlap, the original fixation point remains visible even after the second fixation point appears. Although, both methods require the participant to disengage their gaze from the original target to the lateral target; saccadic latencies are longer in the overlap method compared to the gap method. If sleep deprivation alters disengagement of attention, we should observe an increased gap between these two methods. If sleep deprivation decreases alertness, there should be an observed decrease in saccadic peak velocity. Our team believes that testing for response time is also useful for measuring visuospatial attention which can be linked to alertness.

3 METHODOLOGY

3.1 Apparatus

In all conditions for the experiment, the hardware used consists of a Gazepoint GP3 Eyetracker, and a monitor on which participants will be able to complete the experiment. Participants will also be given a keyboard to interact with the experiment program. The Gazepoint GP3 is a pupil-corneal reflection (PCR) video-based eye tracker with a sampling rate of 60 hertz and an accuracy of 0.5-1.0 degrees. The screen participants will be viewing the experiment on is 22 inches diagonally at 1,680 x 1,050 resolution. Participants will be positioned roughly 60cm (23.62 inches) away from the monitor. Participants' head movements will not be restricted during trials.

3.2 Subjects

For this experiment, we had a study group of 13 participants. These participants were picked from a university student body, and between the ages of nineteen and twenty-seven, with diverse ethnic backgrounds, and both male and female representation. The subjects are expected to have variable amounts of sleep. Participants will be asked prior to starting the experiment if they require contacts or corrective eyewear. Participants are still eligible to participate if they require corrective lenses or eyewear as long as they are currently using them and thus unimpaired in ability to do the experiments. Additionally, participants will be asked how much sleep they have had in the last 24 hours and how long they have been awake. Participants were divided into 3 separate groups. The groups are sleep deprived (less than 4 hours), little sleep (4-6 hours), and good sleep (7+ hours). Four participants fell under the category of sleep deprived, three had little sleep, and the remaining four had good sleep.

3.3 Experimental Design

Upon entering the lab, participants will be given a waiver. When the participant signs it they will be asked a series of questions to make sure they are eligible to participate. If eligible, participants will begin the calibration process for the Gazepoint GP3 eye tracker. Next, there will be instructions displayed on the monitor explaining how to complete the experiment. They will be given the minimum amount of instructions to be successful at the task. If the participant has no questions they will be prompted to hit the spacebar key to continue the experiment. The experiment is a 2x3 within-subjects mixed design. The independent variables are the two methods (gap and overlap) and the amount of sleep the participant had the night before (low, medium, and high).

3.4 Procedures and Stimulus

The purpose of this experiment is to measure search time and saccadic eye movements - specifically saccadic velocity and saccadic latencies. In the experiment, to ensure the proper functionality of the equipment, participants must first go through a calibration phase. This does not take more than 2 minutes if everything is working properly on the first calibration period.

For the first component of the experiment, the participants will be explained the requirements of the main experiment on the screen. The instructions are as follows.

"In this phase, you will be scored on two components. The first part of your task is to focus your attention at the dot stationary in the center of the screen. Additionally at the same time, on the screen will appear a letter or number. If the letter is a ‘B’ you need to press space. If the symbol is not a ‘B’, do not press a key. You will need to look at the stationary dot for as much of your time as possible while also glancing at the symbol to determine if it is a ‘B’. You are required to continue until a screen appears prompting you that this section is complete. Please click the spacebar to continue."

Figure 1: Experiment Component 1 visual stimulus

Participants are instructed to focus their gaze on a black dot stationary at the center of the screen. A random character from the list [H, R, 4, 6, G, K, P, B] will be selected and appear in a random corner at intervals of every 5 seconds. Slightly before a character is introduced, the center dot disappears.

These characters were chosen because they all look similar to the target letter "B" Participants have been instructed to divert their attention to the letter and if the letter is the target letter, they need to press the spacebar.

Figure 2: Experiment Component 2 visual stimulus

For the next component of the experiment, participants will be given the instructions of "You will now do the same experiment exactly as you did before. The only difference this time is the dot that you are tracking will not disappear when a letter appears on the screen. Press "Spacebar" when you are ready!". As the instructions stated, the goal of the experiment is the same as the previous component except that the target dot does not disappear when a letter appears. The experiment was designed in this two part system so we can measure both the gap and overlap method. As the background suggests, both methods require the participant to disengage their gaze from the original target to the lateral target. If our hypothesis is correct, we should observe increased saccadic latencies in the overlap method.

4 RESULTS

While a total of 13 participants were recruited for this study, only 11 participants were analyzed due to calibration issues that were unable to be solved. For one participant we believe this may be due to their eye color while the other had thick glasses that interfered with the eye tracker. The 11 eligible participants were then grouped into 3 categories based on their amount of sleep they had the night before. 4 participants were considered sleep deprived which is 4 or less hours of sleep. 3 participants were categorized as "little sleep" which is 4-6 hours. The remaining participants were classified as having good sleep (7 or more hours).

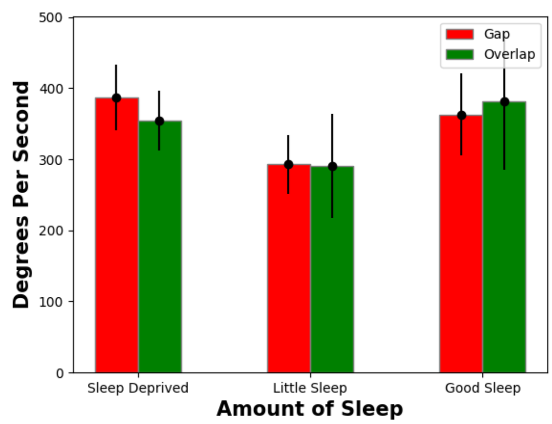

Figure 3: Average Saccadic Velocity by group

Looking at figure 3, the team took the average saccadic velocity of each group for both experiments and graphed it using matplotlib. We did not discover a significant relationship between amount of sleep and average peak saccadic velocity for either the gap or overlap methods. We found a very weak correlation between amount of sleep and saccadic peak velocity measured using the gap method with a coefficient of $r = 0.17$ and a moderate correlation for overlap with a coefficient of $r = 0.41$.

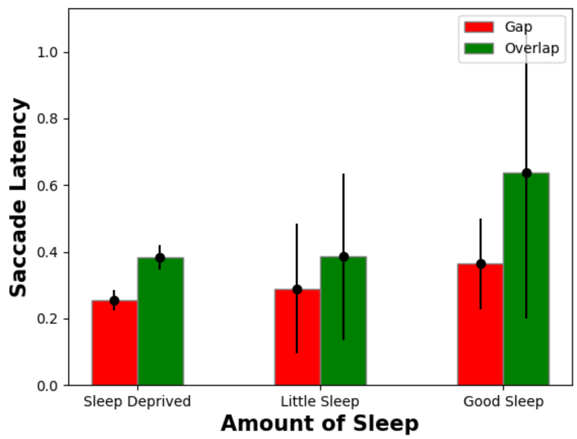

Figure 4: Average Saccadic Latency by Group

In figure 4, we calculated the average saccadic latency for each group split by the gap and overlap methods. We did not discover a significant relationship between amount of sleep and saccadic latency. Latency was calculated as the amount of time after a stimulus was presented at which a saccade occurred.

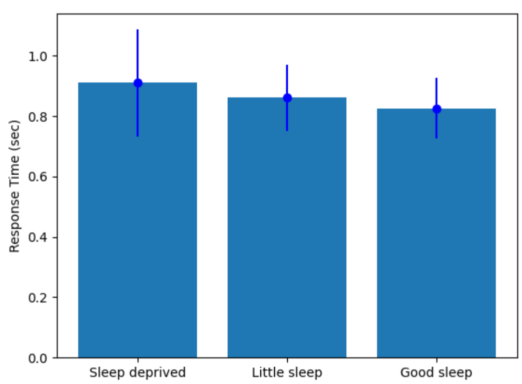

Figure 5: Average response time by group

In figure 5, we calculated the average response time for each group. The response time is how many seconds passed while the target character "B" was on screen before the participant pressed the spacebar. While we did not find anything of statistical significance, a weak negative correlation of r = -0.2012 was found.

5 DISCUSSION / CONCLUSION

Overall, we were unable to find statistical significance to prove that our hypothesis that sleep deprivation lowers your attention, arousal, and alertness. Figure 3 does not show that the saccadic peak velocity lowers with less amounts of sleep. As mentioned in the background, if sleep deprivation decreases alertness, there should be an observed decrease in saccadic peak velocity. Alertness is greatly controlled by your glucose metabolism in the front and parietal cortices in your brain. Drummond and Brown's verbal learning experiments showed that sleep deprivation is linked to decreased glucose metabolism in the same parts of the brain. We were trying to observe the effects of decreased glucose metabolism in our participants with bad sleep. (figure 3) We also observed a weak negative correlation between visuospatial attention and amount of sleep. The response times were higher with the less amount of sleep the participants had. Although our margin of error was too high to prove real statistical significance (figure 5). We did not find any correlation between attention and amount of sleep. In fact, we observed the opposite results of what we expected. It was expected that sleep deprived participants would have an increased gap in saccadic latencies between the two methods but it was actually the smallest while participants with good sleep had the largest (figure 4).

5.1 Limitations

This study contained several limitations. First, we had the limitation of how many participants we conducted the experiment on. With only 11 participants to analyze, our margin of error was too high to prove statistical significance. Second, we had to rely on the participants to accurately recall how much sleep they had the night before. Third, sleep deprivation cannot be measured by the amount of sleep the participant had the night before. It may be more accurate to measure the participants' sleep using a sleep tracker for multiple days before conducting the experiment. Next, we are unable to know if the participants were under the influence of any medications or drugs such as caffeine and other stimulants that may skew the results.

REFERENCES

[1] Centers for Disease Control and Prevention. (2020, August 24). Impaired driving: Get the facts. Centers for Disease Control and Prevention. from https://www.cdc.gov/transportationsafety/impaired_driving/impaired-drv_factsheet.html.

[2] Corbetta M, Akbudak E, Conturo T, Snyder A, Ollinger J, Drury H, Linenweber M, Petersen S, Raichle M, Vanessen D, Shulman G. A common network of functional areas for attention and eye movements. Neuron 1998;21:761–73.

[3] Coull JT. Neural correlates of attention and arousal: insights from electrophysiology, functional neuroimaging and psychopharmacology. Prog Neurobiol. 1998 Jul;55(4):343-61. doi: 10.1016/s0301-0082(98)00011-2. PMID: 9654384.

[4] Crommelinck M, Roucoux A. Characteristics of cat's eye saccades in different states of alertness. Brain Res 1976;103:574–8.

[5] Drummond SP, Brown GG. The effects of total sleep deprivation on cerebral responses to cognitive performance. Neuropsychopharmacology 2001;25:S68–S73.

[6] Drummond SP, Brown GG, Stricker JL, Buxton RB, Wong EC, Gillin JC. Sleep deprivation-induced reduction in cortical functional response to serial subtraction. NeuroReport 1999;10:3745–8.

[7] Fischer B. The preparation of visually guided saccades. Rev Physiol Biochem Pharmacol 1987;106:1–35.

[8] Fischer B, Weber H. Express saccades and visual attention. Behav Brain Sci 1993;16:553–610.

[9] Harrison Y, Horne JA. Sleep loss impairs short and novel language tasks having a prefrontal focus. J Sleep Res 1998;7:95–100

[10]Media, N. H. T. S. A. (2021, June 3). 2020 fatality data show increased traffic fatalities during pandemic. NHTSA. from https://www.nhtsa.gov/press-releases/2020-fatality-data-show-increased-traffic-fatalities-during-pandemic.

[11]Muzur A, Pace-Schott EF, Hobson JA. The prefrontal cortex in sleep. Trends Cogn Sci 2002;6:475–81.

[12]Drivers are falling asleep behind the wheel. National Safety Council. (n.d.), from https://www.nsc.org/road/safety-topics/fatigueddriver.

[13]Nobre AC, Gitelman DR, Dias EC, Mesulam MM. Covert visual spatial orienting and saccades: overlapping neural systems. Neuroimage 2000; 11:210–6.

[14]Portas CM, Rees G, Howseman AM, Josephs O, Turner R, Frith CD. A specific role for the thalamus in mediating the interaction of attention and arousal in humans. J Neurosci 1998;18:8979–89

[15]Posner M. I., Petersen S. E. (1990). The attention system of the human brain. Annu. Rev. Neurosci. 13, 25–42. 10.1146/annurev.ne.13.030190.000325

[16]Ron S, Robinson DA, Skavenski AA. Saccades and the quick phase of nystagmus. Vision Res 1972;12:2015–22.

[17] Thomas M, Sing H, Belenky G, Holcomb H, Mayberg H, Dannals R, Wagner H, Thorne D, Popp K, Rowland L, Welsh A, Balwinski S, Redmond D. Neural basis of alertness and cognitive performance impairments during sleepiness. I. Effects of 24 h of sleep deprivation on waking human regional brain activity. J Sleep Res 2000;9:335–52.

[18] Wilkinson RT. The measurement of sleepiness. In: Broughton RJ, Ogilvie RD, editors. Sleep, arousal and performance. Boston, MA: Birkhauser; 1992. p. 254–65.