Measuring the Impact of Sleep on Human Reaction Time and Accuracy

Kannan Gnanasegaram, Sadman Sakib, Nishtha Shrestha
Dept. of Electrical Engineering and Computer Science
York University
Toronto, Ontario, Canada M3J 1P3
kannan11@my.yorku.ca, nstha21@my.yorku.ca, skilzer@my.yorku.ca

ABSTRACT
We conducted a study comparing the difference in reaction time and accuracy of two groups who had different amounts of sleep, group 1 with five hours of sleep, group 2 with eight hours of sleep). The study involved 6 participants and employed the use of the *Reaction Time Experiment*[1] software to test the reaction time and accuracy of the participants. Participants performed three sets of reaction testing tasks throughout the day (1 hour after waking, 6 hours after waking, and 10 hours after waking). The result for the reaction time is inconclusive as they were all statistically insignificant. The results for the reaction accuracy was also inconclusive as both groups performed their tasks with no errors.

Keywords
Sleep, sleep deprivation, human-computer interaction, reaction time

INTRODUCTION

As a necessary biological process, individuals undergo sleep sessions as part of their routine. Humans restore themselves physically, neurologically, and emotionally through these vital sessions in preparation for their next set of waking hours. This process is a necessity for human life. When one is unable to attain sufficient sleep and reaches a state of deprivation, the ramifications are often felt intuitively.

Sleep is important, and not having enough affects how one carries themself and interacts with others. While this is generally accepted as a fact, it is also an extremely nuanced statement that carries multiple opportunities for further exploration. One such facet is a human's interaction with computers in relation to sleep. As society moves towards a greater dependence on technology, exploration in this field is extremely relevant.

There has been a huge migration towards technology-supported operations. Coupled with this is a growing social culture based on digital media consumption. Does sleep play a role in how one interacts with technology? Does sleep deprivation hinder the overall quality of human-computer interactions?

While this dependence is already growing at an exponential rate, its scale and pace have only intensified with the recent onset of the COVID-19 pandemic. Many key components of modern-day life have shifted to an online delivery format, such as schooling, conferencing, and social gathering. Individuals must adjust to an increase in computer interaction to cope with unprecedented times.

How has the relationship between sleep and human-computer interaction been explored? In the next section, we will explore existing research towards sleep's role in human performance and human-computer interaction. Following this, we will introduce our study which aims to explore how sleep affects human-computer interaction via reaction testing, and the extent to which individuals are willing to change sleep patterns for the sake of improved interactions.

Related Work

Pilcher and Huffcutt [1] performed a meta-analysis over 19 previous studies on sleep deprivation. They concluded that sleep deprivation greatly impaired human functioning. They found that, in order of increasing severity, motor performance, cognitive performance, and mood were negatively affected by sleep deprivation. Moreover, they revealed that the negative effects are strongest when there is partial sleep deprivation, which equates to less than five hours of sleep in a 24-hour period.

A study performed by Ratcliff and Van Dongen [2] over reaction time distribution models included measuring the response time of sleep-deprived participants during psychomotor vigilance tests (PVT's). PVT's are one-choice reaction time tests commonly used in research. Their experiment involved having participants respond to a timer as soon as possible, pressing a key when they first see it appear on a display. They found that the mean response times were widely different, with the average reaction time of non-deprived participants being 368 ms and sleep-deprived participants being 876ms.

Pusateri et al. [3] have been undergoing work in "sleepy games", a relatively less explored area in Human-Computer Interaction. Rather than using the principles of HCI to create games that explicitly educate proper sleeping practices or reward sleep quality and quantity, they employ these principles in a broader

[1] *http://www.yorku.ca/mack/ExperimentSoftware/*

manner. Upon developing three games designed around sleep, they enlisted the help of playtesters with known sleep issues, including sleeping disorders, unconducive sleeping environments, and irregular sleep/wake cycles. During a period of playtesting, they discovered that participants were "enthusiastic about exploring new solutions to increase sleep quality". They also found that participants acquired increased awareness of their choices regarding sleep.

In a study conducted by Nuutinen et. al [4], sleep and its relationship to computer use and symptom loads among adolescents were explored. They studied the data of 5402 15-year olds in Finland, France, and Denmark. This data was reported through a questionnaire from the World Health Organization's Health Behaviour of School-aged Children Study in 2010. Through their study, they found that increased computer use led to shorter sleep durations, as well as higher rates of somatic and psychological symptoms such as aches, nervousness, irritability, and dizziness.

METHOD

A study was conducted in order to investigate the effects of sleep on human reaction time and accuracy. This section describes the methodology used, including the independent variables, dependent variables, and how the data was acquired.

Due to the restrictions of the COVID-19 pandemic, this study was conducted in a virtual manner where the instructions were sent to the participants in an email format with the data being self-reported by them.

Participants

Six voluntary participants were selected via their response to a recruitment post on various *Discord* servers dedicated towards different EECS courses offered at York University. There were three males and three females, with the average age of participants being 26 (min 23, max 38) The participants were numbered off into group 1 (five hours) and group 2 (eight hours) on a first come first serve basis.

Apparatus

The participants downloaded the *Reaction Time Experiment* software, available on Professor Scott MacKenzie's Experiment Software website, on to their personal computers in order to participate in this study.

They were divided into two groups (1 and 2) on a first come first serve basis once they volunteered to participate in the study. Group 1 participated in the study with five hours of sleep, while group 2 participated with eight hours of sleep. All participants performed the "Visual Search" exercise with 16 letters in the *Reaction Time Experiment* software in three different blocks at various times of the day. See Figure 1.

The set-up of the "Visual Search" mode was such that the initial stimulus contained a letter, see Figure 2.1. After a delay of five seconds, the squares in the grid were populated with letters selected at random, see Figure 2.2. A match was deemed to occur if the initial letter appeared in the grid. This was repeated five times per block.

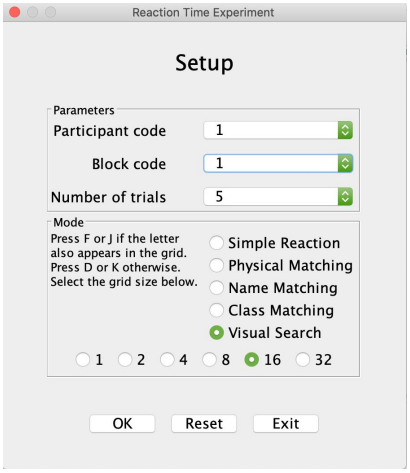

Figure 1. Example of Participant 1 setting up their block 1, six hours after they have been awake.

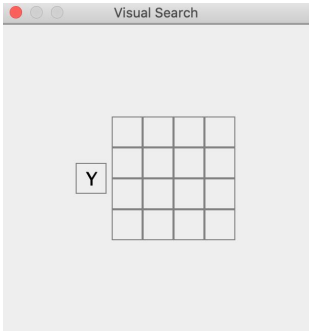

Figure 2.1. Initial stimulus for the "Visual Search" mode in the *Reaction Time Experiment*.

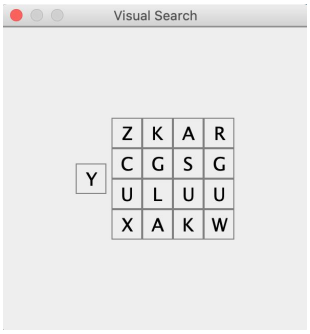

Figure 2.2. Randomly populates the grid for the "Visual Search" mode in the *Reaction Time Experiment*.

For each trial, there was a 50% probability of a match. For trials in one block, 50% were match trials and the other 50% were no-match trials. Once a block was over, the software automatically calculated and shared the results with the participant, see Figure 3. The data file was also automatically saved to the participants' device, which was then uploaded at the end of the post-study survey.

In addition to the software, participants were asked to complete a questionnaire in a spreadsheet after each block, and a post-study survey on Google *Forms* after the completion of their final block. The spreadsheet had two parts, the first one being a yes or no section asking participants about their caffeine intake one hour before the start of the block, and if they were experiencing any tiredness, headache, sensitivity to light, irritability, or loss of focus. The second part had the participants answer some subjective questions, such as whether the task was straightforward and easy, if they were satisfied by their performance during the block, if they think they could have gotten a better score with coffee consumption prior to the block, or with more sleep, on a 5-point Likert scale.

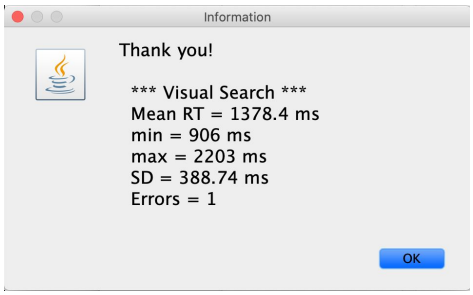

Figure 3. Sample results screen in *Reaction Time Experiment*.

The post-study survey asked the participants about their age, gender, familiarity of *Reaction Time Experiment* software, regular usage of word search/puzzle games, and some questions about whether or not they agree that their performance could have been improved with a difference in the amount of sleep they received, if participating in this study brought any awareness to their current sleep habits, and if they felt that sleep was important for their alertness levels.

Procedure

Once chosen, participants were sent a confirmation email with individualized details for their data recording and links to key resources such as the software download page, participant instruction document, block reporting sheet, a link to the post-study survey.

As stated in the previous sub-section, the study was conducted in three blocks, with each block representing a specific point in the participants' day; one hour after waking, six hours after waking, and 10 hours after waking. For each block, once the participant set up the appropriate parameters in the setup wizard and selected "Ok", they first observed the letter stimulus on the box to the left. After a few seconds, once the grid on the right got populated, if they believed that the letter on the left was present on the grid on the right, they pressed the F or J key on their keyboard to confirm, if not, they pressed the D or K key to deny. This was repeated five times per block, with the completion of each block taking the participants an average of 6.8 seconds. The average total time spent by the participants performing the tasks for this study was 1 minute and 30 seconds.

The participants filled out the appropriate sections on the Google *Sheets* after the completion of each block. Once their final block was complete, they completed their post-study survey where they also uploaded the files generated by the *Reaction Time Experiment* software.

Design

This study employed a 2 x 3 x 5 between-subjects design with the following three independent variables and levels:

- Amount of sleep in hours (5, 8)
- Block (0, 1, 2)
- Trials (1, 2, 3, 4, 5)

Block 0 represented the session that the participant completed one hour after they woke up, block 1 represented the session that the participant completed six hours after they woke up, block 2 represented the session that the participant completed 10 hours after they woke up.

The dependent variables were the average reaction time and error rate (number of mistakes), both of which were automatically calculated by the *Reaction Time Experiment* software. The time was automatically calculated by the software based on how long it took the participant to press a key. The error rate was calculated based on how many mistakes a participant made per block.

Participants from the two groups completed three blocks of five trials each. Thus, the total number of trials were 6 participants x 3 blocks x 5 trials = 90 trials.

In addition to the reaction time study, participants were asked to complete a questionnaire after every block, block reporting, to report about their coffee consumption one hour prior to the start of the block, how they felt during their block, and to rate the difficulty of the task they had to complete. Once the final block was complete, they were asked to complete a post-study survey where they answered questions about their age, gender, average sleep hours, and to reflect if participating in the study brought alertness to their current sleep schedule and whether they felt that sleep was important for their alertness level. The second one was answered after each block.

RESULTS AND DISCUSSION

All trials were completed successfully. Participants performed the necessary tasks and submitted their files containing the statistics of their performance as well as their completed questionnaires. All of the reported qualitative data were imported into Google *Sheets* to calculate the mean and standard deviation, and create graphs, and an analysis of variance test was performed using the *GoStats*[2]application.

Accuracy

The data that was collected in regards to accuracy did not provide any meaningful conclusions. Both groups performed their tasks with no errors. As such, we can not

[2]*Available as a free download at http://www.yorku.ca/mack/HCIbook/.*

confirm that sleep plays a role in accuracy in regards to human reaction testing. To gain a more conclusive result, this study should be repeated with a larger sample size, and more observation blocks

Reaction Time

Average Task Completion Time

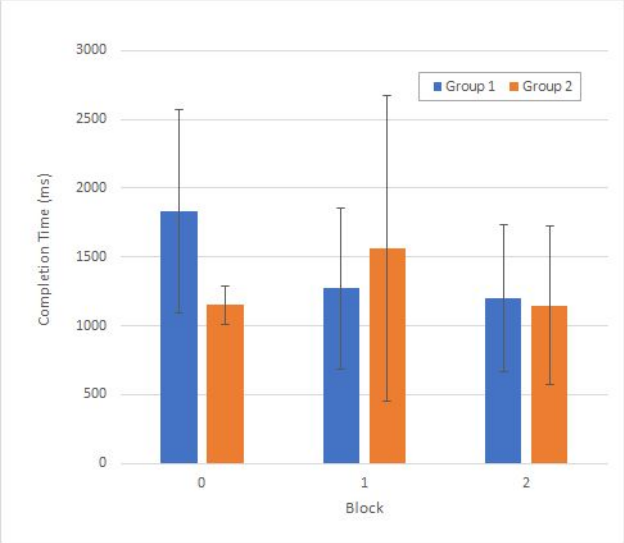

Figure 4. Average completion times (ms) for each block for group 1 and group 2. Error bars show ±1 SE.

The task completion time was used as a measure of reaction time in our study. A task was deemed complete once a participant concluded whether or not a match occurred. A faster completion time per task indicates a quicker reactionary response.

In block 0, there seemed to be a significant difference between the average completion time of the two participant groups. The mean completion time for group 1, who performed the task after having five hours of sleep, was 1833.8 ms. The mean completion time for Group 2, who performed the task after having eight hours of sleep, was 1150.067 ms, which is 37.3% faster. However, upon performing an ANOVA test on the data for block 0, this was concluded to be not statistically significant ($F_{1,4} = 2.475$, $p > .05$).

The blocks that followed did not provide any conclusive evidence of an impact as well. In block 1, for which participants performed their tasks after five hours of waking, group 1 outperformed group 2, as shown by a lower average completion time.

In block 2, group 2 outperformed group 1, though the difference was minimal, being only 52.6 ms, or 4.38%, faster. The low average completion times for both groups compared to the previous blocks could be a result of learning effects, as participants would have been accustomed to the task after performing it numerous times.

When analyzing the data overall, it was concluded that the effect of group on task completion time was not statistically significant ($F_{1,4} = 0.103$, ns). This shows that the amount of sleep a participant had did not have a significant impact on reaction time.

Partial Search Time

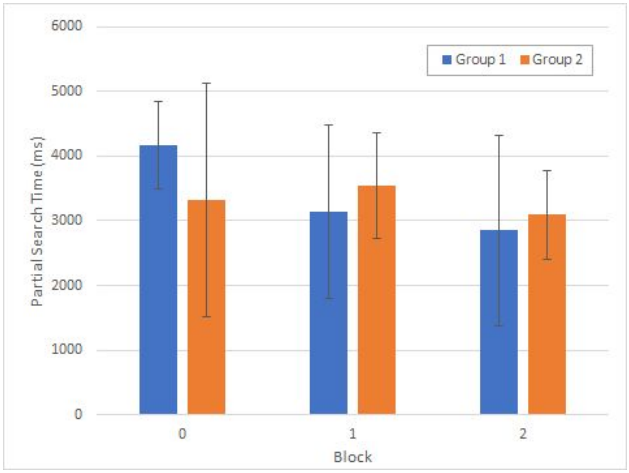

Figure 5. Average partial search time (ms) for each block for group 1 and group 2. Error bars show ±1 SE.

Partial search time was measured during trials in which the letter in question existed within the generated grid. Because a participant does not need to look through the entire grid during this kind of trial, they perform a partial search. This data is differentiated by the experiment software Within every block, three of the five trials measure partial search time.

After performing an ANOVA test, it was concluded that group effect on partial search time was not statistically significant ($F_{1,4} = 0.006$, ns). It was also concluded that the Group interaction effect X Block was not statistically significant ($F_{2,8} = 1.145$, $p > .05$).

Exhaustive Search Time

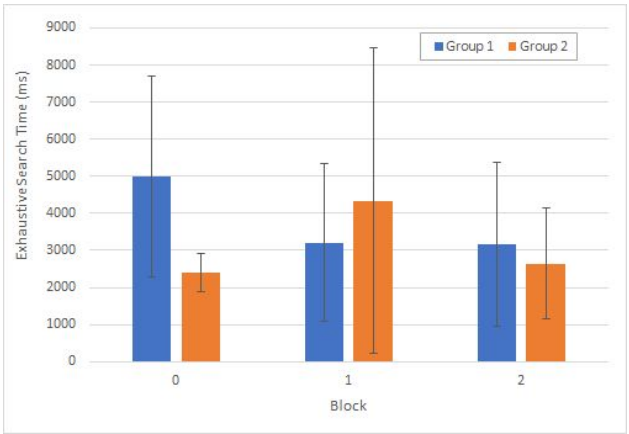

Figure 6. Average exhaustive search time (ms) for each block for group 1 and group 2. Error bars show ±1 SE.

Exhaustive search time was measured during trials in which the initial stimulus letter was not present within the

randomly populated grid. A participant needs to look through the entire search space to make this conclusion, hence they perform an exhaustive search. This data is differentiated by the experiment software. Within every block, two of the five trials measure exhaustive search time.

After performing an ANOVA test, it was concluded that group effect on exhaustive search time was not statistically significant ($F_{1,4}$ = 0.157, ns). It was also concluded that the group interaction effect X block was not statistically significant ($F_{2,8}$ = 1.783, p > .05).

Participant Feedback

Based on the questionnaire provided at the end of the experiment, we saw a significant increase of awareness in the importance of sleep and their sleeping habits in all the participants. The data confirms that all six participants found the experiment straightforward and easy. A few participants from group 1 noted experiencing headaches, loss of concentration and sensitivity to light for the initial block experiment when they had only woken up an hour before.

When asked for a rating on a Likert scale from 1 (least likely) to 5 (most likely), if their performance would have been better with more sleep. The average rating we received was 3.44, which general shows the participants believed sleep had some impact on their reaction time . The consequences of not having proper sleep have been brought to light through this post-study survey, making the participants more aware of their sleep schedule.

CONCLUSION

All of our results were statistically insignificant. This is caused by the enormous error bars in our data points and the small sample size. The major contributing factors for the error bars could be the participants not following the written instructions properly, either because they did not understand it well or because they may have forgotten to time themselves, another potential contribution factor could be the potential distractions around them during their session times.

In order to have more conclusive results, it is necessary that this study be conducted again in a controlled environment and with a larger sample size to mitigate any cause for error and clarify if sleep has an impact on human reaction time and accuracy.

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