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Rhythm of the Night: Brain Activity and Performance on a Sustained Attention Task is Modulated by Circadian Typology and Time of Day

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RHYTHM OF THE NIGHT: BRAIN ACTIVITY AND PERFORMANCE ON A SUSTAINED ATTENTION TASK IS MODULATED BY CIRCADIAN TYPOLOGY AND TIME OF DAY

by

Carly Cooper

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The members of the Honors Thesis Committee appointed
to examine the thesis of Carly Cooper
find it satisfactory and recommend that it be accepted.

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ABSTRACT

Rhythm of the Night: Brain Activity and Performance on a Sustained Attention Task is Modulated by Circadian Typology and Time of Day

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The human circadian system plays an important role in biological and psychological processes in both health and disease. Circadian typology refers to individual differences in circadian rhythm and is categorized into three general chronotypes: morning, evening, and neither. Research suggests that an individual's diurnal preference may be associated with differences in cognitive abilities, personality traits, and incidence of psychiatric disorders. In the present study, we utilized a Sustained Attention to Response Task (SART) and an electroencephalogram (EEG) in a desynchrony protocol. Morning-type and evening-type participants completed a SART task on two separate occasions during which brain activity was recorded. This allowed us to examine the difference in the underlying neural networks corresponding to alerting and sustained arousal when participants are in-phase versus out-of-phase of their diurnal preference. When examining both reaction times and response accuracy, performance and EEG differences were observed between participants' optimal testing time, where we found decreased performance in out-of-phase testing sessions. This suggests that differences in task performance may be instantiated through transient changes in brain network function. These preliminary results may offer further insight into how task performance can change throughout the day, and the neural networks associated with those performance changes.

Keywords: circadian typology, desynchrony, chronotype, attention, EEG

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Rhythm of the Night: Brain Activity and Performance on a Sustained Attention Task is Modulated by Circadian Typology and Time of Day

1. Introduction

The human circadian system is the body's internal clock that dictates biological processes and fluctuations within a 24-hour period. Although circadian rhythms are best understood to control the sleep-wake cycle, research indicates it plays a crucial role in various biological, behavioral, and cognitive processes. Some biological rhythmic fluctuations may include homeostatic regulation of body temperature, hormone secretion, and heart rate, all of which are dependent on the internal clock. However, cognitive performance, personality traits such as impulsivity and risk-taking, and various psychiatric disorders have been associated with individual differences in circadian typology (Adan et al., 2012). Circadian typology (CT) is used to categorize the differences in circadian rhythmic patterns among individuals and can be classified into three general chronotypes: morning-, evening-, and neither-type (Horne & Ostberg, 1976). Morning-type (MT) individuals tend to wake early, go to bed at early, and achieve their optimal peak performance early in the day. In contrast, evening-types (ET) wake late, go to bed late, and reach peak performance later in the day. Approximately 40% of the adult population can be classified as one of the two extreme chronotype groups mentioned (Adan et al., 2012). Although research exists demonstrating the effects of time of day on behavioral tasks, few studies have examined the effects of time of testing on EEG activity. Our research attempts to bridge this gap in literature by investigating extreme chronotype, time of day, functional brain activity, and cognitive task performance.

The present study uses four experimental tasks: 1) the Single Outcome Gambling task, 2) a Go/No-Go task, 3) the Sustained Attention to Response Task, and 4) a skilled object manipulation task. However, the primary focus of this thesis is the Sustained Attention to Response Task (SART). The SART is used in the study to measure vigilance and executive control for response inhibition over a given period of time. Results from the SART provide insight into the effects of time of day and CT on cognitive performance in both the behavioral and neurophysiological aspects of impulsivity. The experimental procedure and results from the SART are discussed in later sections while the remaining tasks will be addressed in other reports.

1.1 Circadian Typology

Circadian cycles can be reflected through changes in attention and arousal levels throughout the day. Numerous studies have illustrated a profound relationship between chronotype and neurobehavioral functions, especially for individuals with morningness or eveningness preference (Schmidt et al., 2007). These time-of-day preferences influence cognitive processes and executive functioning, including one's ability to exert self-control, make decisions, and solve problems (Schmidt et al., 2007; Valdez, 2019). Endogenous biological rhythms, governed by the suprachiasmatic nucleus (SCN) located within the anterior hypothalamus, are naturally occurring cycles responsible for shaping human sleep-wake patterns and homeostatic processes (Schmidt et al., 2007). Some of these biological and physiological rhythmic processes serve as markers to identify circadian rhythmicity and are among the several methods used to measure individual differences in circadian arousal patterns. The most common physiological markers include body temperature, cortisol levels, and melatonin levels. However, evidence suggests body temperature is the gold standard of markers in human circadian rhythms because of its connection to CT (Adan et al., 2012). In an attempt to explain the interrelation of physiological CT markers and cognitive performance, Kleitmen (1963) developed the following theory: "Circadian rhythm in metabolic activity modulates brain activity, producing oscillations in cognitive performance. Some cognitive processes show oscillations with a phase similar to the body temperature rhythm" (Kleitman, 1963; Valdez, 2019). This theory has been supported in numerous studies that measured body temperature fluctuations and its relation to cognitive performance on simple tasks of vigilance (Adan et al., 2012), similar to the SART used in our study.

In more recent evaluations of CT, self-assessment questionnaires such as the Morningness-Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976) are used, as they have shown to be accurate and reliable measures of CT. Chronotype questionnaires, like the MEQ, have shown strong correlations to cognitive arousal periods and physiological measures of circadian rhythms previously mentioned (Adan et al., 2012). Questions regarding time-of-day preference on the MEQ are used to determine one's CT on a continuous scale; high scores on the MEQ identify morning-type (MT) individuals, intermediate scores represent neutral-types, and low scores identify evening-type (ET) individuals (Horne & Ostberg, 1976). In the present study, we examined performance differences between MT and ET participants in order to assess whether task performance is modulated by CT or time of day.

1.2 Morningness and Eveningness

All humans have circadian rhythms that fit into one of the three previously mentioned chronotypes. The extreme chronotypes (MTs & ETs) are "phase shifted," meaning their peaks in physiological circadian markers (e.g., body temperature) occur earlier or later in relation to circadian markers of neutral-type individuals, who are synchronized and adapted to external clock time (Schmidt et al., 2007). MT individuals show a phase advance and ETs show a phase delay in circadian rhythms (Valdez, 2019). It's important to note, however, that circadian rhythmic expression can change across the lifespan, due to individual factors such as age and sex, as well as environmental and societal influences (e.g., light exposure; school/work schedule) (Adan et al., 2012). As one ages, circadian preference and cognitive arousal peaks tend to shift to earlier times of day (Riley et al., 2017). Accordingly, 75% of elderly individuals report having a morning preference compared to only 7% of young adults (Curtis et al., 2014).

In addition to endogenous rhythms and diurnal preference, psychological processes and task performance differences have been observed between MT and ET subjects. Studies investigating the relationship between CT and personality traits reported that ET individuals display higher levels of impulsiveness (Adan et al., 2010; Wang et al., 2015), particularly in the prospect of immediate rewards (Sokolowska, 2006; Stolarski, Ledzinska, & Matthews, 2013). Similar findings found that ET subjects tended to be more extroverted, novelty seeking, and had lower scores in harm avoidance, whereas MT subjects tended to be introverted, agreeable, and conscientious of their actions (Adan et al., 2012). When comparing personality traits and cognitive task performance, Song and Feng (2017) demonstrated ET participants showed higher impulsivity through disinhibition and response inhibition during cognitive tasks when compared to MT participants. However, it is unclear whether cognitive task performance is dependent on the individual differences in CT or if performance is modulated by time of day. Despite the growing body of literature on circadian rhythms and diurnal preference, there is a lack of research examining the relationship between chronotype, time of day, functional brain activity, and cognitive performance tasks in an age-controlled sample.

1.3 Time of Day Effects

In order to investigate time-of-day variations on task performance, a desynchrony protocol was used in the present study. Results from similar experiments using a desynchrony protocol have suggested that time-of-day variations may be responsible for the differences in task performance between the two extreme chronotypes (Curtis et al., 2014). For example, MT and ET individuals demonstrate improved task performance when tested in-phase with diurnal preference when compared to performance out-of-phase (Curtis et al., 2014). May and Hasher (1998) provided further support for this claim by revealing that optimal task performance parallels with peak circadian arousal—known as the "synchrony effect." In particular, cognitive efficiency and time of day is best studied using repetitive tasks involving attention and inhibition in order to demonstrate the differences between the MT and ET groups (Lara et al., 2014). More recent investigations using these methods reported significant effects of chronotype and time of day on brain responses that are responsible for inhibitory control on attentional tasks, suggesting that cortical activation levels related to inhibition were significantly higher in MT subjects than it was in ET subjects (Song & Feng, 2017). These assessments provide evidence that time-of-day affects participants' ability to withhold the compulsion to respond when performing tasks that measure attentional impulsivity (Harrison et al., 2007; Manly et al., 2002), similar to the inhibitory control in the SART used in the present study. Impulsivity, from a behavioral perspective, is the inability to suppress undesirable responses and has been associated with various personality traits such as impatience and reward seeking (Lansbergen et al., 2007). Impulsive behavior depends on inhibitory control, or the ability to suppress irrelevant or off-task information and is an essential component to cognitive processes like attention (May & Hasher, 1998). The present study expands on the current literature by exploring the relationship between chronotype, neurophysiology, behavioral task performance, and three types of impulsive decision making— "non-planning", "motor", and "attentional" (based on subscales of the Barrett Impulsivity Scale; BIS11). The present paper highlights the portion of our study that examines attentional impulsiveness using the SART. The SART was used in our investigation because it allowed us to measure the ability to sustain higher-order cognitive functions for an extended period of time and has previously produced accurate measurements of attentional impulsivity when compared to less complex tasks (Harrison et al., 2007). For example, Monk and Leng (1986) demonstrated performance differences in tasks that require more cognitive resources or changes to strategy. However, less effortful tasks, such as visual search tasks, produced no difference between CT.

In an attempt to better understand the neurophysiological aspects of attentional impulsivity, we used an electroencephalogram (EEG) to record the electrical activity in the brain during the SART in behavioral testing sessions. Electrical impulses produced by neurons can be used to measure cortical activity, expressed as brain waves, that differ in frequency. EEG oscillations are categorized according to their range within the frequency bands delta, alpha, beta, and theta. These frequency bands reflect differences in cognitive states that represent levels of alertness and attention.

When examining CT through the EEG, functional changes in the brain were found to reflect task performance as a measure of attention (Van Dongen & Dinges, 2000). In order to interpret task performance in terms of cognitive processing, we analyze event-related potentials (ERPs). ERPs are electrical signals that are generated in response to a stimulus that are often used as a measure of alertness in repetitive tasks (e.g., SART), and believed to reflect circadian rhythm (Venkat et al., 2021). Specifically, the location and amplitude of these ERPs are suggested to demonstrate circadian fluctuations in alertness (Van Dongen & Dinges, 2000). The present study expands on prior investigations that analyzed EEG frequency bands and attention which reported a low theta/beta ratio is associated with impulsivity, whereas elevated theta or theta/beta ratio is associated with hyperarousal (Kitsune et al., 2015). Our experimental setup using EEG recordings for the SART may provide additional support for this evidence by incorporating advanced neural network analyses to assess CT.

In our study, my role as a student researcher included overlooking the SART, hence the emphasis of this task in this thesis and its neurobehavioral relationships. With the assistance of my mentor, Dr. Lee Baugh, and other members of the Baugh Neuro Lab, my role included administering components of the SART and assisting with EEG setup and recording.

2. Hypotheses and Predictions

The present study was conducted to explore the relationship among chronotype, behavioral task performance, and impulsive decision making in an age-controlled sample using a desynchrony protocol. The experiment was designed to address the following hypotheses, as related to the Sustained Attention to Response Task (SART):

Hypothesis 2a. Participants tested outside their diurnal preference will display higher impulsivity, lower accuracy, and less motor perseverance during the SART than when tested in-phase. We believe lower task performance will be observed when participants are tested at their non-optimal times when compared to their optimal time-of-day. That is, ET participants tested at the 8 a.m. testing session will show higher error rates and slower response times in the SART when compared to their in-phase testing time of 6 p.m., and MT participants are expected to have the reverse of these results.

Hypothesis 2b. ET participants will be more impulsive and show less motor perseverance than MT participants regardless of time of testing. Namely, ET participants will perform worse than MT participants when both in-phase (evening testing session) and out-of-phase (morning testing session) of diurnal preference. Previous studies found ET participants to have higher impulsivity and impaired response inhibition when compared to MT participants (Song & Feng, 2017). We expect to find similar results in our SART; ET subjects are hypothesized to perform with less accuracy and faster reaction times, as both are related to impulsivity, and MTs to perform with better response inhibition. The SART is able to measure participants' motor perseverance by examining inhibitory control throughout the prolonged task. Performance in the SART will reflect attentional impulsivity differences between the two extreme chronotypes.

Hypothesis 2c. Behavioral differences in either chronotype (MT vs ET) and testing time (in-phase vs out-of-phase) are hypothesized to be reflected in neuronal network changes using EEG data as assessed through BRAPH network theory. We only expect fluctuations in brain activity if we are first shown significant differences in behavioral task performance, in which we will restrict our EEG data analyses to where any significant task differences may be seen.

3. Method

3.1 Participants

We recruited college-aged participants through fliers posted on the University of South Dakota campus and contacted volunteers from previous Baugh Lab studies through email. The initial study design included 24 extreme morning and 24 extreme evening-type adults to participate in the experiment. However, only seven participants were included in the study before research was halted due to the COVID-19 pandemic. The seven participants included three MT individuals and four ET individuals, as assessed by the MEQ (Horne & Ostberg, 1975). Participants' ages ranged from 18 to 30 years old. College-aged participants were chosen due to age-related differences in motor learning, impulsive decision-making, and cognitive performance. Previous studies that included both elderly subjects and young adults reported a confounding effect due to the effects that aging has on circadian and sleep variations (Schmidt et al., 2007). All of the participants included in the study met the inclusion criteria: scores within the extreme morning or extreme evening chronotypes, reported a regular sleep-wake cycle, had no history of a rotating shift work in the three years prior, and no trans-meridian travel three months before the study. Exclusion criteria included any history of neurological, psychiatric, psychological condition, or history of taking psychoactive medication as these may alter brain wave activity as assessed by the EEG. Table 1 below shows the demographic data of the participants tested.

Description	Evening-Type	Morning-Type
Age	18-30	18-30
Total Participants	24	24
Participants Tested	3	4

Table 1. Demographics of participants.

3.2 Apparatus and Materials

3.2.1 Surveys and Questionnaires. Circadian typology was measured by the Morningness-Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976). This 19-item scale is used to assess chronotype where individuals are categorized as either morning-type, intermediate-type, or evening-type. This widely used scale has been reported as a reliable measure of CT and subjects' correlating behavior (Adan et al., 2012). The Sleep History Questionnaire was used to determine participants' typical sleep-wake patterns. Age, visual acuity, handedness, and questions relating to neurological functioning was evaluated by the Demographic Questionnaire. This form was important in the study to assess any history of psychiatric disorders or any history of taking psychoactive medication as both may affect brain wave activity when recording through the EEG. The MEQ, Sleep History Questionnaire, and Demographic Questionnaire were administered prior to behavioral testing sessions.

Six questionnaires were administered to participants during the laboratory session before completing the tasks: 1) Barratt Impulsivity Scale (BIS; Barratt et al., 1995) is a self-rated 30-item scale used to assess both personality and behavioral constructs of impulsiveness. 2) Sleep History Questionnaire (described above) was administered to participants before testing to ensure they had an adequate amount of sleep before completing tasks. 3) Brief Sensation Seeking Scale (BSSS; Zuckerman et al., 1978) is an

8-item scale used to measure sensation seeking and has been analyzed as a viable measurement by several previous studies. These studies reported that the BSSS accurately measures individuals' sensation seeking, which is associated with risky behavior and predicting substance use (Hoyle et al., 2002). 4) Domain Specific Risk-Taking Scale (DOSPERT; Weber, Blais, & Betz, 2002) is a 30-item scale that was administered to assess risky activity/behaviors in five domains that include ethical, financial, health/safety, social, and recreational. This scale has been determined a valid measure for the degree of risk taking in specific domains (Weber, Blais, & Betz, 2002). 5) NASA Task Load Index (NASA TLX) subjective workload scale is a multidimensional assessment tool that rates perceived workload in order to assess a task. Specifically, this scale was used to determine how much effort, frustration, time demands, mental demands, fatigue, and physical demands factored into the participant's experience of the task and was completed after each experimental task. 6) Self-Control Scale contains items related to the participant's views on their own self-control (e.g., I lose my temper too easily, I often act without thinking through all the alternatives, etc.). Our study used the brief, 13-item version of the scale which assesses subjective levels of self-control (Digdon & Howell, 2008). Finally, an exit questionnaire was given to participants after both laboratory sessions in paper-based form used to assess the participant's overall experience during the course of the study.

3.2.2 Electroencephalogram Recording. During all tasks, we recorded brain wave oscillations through the Baugh Lab electroencephalography (EEG) equipment. EEG recordings were used in the study because circadian rhythm in task performance is believed to reflect functional changes in brain activity due to changes in alertness levels

(Van Dongen & Dinges, 2000). Results from previous studies indicated that cognitive processes involving sustained attention correlate with EEG engagement, such that engagement levels increase with task difficulty (Berka et al., 2007). When analyzing EEG recordings, we used event-related potentials (ERPs) to measure alertness during the SART and analyzed particular band differences to assess attentional aspects of impulsivity. Neural oscillations of focus in this task included delta, alpha, theta, and beta bands, in which we compared the difference in frequencies between morning and evening test sessions for each participant. Several studies indicate circadian variations in alertness can be evaluated in the diurnal changes and can be seen in the amplitude and location of ERP waves (Von Dongen & Dinges, 2000). The EEG recordings allowed us to explore the relationship between impulsivity, motor performance, and cortical activation as participants completed each task.

3.2.3 Task. The Sustained Attention to Response Task (SART) was used to assess attentional aspects of impulsivity. The SART requires participants to maintain continual responses to digits ranging from 0 to 9 (go digit), unless the target digit is presented (no-go digit), to which they must withhold their response. This task demands prolonged attention in order to provide successful response inhibition for the infrequent target stimulus (Lara et al., 2014). Previous studies show a time-of-day effect on overall response inhibition in the SART; that is, successful response inhibition was lower during morning and night testing sessions compared to evening testing sessions (Lara et al, 2014).

3.3 Procedure

3.3.1 Screening. Prospective participants completed informed consent, the MEQ (Horne & Ostberg, 1976), the Sleep History Questionnaire, and a demographic questionnaire using an online survey software tool, PsychData, to determine eligibility prior to laboratory sessions. Participants who scored as either Definite Morning Type (MT) or Definite Evening Type (ET) were deemed eligible for the study and invited to the Baugh Neuro Lab for the laboratory testing phase of the study. Only participants that reported 7-9 hours of sleep in the night before laboratory sessions were allowed to be tested.

3.3.2 Laboratory Sessions. In order to investigate time-of-day variations on task performance, a desynchrony protocol was used in the present study. This protocol enabled us to assess task performance of MT and ET participants at different times of day, once while in-phase with diurnal preference and again when out-of-phase with their diurnal preference. Testing sessions were conducted at the Baugh Neuro Lab at Sanford School of Medicine and were conducted as 2-hour lab sessions on two separate occasions: the first session taking place in the morning (8 a.m.) on one day and the second session in the evening (6 p.m.) on a different day, in counterbalanced order. The present study is unique in that our late testing session is outside of normal working hours (start time of 6 p.m.), whereas most CT studies test in the morning and early afternoon.

On day one of laboratory testing, participants completed the informed consent followed by six questionnaires: the Barratt Impulsivity Scale (BIS), the Sleep History Questionnaire, the Brief Sensation Seeking Scale (BSSS), the Domain Specific Risk-Taking Scale (DOSPERT), the NASA TLX, the Self-Control Scale and an exit questionnaire. On day two of testing, participants again completed informed consent, and three questionnaires: the Sleep History Questionnaire, NASA TLX, and the exit questionnaire. For both lab sessions, the informed consent was provided on paper whereas the questionnaires were completed on a computer as part of the PsychData survey. The NASA TLX online survey was completed by participants after performing each task.

Participants were fitted with a 64-channel electrode cap, used for the EEG measurements that detect voltage fluctuations and related electrical activity while the various tasks were performed. The electrodes on the cap were filled with electrode gel by experimenters using a blunted needle, in which the scalp was lightly abraded in order to lower impedance values. The electrode cap was plugged into the Biopac System data acquisition device used for online recordings of brain wave activity. Brain activity recordings provide information for cortical activation differences when a stimulus was presented to the participant during the SART. The process of completing the questionnaires, fitting the electrode cap and attaching the cap to the recording system took approximately 30 minutes. Figure 1 below illustrates the experimental setup for EEG recordings during the SART.

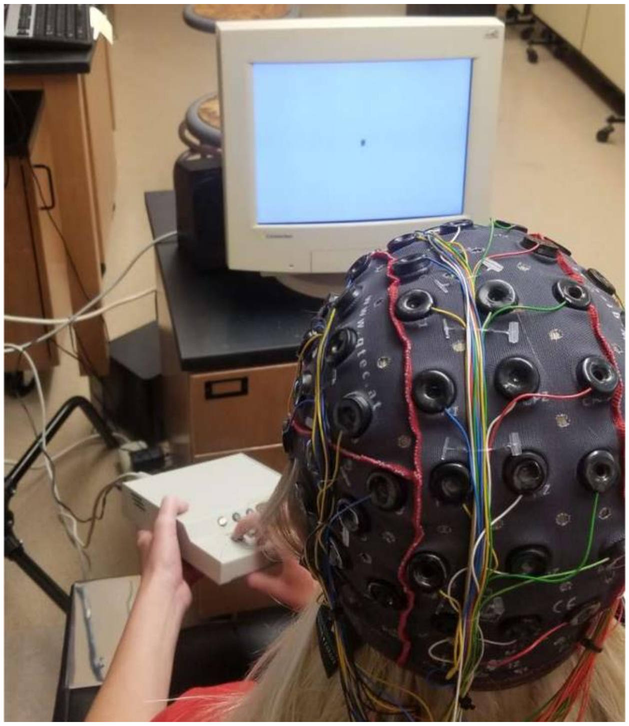

Figure 1. Experimental setup for recording EEG data during the SART. A button box was used by participants to respond to visual stimuli.

3.3.3 Sustained Attention to Response task (SART). Following the EEG electrode cap fitting, participants completed the SART. For the SART, a similar protocol to Lo, Groeger, Santhi (2012) was used to identify performance differences between MT and ET participants as well as differences in the morning and evening testing sessions. The SART is a type of go/no-go task in which a series of single digits ranging from 0 to 9 are presented to the participants. Participants are instructed to respond to each digit presented with the exception of the predetermined no-go target number, (i.e., 3) which they must withhold their response. Participants were instructed to respond to all non-3 digits by pressing a button using their right index finger. The target to distractor ratio used was 15:85 with an inter-stimulus interval of 900 milliseconds. Participants completed the SART over four blocks, with each block lasting approximately four minutes. Individual blocks consisted of 225 digits, with each digit presented 25 times. Experimenters instructed participants to respond to their best ability on both accuracy and speed and were allowed a practice trial before beginning the task.

Participants' performance on the SART was evaluated using the frequency of hits, misses, false alarms, and correct rejections. Correct responses in the trials included hits and correct rejections. A hit was recorded when a response was made on non-target numbers, and a correct rejection was recorded when no response was made on the target number. Conversely, incorrect responses included misses and false alarms. A miss was recorded when no response was made for the non-target numbers, and a false alarm was recorded when a response was made on the target number.

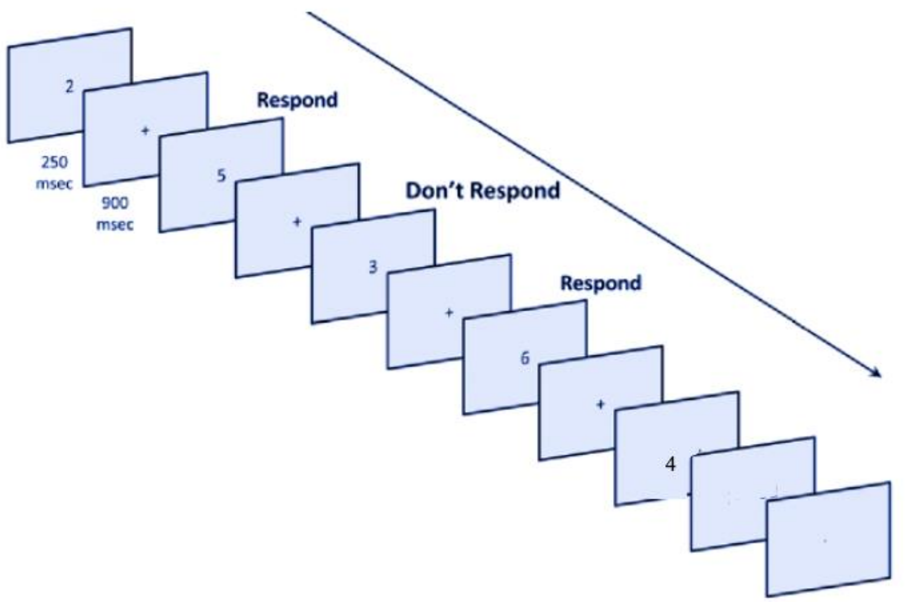

Figure 2. The Sustained Attention to Response Task. Participants viewed a continuous display of numbers ranging from 0 to 9 and were instructed to press a button for all numbers (non-targets), except when the number 3 (target) was presented.

3.4 Analysis

Statistical analyses for behavioral data were analyzed using JASP 0.14.1 (JASP Team, 2020). A significance value of alpha = 0.05 was used for all analyses. In the SART we examined the effects of time-of-day (in-phase vs out-of-phase) and chronotype (MT vs ET) on task performance. Task performance in the SART was measured by reaction time (RT) and accuracy rate, which were later combined into an inverse efficiency score (IES) measurement which we used to appropriately weigh the impact of both RT and accuracy on performance. The RT analysis in the SART included calculating mean reaction times (measured in milliseconds) of correct responses given for non-target digits (i.e., hits). Accuracy rate was calculated as the mean percent correct (PC) responses during the task. The IES measurement encompassed both RT and accuracy in order to control for the speed-accuracy trade off and is calculated as: $IES = \frac{\text{RT}}{1-\text{PC}}$. T-tests were performed on mean RT, accuracy rate, and IES. Dependent-sample t-tests were conducted to compare performance between the in-phase and out-of-phase testing times (within-participants factor). Independent-sample t-tests were conducted to compare performance between morning-type (MT) and evening-type (ET) participants (between-participants factor).

Brain Analysis using Graph Theory (BRAPH) software was used to analyze the EEG data during the SART. This BRAPH software allowed us to observe the functional differences in specific areas of the brain with differing network activity, which was analyzed according to delta (0.5-3.5 Hz), alpha (7.5-12.5 Hz), theta (4-7.5 Hz) and beta (12.5-30 Hz) band differences between participants in the experimental condition. During cognitive tasks like the SART, several brain regions work in unison in order to produce higher-order cognitive functions including sustained attention. Graphs are a representation of the brain networks that consist of nodes (vertices) linked by edges (connections). Here, the edges may represent a structural or functional relationship that exists between the nodes. We characterize the graph by two measures, the average shortest path length between the nodes and the clustering coefficient (measure of interconnectedness of the graph). There are a number of network measures used to detect aspects of functional integration and segregation. For our EEG analysis, the measurements included eccentricity, radius, diameter, characteristic path length, average degree, average strength, global efficiency, local efficiency, clustering, transitivity, modularity, assortativity, and small-worldness. Eccentricity is the maximum shortest path length between a node and any other node, the radius is the minimum distance between any two nodes while the diameter is the largest distance between any two nodes. Further, the characteristic path length is the average path length in the network, the degree of a node is the number of links connected to the node, and the strength is the sum of weights of links connected to the node. Global and local efficiency refers to the average inverse shortest path length in the network, clustering is the fraction of node's neighbors that are neighbors of each other, and transitivity is the connectivity of a given region to its neighbors. Finally, modularity is the degree the network tends to segregate into relatively independent modules, or subnetworks, assortativity is a correlation coefficient between the degrees of all nodes on two opposite ends of the edges, and small-worldness refers to a combination of strong local clustering and short characteristic path length (Van Straaten & Stam, 2013). We used these measures in the EEG analysis for the factor of time of day (in-phase vs out-of-phase testing sessions) because this is where we saw a significant difference in the EIS value for behavioral testing. Though we also collected data for numerous surveys and questionnaires, additional behavioral tasks, and ERPs, those results are outside the scope of this thesis and will not be discussed.

4. Preliminary Results

4.1 Behavioral Results

4.1.1 Reaction Time. The mean of all reaction times was calculated for statistical analyses. T-tests with time of testing (in-phase vs out-of-phase) as the within-participants factor and chronotype (MT vs ET) as the between-participants factor were performed for RT data in the SART. Performance differences between the two extreme chronotypes revealed no significant differences ($p=0.130$) in mean RT between MT participants ($M=276.167$; $SD=91.106$) and ET participants ($M=190.759$; $SD=28.973$), $t(5)=1.809$. Analysis of the time-of-day effects on RT also found no significant differences ($p=0.071$) between in-phase ($M=198.426$; $SD=49.996$) and out-of-phase testing sessions ($M=256.286$; $SD=102.435$). Results for RTs between MT and ET participants and testing in varying phases are shown in Figure 3 below.

4.1.2 Accuracy. The mean percent correct hit responses were calculated for accuracy rate. T-tests were performed similar to that of RT. Analyses of accuracy rate in the SART showed no significant effects in both factors: time of testing (in-phase vs out-of-phase) and chronotype (MT vs ET). Mean accuracy rates did not differ significantly ($p=0.356$) between MT ($M=86.167$; $SD=4.193$) and ET participants ($M=88.750$; $SD=2.598$); $t(5)=1.016$. Similar results were seen for time of testing; in-phase ($M=88.571$; $SD=4.577$) and out-of-phase testing sessions ($M=86.571$; $SD=5.381$) showed no significant difference (p=0.492); t(6)=0.729. Results for accuracy rate of MT and ET participants and testing phase variation are shown in Figure 4 below.

4.1.3 Inverse Efficiency Score. The Inverse Efficiency Score (IES) was used in our study to provide an integrated dependent variable of RT and accuracy rate in the SART. Analysis of the IES value comparing MT (M=2.837; SD=1.508) and ET participants (M=2.178; SD=0.306) did not reveal a significant difference (p=0.420); t(5)=0.878. However, we found a significant difference (p=0.043) between in-phase (M=2.263; SD=0.540) and out-of-phase testing sessions (M=3.003; SD=1.125); t(6)=2.550. IES analysis results for the two extreme chronotypes and testing sessions are shown in Figure 5 below.

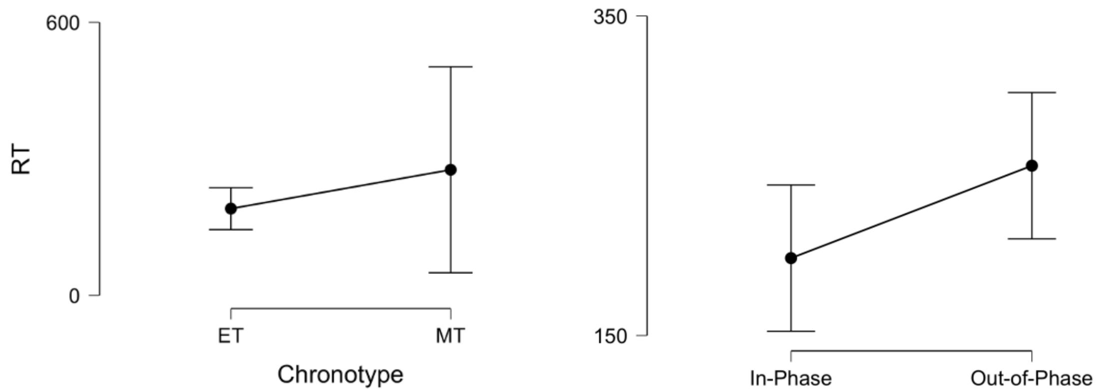

Figure 3. Mean reaction times as a function of chronotype (left figure) and time of day (right figure) in the SART. The left figure shows mean RT variations between the morning-type and evening-type participants. In-phase and out-of-phase variations in RT are shown in the right graph. We found no significant difference in either factor.

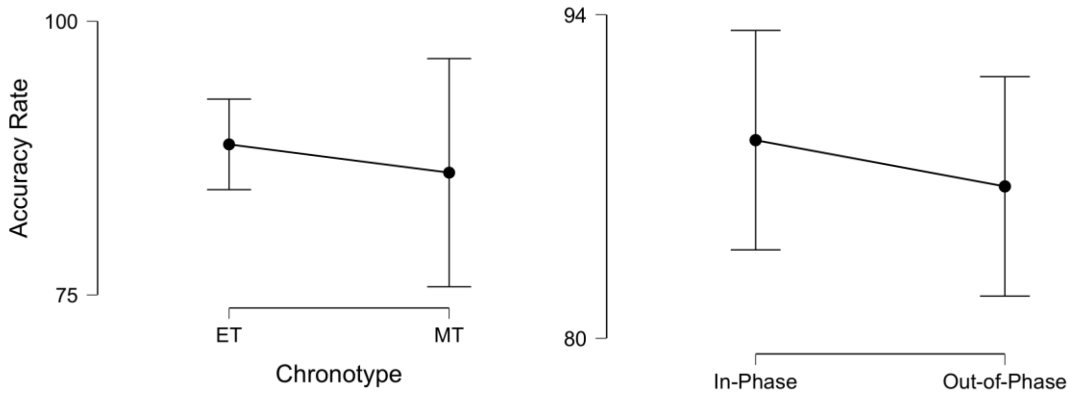

Figure 4. Mean accuracy rate as a function of chronotype (left figure) and time of day (right figure). Variations in accuracy rate between the morning-type and evening-type participants is shown in the left figure. In-phase and out-of-phase mean accuracy rates are shown in the right figure. There is no significant difference found in either factor.

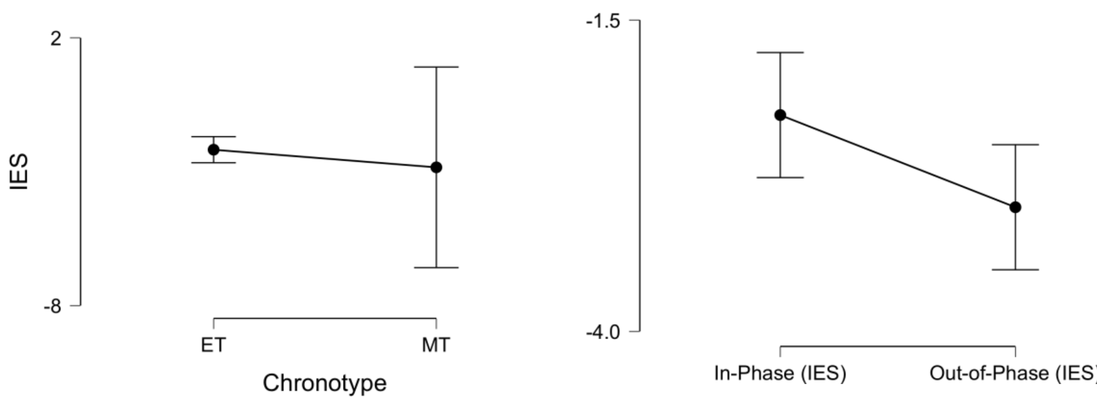

Figure 5. Inverse efficiency score (EIS) as a function of chronotype (left figure) and time of day (right figure). IES results for morning-type and evening-type participants is shown in the left figure. In-phase and out-of-phase performance differences can be seen in the right figure. No significant difference was found between the chronotypes (MT vs ET). Significant differences in the IES value were seen between in-phase and out-of-phase testing sessions.

4.2 EEG Results.

A number of measures were found to be significantly different between phases. These measures include radius, diameter, eccentricity, characteristic path length, characteristic path length within subgraphs, and lastly, small-worldness, all of which having a p-value of $p<0.001$. Results for the significant comparisons are demonstrated in Table 2 below.

Difference	p-value	In-Phase	Out-of-Phase	CI Upper	CI Lower	Measure
-8.0289	1.00E-03	15.5389	7.51	-8.0208	8.0208	Radius
-8.5689	1.00E-03	21.5378	12.9689	-8.5604	8.5604	Diameter
-9.1675	1.00E-03	19.0448	9.8773	-9.1584	9.1584	Eccentricity
-0.12	1.00E-03	3.1273	3.0073	-0.1199	0.1199	Char. Path length
-0.12	1.00E-03	3.1273	3.0073	-0.1199	0.1199	Char. Path length (within subgraphs)
0.1323	1.00E-03	0.6933	0.8256	-0.1322	0.1322	Small-worldness

Table 2. Significant neuronal network differences observed through EEG analyses between in-phase and out-of-phase testing sessions.

5. Preliminary Conclusions

In the present study, we examined diurnal changes in attention, performance, and decision-making properties from a sustained attention task. Preliminary results from our study provide initial support for our hypotheses, although a larger number of participants are needed to validate our conclusions. According to our first hypothesis (Hypothesis 2a), we expected participants to perform worse when tested out-of-phase compared to their in-phase performance. Although we found no significant difference in either RT or accuracy, analysis of the EIS measurement revealed a significant difference in performance when participants completed the SART at their non-optimal time of day. Here, we saw that performance in SART decreased significantly for both MT and ET subjects during the 6 p.m. testing session and the 8 a.m. testing session, respectively. These results indicate that cognitive performance is optimal during peak arousal periods for both chronotypes, indicating a synchrony effect and aligning with previous work suggesting similar phenomena (Curtis et al., 2014). These observations suggest that task performance on attention-based tasks is modulated by time of day when assessing individual differences in chronotype.

In our second hypothesis (Hypothesis 2b), we hypothesized that ET participants will be more impulsive and show less motor perseverance than MT participants regardless of time of day. This hypothesis was not supported by in our results; however, these results may change once we have completed testing for all participants in the initial study design. That said, considering the results of previous work linking ET individuals with higher levels of impulsiveness (Adan et al., 2010; Wang et al., 2015), these results are surprising. One potential explanation could lie in our testing time period. In contrast to most previous work, assessments in the evening were done in the early evening rather than early afternoon. This later testing time may have been more congruent with the ET participants' in-phase time, resulting in behavioral results similar to MT participants tested in the morning. Future studies will be required to further elucidate the connection between impulsivity and ET individuals and whether early afternoon or early evening testing times have an effect on impulsivity. Lastly, brain network activity from EEG data recordings displayed differences between in-phase and out-of-phase testing sessions in the SART. This BRAPH software allowed us to observe the functional differences in specific areas of the brain with differing network connectivity. According to our third hypothesis (Hypothesis 2c), we hypothesized that behavioral differences between chronotypes (MT vs ET) and time of day (in-phase vs out-of-phase) will be reflected in neuronal network changes in the brain as assessed through the BRAPH software. Interestingly, we found significant differences in brain networks between in-phase and out-of-phase testing sessions but not between MT and ET participants. These significant differences in optimal and non-optimal times were found in the following measures: radius, diameter, eccentricity, characteristic path length, and small-worldness. For all of these measures, with exception to small-worldness, the in-phase values were smaller compared to the out-of-phase, suggesting better network efficiency when participants are tested at their optimal time of day. These findings are in line with previous studies demonstrating associations between elevated theta power and hyperarousal (Kitsune et al., 2015) and suggest a connection between hyperarousal and efficiency of neural processing. Further analysis of these network measures is needed to provide a clear interpretation related to the behavioral result differences we saw between phases. These preliminary results may indicate individual differences in circadian typology has an effect on task performance and neuronal processing, especially those requiring sustained attention and inhibitory control.

6. Future Directions

Future investigation for the present study will include testing the remaining participants and gathering data for behavioral data and EEG analyses. Additionally, more in-depth analysis will be performed with the EEG data to provide conclusive results to better understand the brain network activity differences seen during morning and evening testing sessions. Final results from this study will be the first empirical examination of the neurophysiological traits associated with changes in impulsivity as a result of circadian rhythms in a comprehensive set of behavioral tasks. The completed research will provide firsthand knowledge about this specific body-mind relationship and shed light into a novel and innovative hypothesis that circadian typology influences impulsivity and may have implications for the fields of addictive research, mental health, and motor learning.

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