The Effects of Caffeine on Response Time in Young Adults
as Related to Decision-Making

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ABSTRACT

Caffeine is part of day-to-day life for 92% of college students in the United States. While the reasons for choosing to drink caffeinated beverages span from wanting to be more alert to enjoying the taste, the reality is that most young adults do not consider the possibility that caffeine can impact decision-making. Decision-making for young adults is critical as individuals between the ages of 18 and 26 are making more independent decisions. Current research addresses general caffeine consumption as related to decision-making across a broad spectrum of ages and within specific arenas, such as sports; however, there is a gap in literature targeting the impressionable college age population. There is also a need for research that addresses whether the amount of caffeine changes response time in decision-making. This study examined the impact that caffeine had on response time and functional connectivity of 20 young adults. Participants engaged in a two series sequence of tests that included a Go/No-Go Visual Reaction Time Test (GNGT) and an electroencephalogram (EEG). Participants completed a pre- and post- task before and after caffeine consumption. Graph theory analysis was applied to the data, followed by a paired t-test to compare the findings. Results showed a statistically significant change (p-value < 0.05) in functional connectivity for density and the number of connections in the alpha, beta, and mu bands

with 135 mg of caffeine, indicating a more efficient brain network after caffeine intake. There was a statistically significant quicker response time after caffeine consumption of 135 mg.

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Chapter 1. Introduction

Coffee shops and college students are common among young adults in today's generation. In 2025, 92% of college students in the United States self-reported to be caffeine drinkers [1]. The Journal of Health, Population and Nutrition says, 32.7% regularly exceed the safe limit of caffeine based on the Food and Drug Administration (FDA) guidelines [2]. Other studies show that college students are more likely to drink caffeinated beverages when studying to help improve alertness and to help process information at a quicker pace. While studies show that caffeine can improve short term memory, students actually consume the substance with the misconception that caffeine will strengthen the ability to understand content [3].

Caffeine affects the central nervous system of the brain and is commonly known as the "most utilized psychoactive stimulant worldwide" [4]. The drug shares similar properties to other stimulates, such as cocaine and amphetamine [3]. Not only can caffeine be an additive in beverages, it is also a natural substance present in a large number of drinks, foods, and medicines. There are more than 60 plants that contain caffeine [5]. Among these are coffee beans, kola nuts, tea leaves, and cacao beans [4]. With a widespread availability of caffeine and caffeinated products it is no wonder that young adults have become accustomed to having easy access to the substance.

According to the FDA, the maximum safe limit of caffeine for adults is 400 milligrams per day [6]. The average caffeine intake for adults, including young adults between the ages of 18-26 [7], is 135 milligrams daily, which is approximately one and a half cups of coffee. While individuals have varying responses, a general guideline

indicates that caffeine is absorbed in the body within 45 minutes of consumption and remains in the bloodstream between 1.5 hours and 9.5 hours. Once in the bloodstream, caffeine typically peaks between 15 minutes and 2 hours [8].

While recognition that short term memory can show improvement with caffeine intake, there are adverse effects exhibited after consuming caffeine. Among these negative impacts are dehydration, cardiovascular diseases, anxiety, restlessness, and behavioral changes [3], [5]. Since caffeine is a stimulant that influences the central nervous system, it can also play an important role in cognitive function. Caffeine can affect the speed that an individual takes to respond to a stimulus. This response time is called the processing speed, which impacts decision-making abilities [9].

Currently, there is a gap in literature directed toward the impact that caffeine has on the response time of young adults, specifically college-aged students, between 18-26 years of age. Targeting this age group is significant as decision-making is a critical element in the daily lives of college students. For many, college years encompass a new found independence and opportunities to make decisions that have not been afforded previously [10]. The purpose of this study was to examine the response time of college-aged students after consuming varying amounts of caffeine through caffeinated beverages.

Chapter 2. Background

2.1. Physical and Behavioral Impacts of Caffeine

Caffeine causes positive and negative physical and behavioral impacts on the body. Among these positive impacts are improving alertness, strengthening short term memory, and increasing mental awareness. Caffeine can also improve functions of the body, such as reducing neuroinflammation and providing neuroprotection [11]. According to Shuaib, neuroprotection is defined as the protective agent that helps reduce the negative impacts from neurodegenerative and acute diseases on the neural network. Neuroprotection helps to maintain neural function in the brain and reduce possible risks after contracting a disease [12].

However, caffeine absorption in the body can result in negative impacts on physical health. Potential risks that can occur are increased stress and anxiety, restlessness, nervousness, and irregular heartbeat. Other health risks associated with caffeine intake are psychosis, insomnia, and panic attacks [11]. A recent study conducted with college-aged students showed both positive and negative impacts on personal health. Findings from the study were used to conclude that students commonly drank caffeine for the purpose of improving study skills, staying awake longer, or lightening mood. In summary, Bucher offered that caffeine was used by students as a quick source of energy. Based on this particular study, students' reaction times increased with caffeine consumption, and there was evidence of an elevation in mood [13]. Even so, college students are in the adolescent phase of human development, which increases the likelihood that caffeine can result in negative impacts. Bucher also

noted in his findings that increased caffeine consumption has been associated with a delay in brain growth in young adults. Along with potential developmental delays, caffeine in this age group often lead to difficulty sleeping and high systolic blood pressure [13].

2.2. Cognitive Performance

The impact between caffeine consumption and cognitive performance is controversial in research. While some findings show that there is a potential correlation between the two, a recent study by Harvanko, suggests that there is no significant impact in cognitive performance following caffeine intake [14]. In similar studies related to cognitive learning, there is evidence that reaction times vacillate following caffeine ingestion. Specifically, Smith and Maspul agree that motor skills, concentration, and alertness often improve with caffeine consumption, therefore positively contribute to the decision-making process. Increases in cognitive performance have been linked to the interference to neurotransmitters created in the brain by caffeine consumption [15], [16].

While researchers have documented findings that support both positive and negative cognitive impacts from caffeine, most agree that similar variables may contribute to the inconsistencies in studies. Some likely variables that are unaccounted for in research include personal cognitive potential, unknown amounts of caffeine consumption, and physical and environmental factors [14], [16].

2.3. Impacts on Decision-Making

The decision-making process occurs in multiple steps in the frontal lobe of the brain. Steps include neural activity where neurotransmitters transmit messages that

contribute to decision-making [17]. Caffeine is believed to increase dopamine and serotonin levels, which interrupt communication of the neurotransmitters [14], [16]. This interference contributes to the choices made by individuals, thus the decision-making process.

Caffeine consumption and sports appear often in research. Most commonly, studies in this arena look at the impact that caffeine has on sports-related decision-making. After studying decision-making in high school age soccer players, Jafari, summarized findings to show that there was minimal change in low or high level cognitive performance for soccer passes made by twelve players following caffeine intake of 3 mg per kg body mass [18]. These findings are significant to the field of research as the study considered a controlled amount of caffeine, which is often lacking in caffeine related research. Additionally, findings suggest opposition to research that found that processing speed and accuracy increased following caffeine consumption [18].

2.4. Connection Between Response Time and Good Decisions

While there are no exact numbers, research shows that adults make approximately 35,000 decisions per day, compared to children who make between 3,000 and 6,000 decisions a day [19]. With knowledge that college-aged students are faced with heightened decision-making, it is important to capitalize on practices that encourage good decision-making, which include the choice to consume caffeine. Even with years of research, the connection between response time and good decision-making remains inconsistent.

Specifically, DeBoak and Jeon summarize that while longer response times can lead to more accurate responses, this phenomenon is not always true as accuracy

decreases when a response time is too long [20]. However, in a recent study comparing video game players and non-video game players, the response time and accuracy of general decision-making improved for video game players. It was found that there was a quicker response time by approximately 190 milliseconds and the accuracy improved by 2% for video game players [21]. Though inconsistencies exist in research to pinpoint the exact correlation between response time and good decision-making, most research finds that there is some connection [22].

2.5. Electroencephalogram

An electroencephalogram (EEG) is a noninvasive method used to record the brain's electrical activity and to identify irregular brain waves. This method utilizes electrodes, which are metal disks that are connected to an individual's scalp by small wires. An EEG detects the electrical signals from the brain. This EEG process is a safe method with no documented risks of electrical shock and can be used to examine brain waves that are emitted following stimulation. Some examples seen in EEG reports include brain waves studied following relaxation techniques, reading events, flashing light experiences, and viewing images or pictures [23]. EEG results target surface brain waves, rather than processes that occur deep inside the brain.

The electrical signals or impulses used in an EEG are sent to a monitor where a display shows the formation of the brain waves that are recorded from the electrodes that are attached to the brain neurons. The generation of the waveforms are based on the events that occur while connected to the electrodes. Depending on the induced stimulant, the waveform pattern will vary [24]. Most commonly, the brain waveforms from the EEG display are separated on a frequency spectrum. The five brain waveforms

in the spectrum are delta, theta, alpha, beta, and gamma bands [25]. The frequency range for each band is shown in Table 1. The frequency values differ between waveforms, showing that all frequency bands are orthogonal.

Table 1. EEG waveforms and their associated frequency range [25].

Waveforms	**Frequency Range (Hz)**
Delta	0.5 - 4
Theta	4 - 7
Alpha	8 - 12
Beta	13 - 30
Gamma	30 - 80

Delta and theta bands normally occur during sleep or drowsiness and are associated with little activity and can be seen when an individual is unfocused. The alpha band typically occurs from calmness and mental relaxation and decreases from thinking and calculating [26]. The mu band has the same frequency as the alpha band; however, the mu band typically occurs during an action movement or observation during a time of relaxation [27]. Alertness and activity are most often seen in the beta band where problem solving, decision-making, and judgements are made. Gamma band waveforms are demonstrated when the brain is processing information simultaneously from various regions and can be stimulated by agitation or alertness [26]. Using the spectrum ranges and associated descriptions of each waveform, this study targeted the alpha and beta bands.

2.6. Event-Related Potential

According to the National Library of Medicine, event-related potentials (ERPs) are defined as small voltages that are formed in the brain from a stimulus response. ERPs are waveform changes in the EEG based on particular events or stimuli. The events or stimuli that evoke ERPs can be activities related to motor, sensory, visual, or cognitive experiences that occur while recording the brain's activity. ERPs are a sum of postsynaptic potentials formed from "a large number of similarly oriented cortical pyramidal neurons fire in synchrony while processing information" [28].

ERPs consist of two categories that are based on waves and peaks of the brain's activity. The two groups are exogenous and endogenous potentials, which are waveforms characterized by amplitude and latency. Amplitude is measured as the height of the waveform, while latency is the time delay between a stimulus and the response [29]. Exogenous potentials are formed in the early stages of an ERP. They take place directly after a stimulus occurs and before cognition [28], [30]. Endogenous potentials are formed in the late stages of an ERP and occur according to the cognitive responses of the stimuli [30].

When reading an EEG, time of the peaks and waves in the sequence "provide a measure of the brain's communication speed", according to an article written by Artinis Medical Systems. ERP sequences are identified and labeled based on their polarity and latency of the wave. The polarity is the positive or negative direction of the voltage shift. Figure 1 illustrates an ERP waveform.

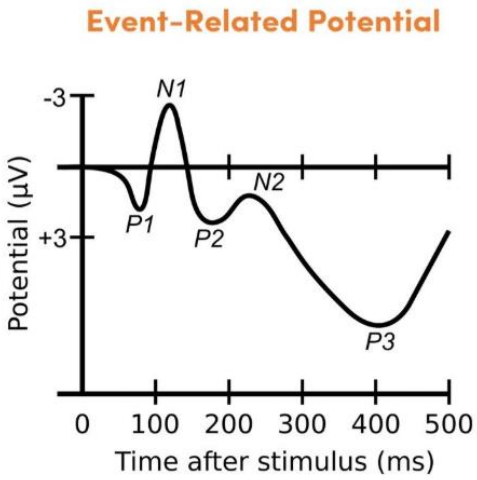

Figure 1. ERP waveform after stimulus takes place [31].

The graph in Figure 1 shows an ERP waveform after a stimulus has occurred. The polarity is represented by the ‘P’ or ‘N’ on the graph showing positive or negative voltages. The number directly beside the letter indicates the time delay of the wave in milliseconds [31]. For example, the ‘P2’ value shows a positive wave occurring after approximately 200 milliseconds. This study uses an oddball paradigm test that targets the P3 or P300 ERP waveform. The waveform typically occurs between 250 and 480 milliseconds. The brain networks and ERP waveforms can be analyzed with functional connectivity (FC).

2.7. Functional Connectivity

Functional connectivity can be analyzed through the temporal concurrence of separate neurological events. When two events or regions have a statistical relationship and have correlated brain activity, they are considered to be functionally connected. FC occurs when the two regions are not directly connected and do not have a causal relationship [32]. ERPs can be analyzed through FC by evaluating the phase

synchronization between the EEG channels at multiple frequency bands [33]. Phase synchronization can detect changes in the brain networks over time when performing multiple trials, showing ERP measurements. Phase synchronization measures include phase locking value, phase lag index, and weighted phase lag index.

Phase measures are calculated using Euler's formula. Euler's formula, $e^{i\varphi}$, is used in the time-frequency analysis to transform complex signals into sinusoidal signals. The angle phi, φ, is multiplied by the imaginary axis to create a frequency domain. The amplitude represents the strength of the signal, and the angle shows the phase of the signal in the complex plane [34].

Phase locking value (PLV) is the measurement to determine the average phase difference between two signals over trials. Figure 2 shows the difference between two signals in frequency and time domain.

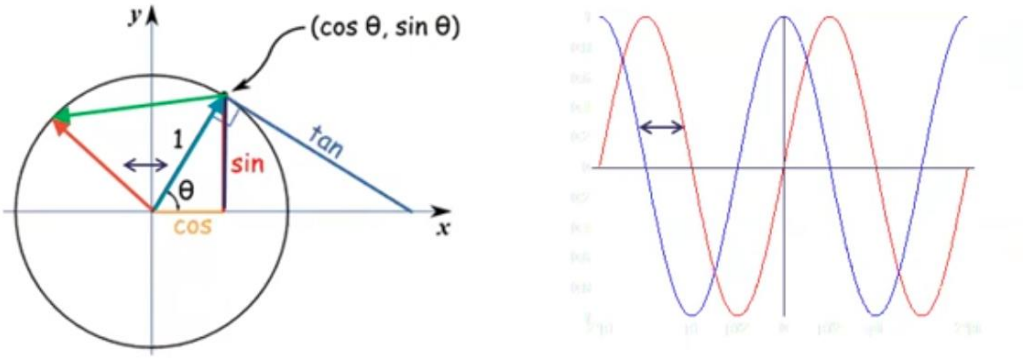

Figure 2. Two different approaches to determine the phase difference between signals. The image on the left shows the difference in frequency domain and the image on the right shows the difference in time domain [35].

Over trials, when the phases for each signal are clustered, the cluster represents phase synchronization. A disadvantage of using PLV is the ability to detect volume conduction. Volume conduction is the conductive characteristics of the brain that result in electrical signals being detected by multiple electrodes, causing misinterpretation between signals connectivity [36]. The mathematical equation for PLV is shown in Equation 1.

$$PLV = \left| n^{-1} \sum_{t=1}^{n} e^{i(\theta^j - \theta^k)} t \right| \quad (1)$$

This equation is the sum of complex vectors at every phase angle. The phase angle is put into Euler's formula to calculate an averaged complex length vector [37].

Phase lag index (PLI) is a measurement used to identify how distributed the phase values are over multiple trials. The PLI values range from zero to one, zero indicating volume conduction and one showing a perfect phase lag, as represented in Figure 3. PLI differs from PLV by the measurement showing the phase difference based on positive and negative angles according to the horizontal real axis, disregarding phase locking. If the phase difference is centered around 0 or π, it is often due to volume conduction. This indicates that the same signal was picked up by different electrodes [38].

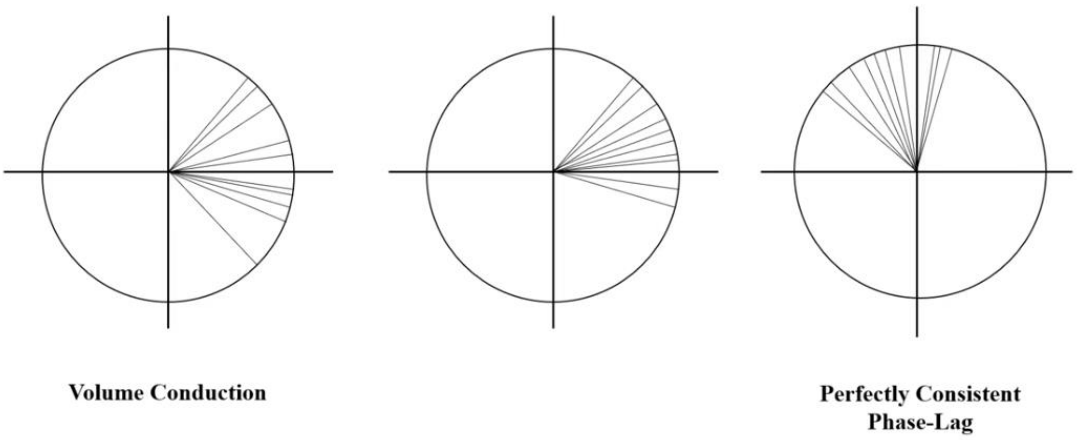

Figure 3. Three possible outcomes for PLI are shown. The left image has a PLI of 0, indicating there is volume conduction. The image to the right has a PLI of 1, showing a strong phase lag. The center image is showing a PLI of 0.4, a phase difference between the two extremes [39].

A disadvantage of using PLI is that the functional connectivity can be impacted by surrounding noise, creating false changes in connectivity. To overcome possible errors, weighted phase lag index could be utilized [36]. The calculation for PLI is shown below in Equation 2.

$$PLI = \left| n^{-1} \sum_{t=1}^{n} sgn\left(Im\left[e^{i(\theta^j - \theta^k)} t \right] \right) \right| \quad (2)$$

The equation for PLI is similar to equation 1 used for PLV. Both calculations use Euler's formula to compute complex vectors. Equation 2 includes two additional operations (*Im* and *sgn*). The first operation is projecting the complex vectors onto the vertical imaginary axis. Each vector becomes a point on the imaginary axis. The next operation is a sign indicator. This transformation adds a negative or positive sign to the vector points that are projected on the imaginary axis. The value is either -1 or 1,

depending on which side of the vertical axis the vector points are on. Resulting in an average PLI value [40].

Weighted phase lag index (wPLI) is a measurement improvement of PLI that calculates the same cross-spectrum imaginary components. The difference between the two measurements is that wPLI is the magnitude of the components, which helps reduce any false changes from phase differences centered on the real axis. The weighted portion of PLI ensures there is less influence from the smaller phase differences around the real axis and more value from the larger phase differences, reducing volume conduction and noise disturbances [41]. The weight difference in PLI can be shown below in Figure 4.

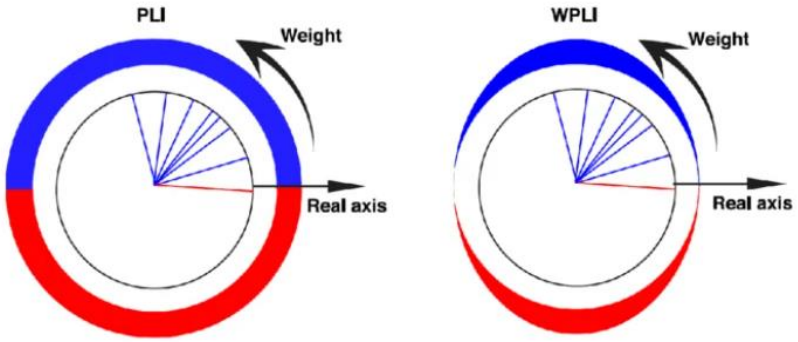

Figure 4. The difference between PLI and wPLI on the unit circle. The blue lines on the unit circle represent the phase difference between signals and the red lines indicate noise disruptions that cross the real axis. The image on the left shows PLI, while the right image is wPLI. The wPLI focuses more weight value on phase differences away from the real axis and lowers the value of the phase difference around the axis [42].

Reducing the effect that volume conduction and noise have on phase index, provides a more accurate estimate of phase synchronization. wPLI has high sensitivity levels to remove any unwanted data and provides a reliable functional connectivity analysis with the data collected over trials. Equation 3 is the mathematical equation for wPLI.

$$WPLI = \frac{|E\{|\Im(Z)|sgn(\Im(Z))\}|}{E\{|\Im(Z)|\}} \quad (3)$$

wPLI is a composition of the imaginary component of the cross-spectrum. Any unwanted artifacts and noises receive a smaller value, as they are closer to the real axis. Ensuring a better quality index value than PLI [41].

2.8. Graph Theory

The application of graph theory is used to model the human brain structure and functional connectivity. The topological graph shows the connections between neural networks in the brain through nodes and edges to create an adjacency matrix. The nodes, or vertices, represent the specific neurons or brain regions, while the edges, or connections, are the networks between the nodes that connect them together [43]. The adjacency matrix is represented by an N×N matrix made up of the nodes and edges. The number of nodes, N, are displayed in the matrix and the edges are characterized by the value of the network connections creating a binary or weighted graph network. Graphs can either be classified as undirected or directed based on the directional information from the network connections as shown in Figure 5 [44].

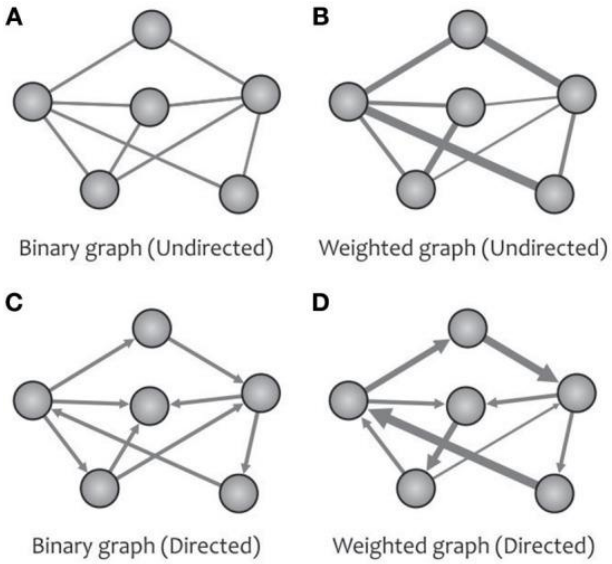

Figure 5. Graph networks can be classified in four categories. A) Binary graph that is undirected. B) Weighted graph that is undirected. C) Binary graph that is directed. D) Weighted graph that is directed [44].

The edges in a binary graph either have present or absent connections, resulting in a 0 or 1 output value, while weighted graphs are represented by a zero or non-zero value based on the strength of the connections [45]. Graph theory can be classified in measurements of clustering, pathway, and centrality.

Clustering is a measure to determine the close relationship between nodes of the network. If the nodes are closely related, the nodes form a cluster. The clustering coefficient in the relationship of nodes to a common node in the network [46]. Clustering can be seen in Figure 6.

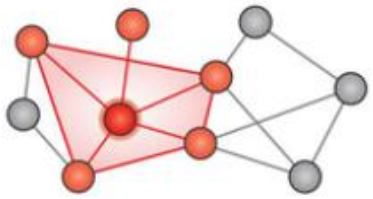

Figure 6. Coefficient clustering structure of a network showing close relationships [47].

Multiple clusters can form a module or community. A module is a group of tightly formed nodes that lack a connection to other nodes outside their community [48]. A high modularity is having numerous links inside the network module. This refers to having strong clusters within a module. Figure 7 shows a network containing five different modules with a strong modularity.

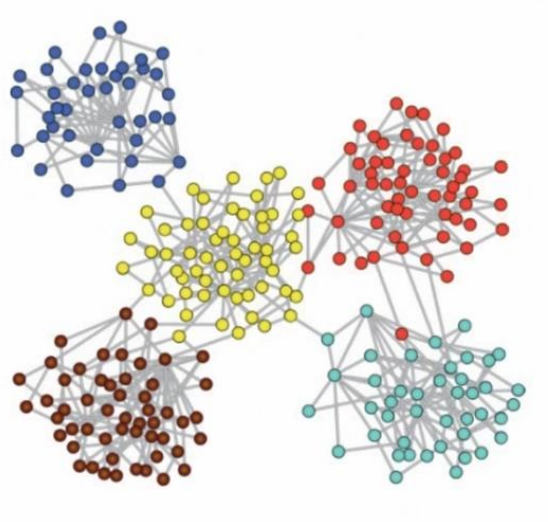

Figure 7. Five tightly formed modules within a network [46].

The pathway in a network is used to find the most efficient path to travel from one node to another. A pathway goes from one node to an edge followed by another node. The most efficient path is formed by the average of path lengths in the network. This is the shortest path length or hopcount of the network. The number of lengths is calculated

by the number of edge lengths between the two nodes [46]. The shortest path length of a network can be shown in Figure 8.

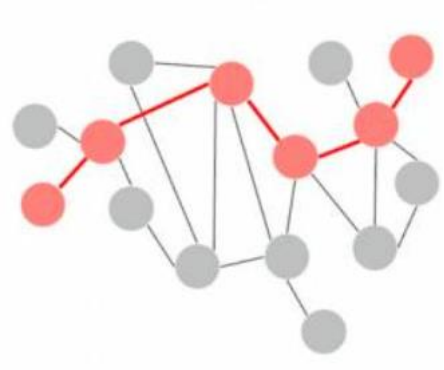

Figure 8. Shortest path length within a network [48].

Centrality measures the importance of a specific node within the network. The node can influence or be influenced from the network connections. Centrality is referred to as the small-world property, due to nodes being close to one another even inside a larger network [46]. Measurement methods of centrality consist of degree, betweenness, closeness, eigenvector, and PageRank centrality.

Degree centrality measures the number of edges that are connected to the central node. This is the most basic measure of centrality. A disadvantage of using degree centrality is that all connections in the network are weighted the same, rather than the impact of each connection [48]. Degree centrality can be seen in Figure 9, where the degree of the red node is three.

Figure 9. Degree centrality determines the number of edges connected to a node [48].

Betweenness and closeness centrality are measured using the shortest path length of the network, as shown in Figure 10. Betweenness centrality finds the importance of a node connection within the shortest path of two nodes. It is measured by the number of times the node can be used as a bridge between the pair of nodes. Closeness centrality refers to the speed at which a node can reach any other node in the network. It is measured by the average distance of the shortest path between a node and any other nodes [48]. A node has a high closeness centrality when the path length is short.

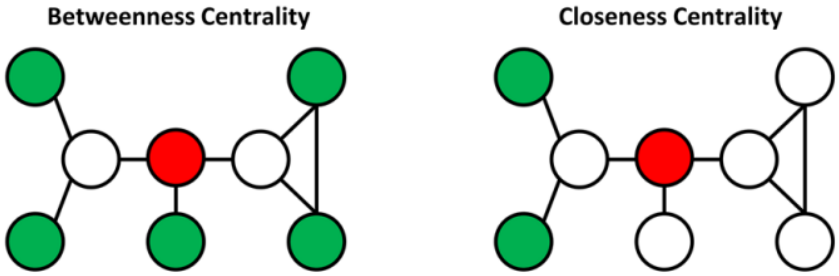

Figure 10. Betweenness and closeness centrality use the shortest path to find the most influential node connections in the network [49].

PageRank and eigenvector centrality are similar to degree centrality, while taking the degree of the neighboring nodes into account. Eigenvector centrality calculates measurement with the influence node connections have on a specific node. The importance of the node is determined based on the degree of importance of the surrounding nodes. PageRank centrality is a variation of eigenvector centrality; however, the method is designed for directed networks, while eigenvector centrality is commonly used for undirected networks [48]. The two centrality methods are shown in Figure 11.

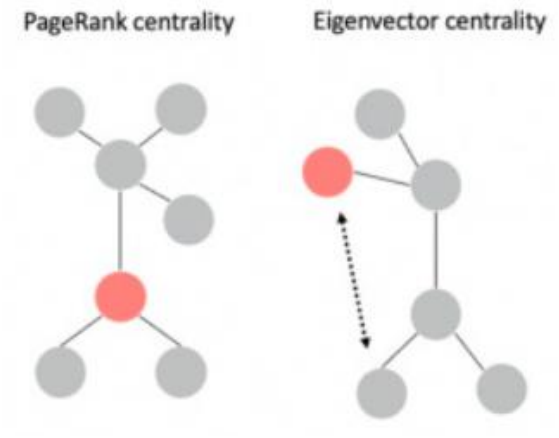

Figure 11. PageRank and eigenvector centrality determine importance of a node based on the connections to neighboring nodes [48].

The most utilized measurement of graph theory is centrality [48]. Graph theory analysis is utilized to measure the functional connectivity and efficiency of the brain networks [44].

Chapter 3. Thesis Hypothesis

3.1. Objective

The objective of this research is to determine the effects that caffeine has on response time in young adults. An experiment will be conducted using an EEG to record the brain activity of young adults, while engaging in the Go/No-go Visual Reaction Time Test. With 92% of college-aged students reporting caffeine consumption, the target audience is college students between the ages of 18-26. The reaction test, along with an ERP analysis, will provide data that will be used to identify the response time of decision-making based on caffeine impact.

3.2. Hypothesis

H_0: It is hypothesized that there is not a significant difference functional connectivity and response time with 135 mg of caffeine consumption in young adults.
H_a: It is hypothesized that there is a significant difference in functional connectivity and response time with 135 mg of caffeine consumption in young adults.

3.3. Significance

The study has the potential to increase awareness of the effects that caffeine has on young adults. Results of this study can be used to help educate college-aged students about positive and negative impacts that caffeinated beverages can have on physical, behavioral, and cognitive performance. Specifically, findings will contribute to the body of research on the relationship between caffeine consumption and decision-

making. The study will also help fill the gap of how caffeine alters brain activity in young adults where there is currently minimal literature that targets this population.

Chapter 4. Methodology

4.1. Subject Recruitment

This study consisted of 20 healthy young adults ranging from 18 to 26 years of age [7]. The participants were required to eliminate caffeine intake 24 hours before beginning the study. The sample size was calculated through the Minitab Statistical Software using the ‘Sample Size for Estimation’. Based on the sample size used in similar studies, the sample size for this study was calculated using the standard deviation and a two sided confidence level of 95%, resulting in a sample size of 20 subjects, as shown in Figure 12.

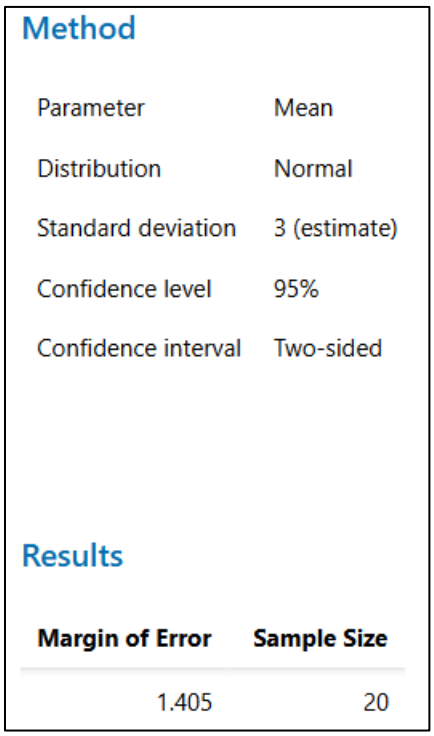

Figure 12. The sample size estimation for the study with confidence level.

The 20 participants were eligible candidates for this study based on the following inclusion criteria from a screening questionnaire: (1) Between the ages of 18 and 26 years old; (2) No history of neurological conditions; (3) No prior brain injuries; (3) No history of kidney diseases; (4) No history of heart conditions; (4) No current use of psychiatric medications; (5) No current substance use; (6) Normal or corrected-to-normal vision; (7) No current pregnancies. Individuals willing to participate provided contact information on the screening questionnaire. Individuals unwilling to participate did not provide contact information and remained anonymous. Individuals that expressed interest in participating in the screening questionnaire were excluded from the study if they did not meet the inclusion criteria. Individuals that expressed interest in participating and met the inclusion criteria were contacted by the researcher.

Subjects were required to sign a consent form, approved by the University Medical Center Institutional Review Board (UMCIRB), agreeing to participate in the processes and procedures outlined in the study. The subjects were given an informed consent document and a detailed explanation of the procedures. The potential participants were provided an opportunity to ask questions before agreeing to participate in the study. Once informed consent was confirmed, a Likert Scale questionnaire was completed by the participant. Processes and procedures in the study included a questionnaire, consuming a caffeinated beverage, taking a Go/No-go Visual Reaction Time Test, and participating in an EEG.

4.2. Data Collection

There were two series of tests for each participant. The data collection within the study included pre- and post- tasks for a Go/No-Go Visual Reaction Time Test (GNGT)

and an EEG in each of two sessions with varying amounts of caffeine consumption. The GNGT is an accepted method to compare response time results. The EEG recordings were used to determine the functional connectivity change before and after consumption. The first task was a GNGT. This is a cognitive reaction test that is based on response inhibition. In various studies, caffeine has shown to impact brain networks associated with attention, cognitive performance, and reaction time [50]. Participants reacted to stimuli on a visual screen. If the go visual was present, then the participant pressed a button on a mouse to indicate their response. If the no-go visual was present the participant did not respond. This task recorded the response time based on the reaction to the provided stimuli [51].

The second task was an EEG recording after the GNGT was completed. A g.Nautilus Research dry EEG cap was used for the recording. The 64 electrode cap was placed on the participant's head based on the 10-20 international system setup. The electrodes were placed in positions of the frontal, central, parietal, and occipital regions of the brain. The ground and reference electrodes were placed behind both ears [33]. Figure 13 shows the EEG cap used for this study.

Figure 13. The g.Nautilus Research dry cap headset [52].

While the EEG recording was taking place, the participant was in a dark room with white noise. The study occurred individually in separate settings. Participants were required to minimize movements during the test, including blinking, in an effort to avoid any disruptions in the recording. The baseline measurement was recorded first to provide a control set for the data gathered during the later task. During the EEG recording, there were stimuli present using a visual oddball paradigm test that was displayed on a screen directly in front of the participant. Instructions were given to the participant, followed by the paradigm beginning and running for five and a half minutes. The visual paradigm displays target stimuli in approximately 10% of the images, which is intended to provoke alertness and attention [53]. The paradigm consisted of two categories, either familiar faces or random objects. The three familiar faces were Dwayne Johnson, Barack Obama, and Robert Downey Jr. There were twenty random familiar object images, such as a clock face, a flower, and a bowling ball. A random image was shown on the screen for 0.175 seconds, followed by a black screen for 0.625 seconds. There was a total of 0.8 seconds between each image. The participant pressed a button on a mouse to indicate a response, as they did in the GNGT. Responding to the stimuli with the mouse helped ensure that the participant was alert and focused. This task prompted the P300 ERP waveform. The data was processed through MATLAB using the EEGLAB toolbox [33].

Following the initial GNGT and EEG, the participants consumed a randomly determined amount of caffeine through a Celsius energy drink. A Celsius drink was chosen based on the caffeine levels of the beverage and the characteristic that the beverage does not contain sugar, which minimized external impacts in the results [54].

The study was a blind study where the participants were not made aware of the amount of caffeine in the beverage provided. The amount of caffeine chosen to use within each Celsius energy beverage was determined in accordance with the average daily adult consumption of caffeine in compilation with the safe amount, of 400 mg, of caffeine per day based on FDA approved guidelines [6], [8], [54]. Within the two segment series of testing the amount of caffeine consumption varied: (1) 135 mg of caffeine; (2) 200 mg of caffeine. The series was conducted in two separate sessions. Based on the amount of time it takes for caffeine to be absorbed in the body, there was a 45 minute wait time before administering the post- tasks following caffeine intake [8].

4.3. Pre-processing

The raw data from the EEG recording was preprocessed through MATLAB using the EEGLAB toolbox. The data was then filtered to remove any unnecessary noise or artifacts from the recordings, which includes surrounding noise and movements, such as blinking. The data was preprocessed using 60 channels to remove any potential blinking artifacts. A bandpass filter with cutoff frequencies of 5 Hz and 30 Hz was applied to the data to remove the noise and artifacts. Once the data was filtered, the data was segmented into epochs. The start of the epoch occurred 100 ms before the stimulus appeared and then continued 700 ms post stimulus. The familiar faces were the target stimuli in this study. This was time-locked for every stimulus to occur at the same time, 0 ms. ERPs were created by averaging the time-locked trials for the target images.

4.4. Time Domain Analysis

There were a total of 54 target ERP trials over one EEG recording. Each target image was shown 18 times during a recording. To create an ERP waveform, the total trials were averaged. The oddball paradigm was intended for the subject to react approximately 300 ms after the stimulus was present [55]. EEG signals often pick up interferences, such as blinking and moving. Due to this possibility, any unwanted artifacts were removed through a process of trial rejection. Epochs were excluded from the data if they contained any unnecessary interferences [33]. The analysis resulted in a precise P300 waveform for each channel.

4.5. Functional Connectivity Analysis

Functional connectivity was calculated using East Carolina University's Sensory-Motor Integration Lab (SMILe) toolbox in MATLAB. The toolbox was used to calculate the wPLI and create an adjacency matrix from the preprocessed data. The time-frequency analysis was formed using the Morlet wavelet from the provided toolbox. The Morlet wavelet transforms an ERP signal into a complex signal that is used to obtain the phase at every time point. This computes the cross-spectrum data, creating a five dimensional matrix.

$$\text{Channels} \times \text{Channels} \times \text{Frequency} \times \text{Time} \times \text{Trials}$$

The data was then split into frequency bands of theta, alpha, mu, and beta. The individual bands were used to calculate connectivity at each time point, generating a four dimensional matrix.

$$\text{Channels} \times \text{Channels} \times \text{Time} \times \text{Simulations}$$

This matrix was calculated using the Monte Carlo simulation. The Monte Carlo simulation utilized random sampling by randomly taking 75% of the total trials to estimate a constant result [56]. The trials were averaged and the wPLI was calculated to compute a three-dimensional adjacency matrix. The matrix is the number of channels twice multiplied by the time to show the FC output.

4.6. Graph Theory Analysis

The adjacency matrix results from the FC analysis show the connectivity between the channels. Graph theory measures transform the matrices into brain networks. The nodes in the graph represent each channel and the edges are the connections between the channels. The network connections are weighted based on the wPLI from the previous analysis. Graph theory shows the efficiency of the brain networks and the graph theory measurements that are utilized between the connections. This analysis was applied to determine the connections of the brain networks for each group of subjects pre- and post- caffeine intake.

4.7. Statistical Analysis

A statistical analysis was conducted using a paired t-test to determine the difference between the pre- and post- response times with caffeine consumption for each group. A paired t-test was calculated for session one and session two, to compare the response time before and after intake of both caffeine levels. The statistical test shows the difference of the averaged pre- and post- subject results, with a 95% confidence interval (significance level of $\alpha = 0.05$) [57]. The p-value was calculated to determine if the data was statistically significant. The post- test was dependent on the

caffeine intake prior to recording. Session one and session two are independent to each other, as they do not impact the outcome of response times.

The effect size was calculated for each session to determine the size relation between pre- and post- caffeine intake. The effect size is the magnitude of the differences between the two groups. The p-value findings conclude if the data is statistically significant, while the effect size informs the research of the size difference between two groups. A higher effect size shows a larger difference between groups. Cohen's d is an effect size measure that is commonly used for comparing the two group mean values [58]. The effect size was calculated for session one and session two comparing the pre- and post- response times.

Chapter 5. Results

From the 20 subjects that participated in the study, 19 data sets were analyzed, and 2 subjects did not complete session two. There were 19 sets of data for session one and 17 sets of data for session two. The GNGT was used to report the average response time for each subject before and after caffeine consumption. The results from this task are shown in Table 2, along with the change between pre- and post- response times for each session. Most subjects had a quicker response time after caffeine intake in session one; however, majority response times slowed down after caffeine in session two.

Table 2. Pre- and post- average response times for each subject during session one and session two.

Subject	Pre-Session 1	Post-Session 2	Change in Session 1	Pre-Session 2	Post-Session 2	Change in Session 2
01	0.389	0.352	-0.037	0.354	0.35	-0.004
02	0.394	0.332	-0.062	0.324	0.319	-0.005
03	0.401	0.367	-0.034	0.366	0.321	-0.045
04	0.392	0.351	-0.041	0.3	0.326	0.026
05	0.375	0.376	0.001	0.31	0.308	-0.002
06	0.329	0.28	-0.049	0.347	0.284	-0.063
07	0.379	0.404	0.025	Not applicable	Not applicable	Not applicable
08	0.348	0.342	-0.006	0.292	0.337	0.045
09	0.369	0.371	0.002	0.358	0.357	-0.001
10	0.366	0.352	-0.014	0.407	0.349	-0.058
11	0.388	0.376	-0.012	0.367	0.395	0.028
12	0.383	0.354	-0.029	0.38	0.372	-0.008
13	0.321	0.303	-0.018	0.333	0.325	-0.008
14	0.389	0.325	-0.064	Not applicable	Not applicable	Not applicable
15	0.365	0.369	0.004	0.326	0.352	0.026
16	0.361	0.355	-0.006	0.344	0.346	0.002
17	0.489	0.359	-0.13	Not applicable	Not applicable	Not applicable
18	0.364	0.385	0.021	0.323	0.363	0.04
19	0.385	0.333	-0.052	0.338	0.342	0.004
20	0.41	0.334	-0.076	0.334	0.31	-0.024

The pre- and post- average response times for session one are shown in Figure 14. The plot illustrates the change in response times for each subject, showing an overall quicker response after caffeine.

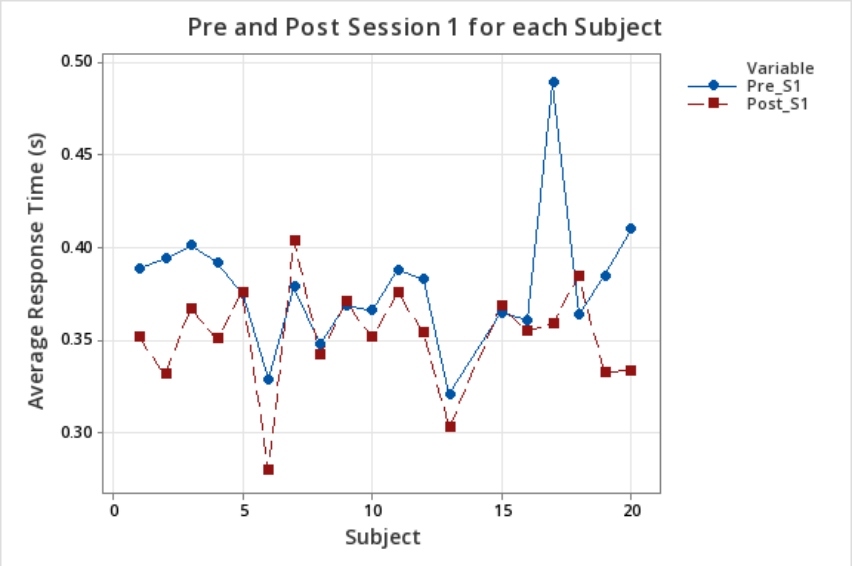

Figure 14. Pre- and post- response times for each subject during session one.

Session two's average response times for each subject had more variation than session one. The plot in Figure 15 displays the average response times before and after caffeine consumption. This shows that the data was inconsistent with some participants having a quicker or slower response after caffeine.

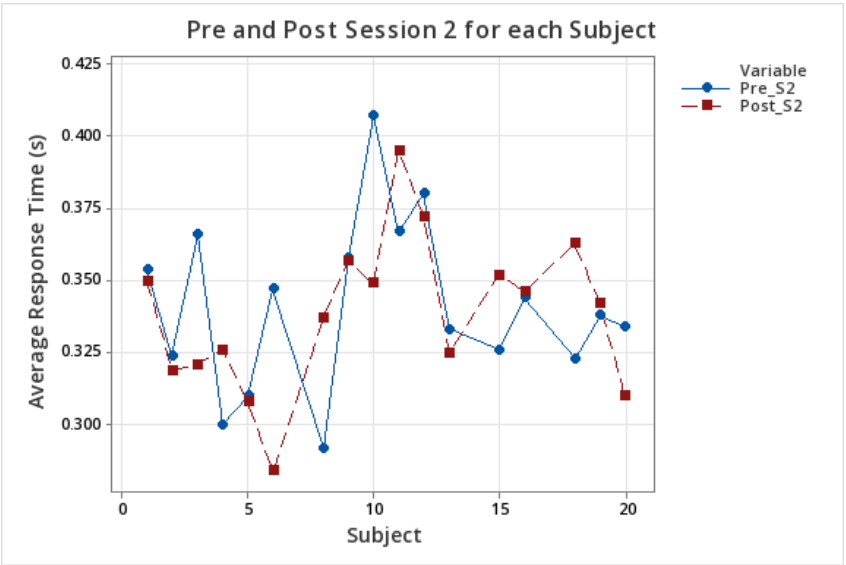

Figure 15. Pre- and post- response times for each subject during session two.

The average response times for pre- and post- of session one can be seen in Figure 16 in boxplots. The plot highlights the differences in the mean response time and the range of response times. Prior to caffeine consumption, the average response time for all subjects was 0.379 seconds. After consumption, the average response time decreased to 0.352 seconds.

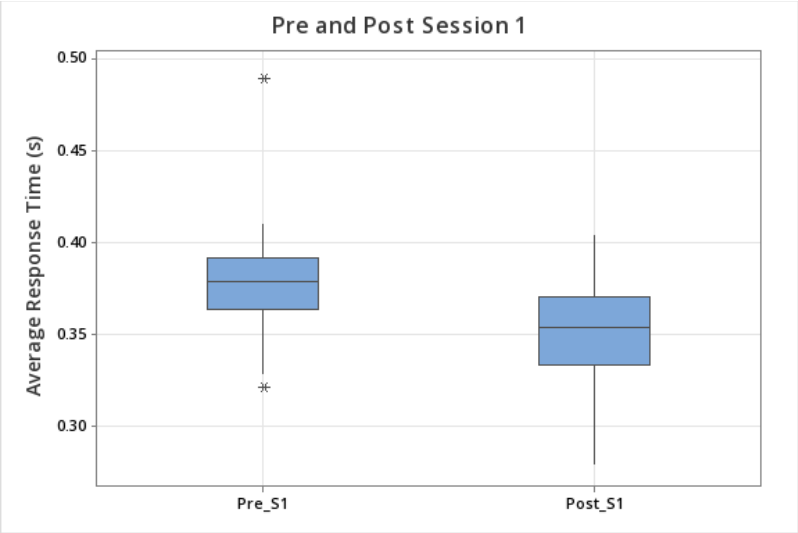

Figure 16. Average of subjects' pre- and post- response times during session one.

Session one was statistically significant between pre- and post- caffeine intake with a p-value of 0.005. The effect size was 0.730, showing a strong change in response time after consumption. The average response times for session two are shown in the boxplots in Figure 17. The mean value of subjects' response times for pre-caffeine was 0.341 seconds, while the mean value for post- caffeine was 0.339 seconds.

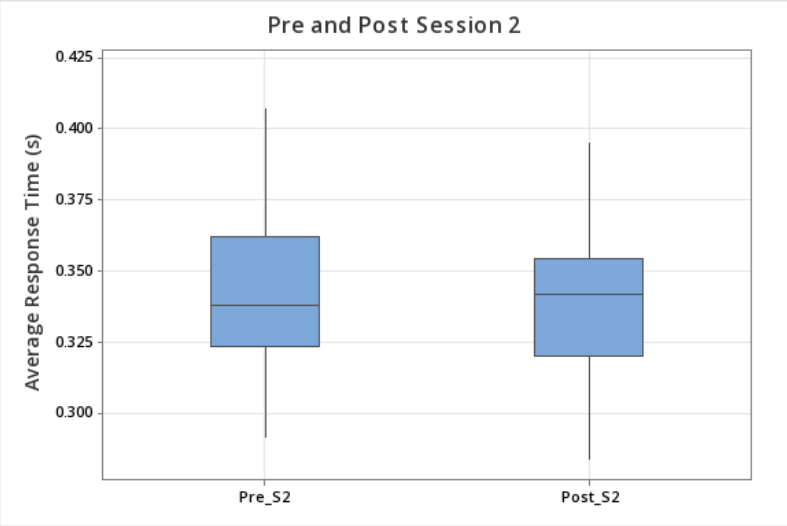

Figure 17. Average of subjects' pre- and post- response times during session two.

Session two was not statistically significant as the p-value was 0.721. The effect size was 0.0879, which shows minimal change in response time. The average response times for both sessions were quicker with caffeine intake; however, the majority of subjects had less change in their response time during session two. Figure 18 shows the change in response time for each subject before and after caffeine. Overall, the response times got slower after caffeine in session two as compared to session one.

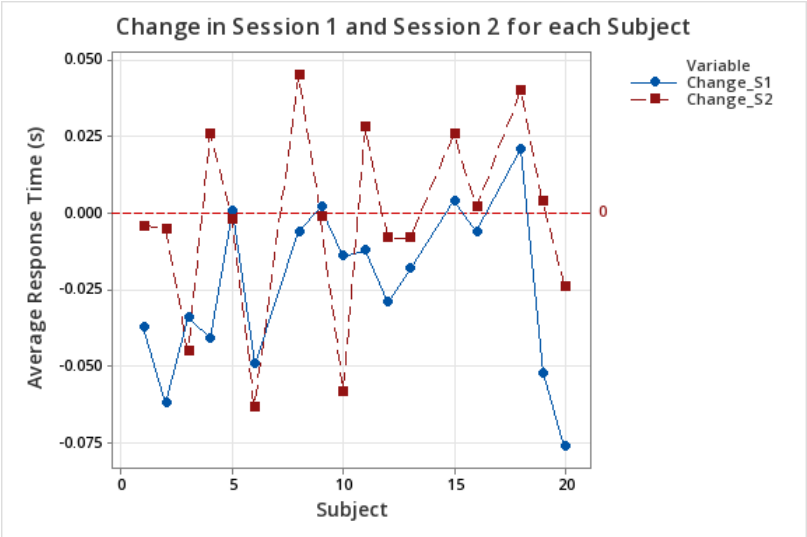

Figure 18. Change in response times over session one and two.

The positive values in Figure 18 represent a slower response time after caffeine consumption, which increases the response time for the subject. When subjects had a quicker response time, they had a negative change value, due to losing time.

Adjacency matrices were calculated and assessed for pre- and post- caffeine intake. The matrices showed the functional connectivity over the 60 channels. The network connections are weighted based on wPLI. A high functional connectivity is represented by a brighter yellow color, and a low connectivity is a darker blue color. The adjacency matrix for session one in the beta band is shown in Figure 19.

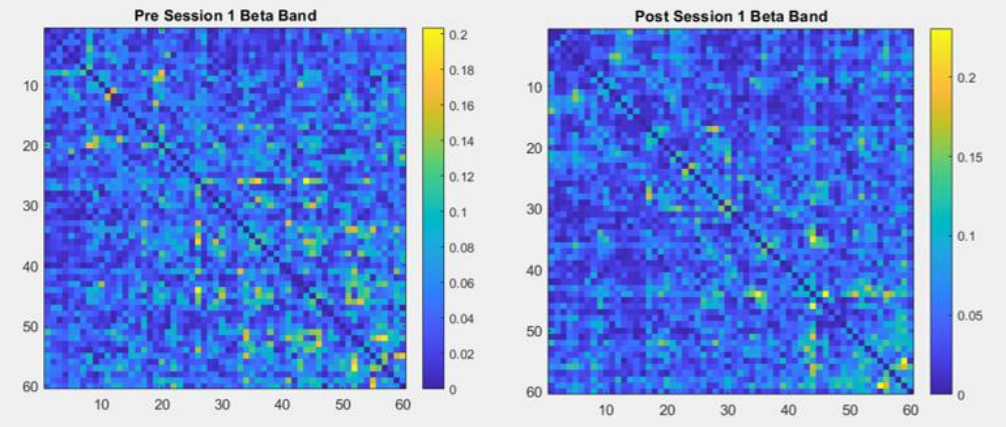

Figure 19. Adjacency matrices for pre- and post- drinking caffeine in session one for the beta band.

A variety of graph measures were analyzed to determine the changes in connectivity before and after caffeine intake. Each measure was tested under four frequency bands that included alpha, beta, mu, and theta bands. For each of the measures, the pre- and post- results for all subjects were averaged together to show the overall difference. There was a consistent decrease in the global density over the alpha, beta, and mu bands. The number of connections in the network followed the same trend

as global density. Based on the effect size and p-values, these graph measures show the most statistically significant changes in the connectivity among the network. Figure 20 shows the average change in density and the number of connections in the alpha band for pre- and post- of session one.

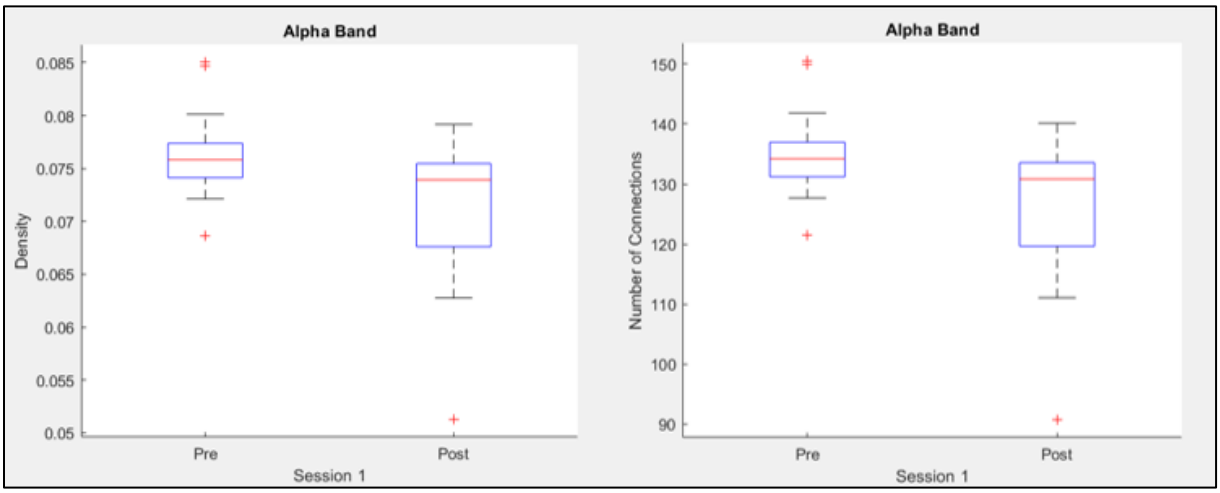

Figure 20. Change in density and number of connections in the alpha band for session one.

The effect size shows a decrease in size after subjects consumed caffeine. The effect size was 0.808, indicating a strong decline in size. The p-value for the alpha band was 0.00646. The p-value shows that the data is statistically significant in the alpha band for the global density and number of connections. Density and connections are closely related, where density is the number of connections divided by the total possible number of connections. These values indicate that there was a loss in large network connections and an increase in local connectivity in the alpha band. The beta band from session one is shown in Figure 21.

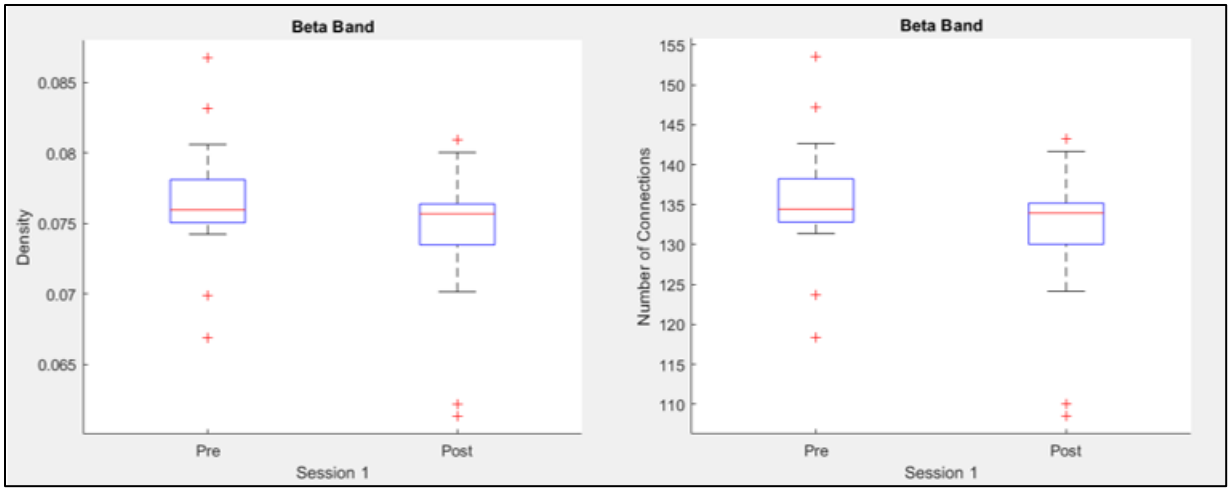

Figure 21. Change in density and number of connections in the beta band for session one.

The beta band shows statistically significant results in the density and number of connections measures. The effect size was 0.526, showing a another decrease in size post- caffeine intake; however, the change was not as large as it was during the alpha band. The p-value was 0.0396 for density and the number of connections. This resulted in a loss in network connections and increased local connectivity in the beta band. The mu band for global density and the number of connections from session one can be seen in Figure 22.

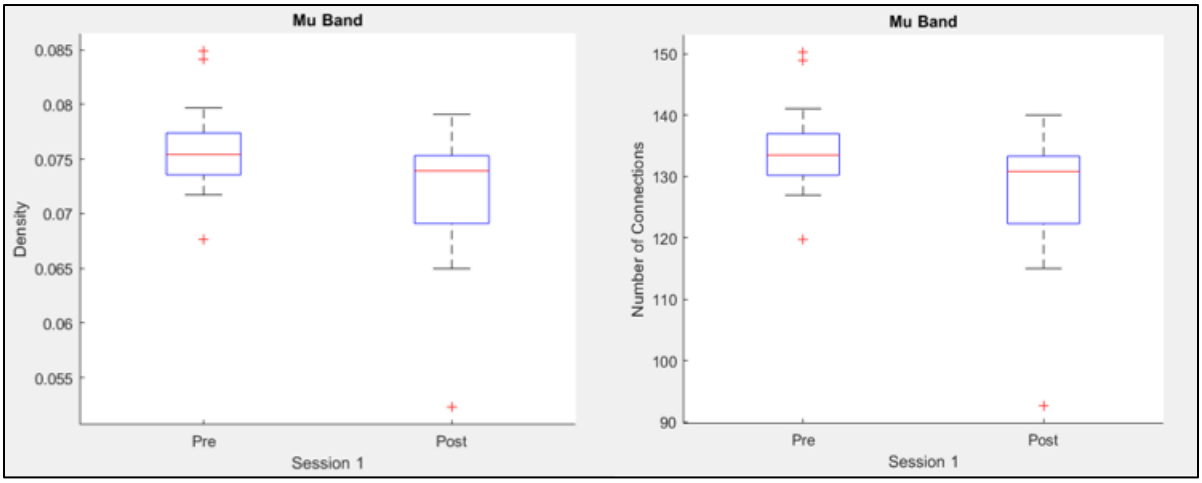

Figure 22. Change in density and number of connections in the mu band for session one.

The mu band followed a similar trend to the alpha and beta bands. The effect size for the density and number of connections was 0.695. This indicates a strong decrease in the two measures after caffeine consumption. There was a statistically significant difference between pre- and post- with a p-value of 0.0213. There were fewer network connections after caffeine intake, increasing local functional connectivity. Figure 23 shows the change in modularity in the alpha band.

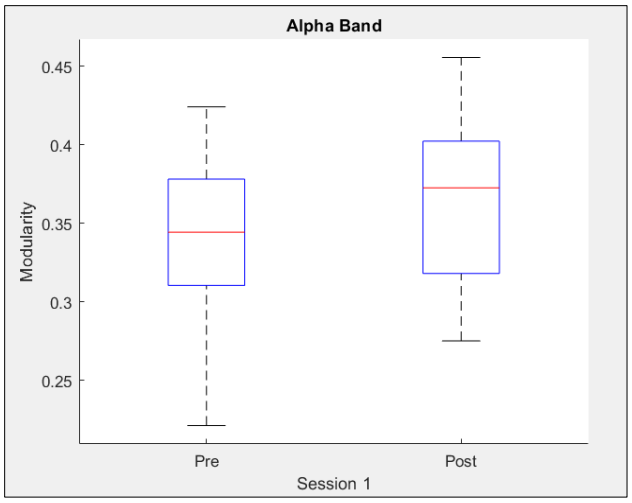

Figure 23. Change in modularity in the alpha band for session one.

In the alpha band, the modularity had an effect size of 0.503. There was an increase in change between the pre- and post- responses in session one. This shows a strong change. The p-value was 0.0539. While this was not significant, it does show there was an increase in the communities formed after caffeine. An increase in modularity shows that the participants were more focused on the oddball paradigm task after caffeine consumption. The brain network was less integrated and more organized to focus on a single task post- caffeine.

Session two was statistically analyzed using the same graph theory measures as session one. Between all of the frequency bands, there were no graph measures that were statistically significant; however, eccentricity did have a positive effect size in the alpha and beta bands. Figure 24 illustrates the size change in the alpha and beta bands.

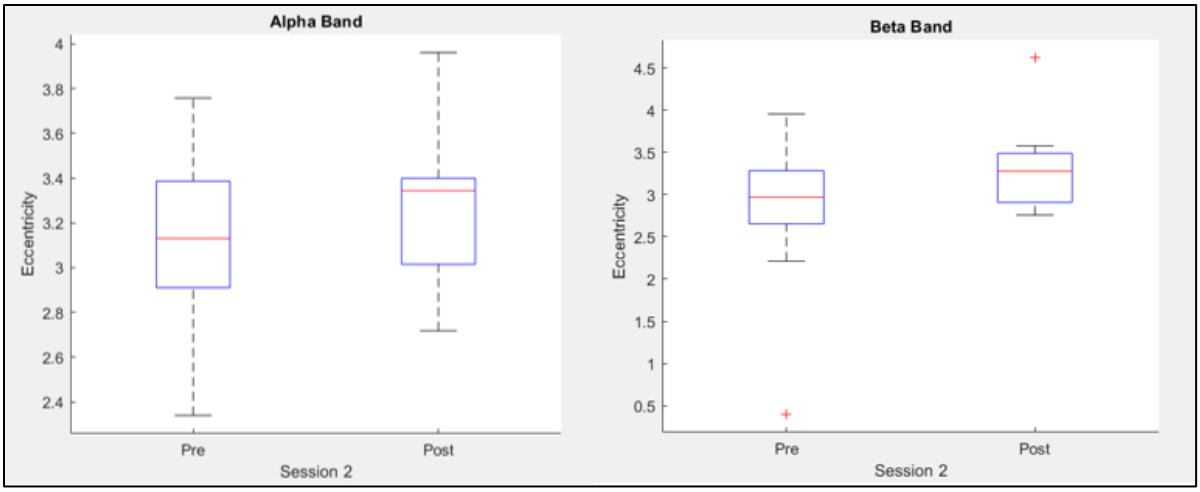

Figure 24. Change in eccentricity in the alpha and beta bands for session two.

The effect size for eccentricity was 0.508 and the p-value was 0.116 for the alpha band. For the beta band, the effect size was 0.632 and the p-value was 0.0587. The boxplots indicate that the change in eccentricity was moderate, but not enough to be statistically significant. Having a higher eccentricity results in a longer path from one node to another. The distance between nodes in the network increase with a high eccentricity. This measure aligns with an increase in modularity in the brain network. The path length increases between nodes in the network, resulting in tighter communities. Appendices E and F show the descriptive statistics for all frequency bands and graph measures for sessions one and two.

The results from the Likert Scale questionnaire are shown in Figure 25. All 20 subjects answered the five questions based on their caffeine usage.

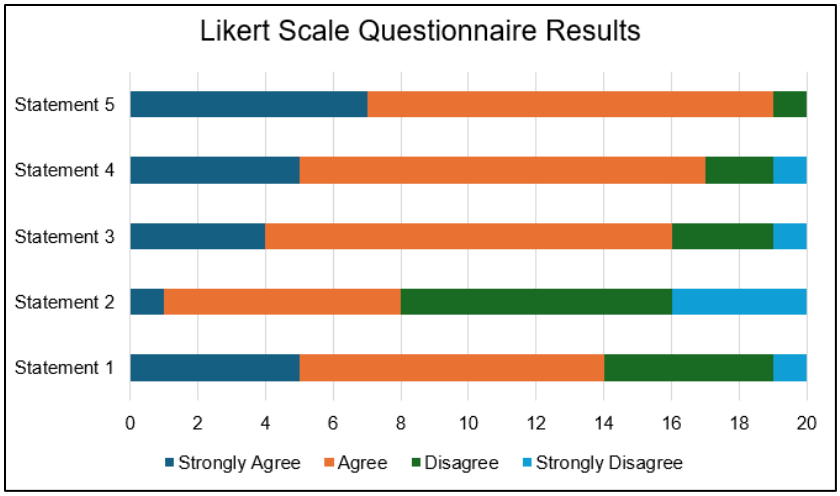

Figure 25. The Likert Scale questionnaire responses for each subject.

Appendix F shows each of the statements that are represented in the above figure. Overall, majority of the subjects reported that they agreed that caffeine consumption makes them feel better and helps them perform better in their daily tasks.

Chapter 6. Discussion

After data collection and analysis, it is suggested that there was a significant difference in functional connectivity and response time in young adults after consuming 135 mg of caffeine in session one. This finding is consistent with literature that supports the likelihood that caffeine impacts cognitive function [9]. Specific to this study on 18-26 year old participants, findings showed that subjects were able to complete the GNGT at an increased speed after drinking 135 mg of a Celsius caffeinated beverage. Analysis of the results yielded a statistically positive increase in the average speed of the response time. This finding aligns with broader research that concluded that the stimulant properties of caffeine can impact processing speed [9].

Further, a statistically significant difference between pre- caffeine and post-caffeine consumption of 135 mg was evidenced in the data collected and analyzed following EEG testing in the study in session one. It is important to note that the oddball paradigm test completed by participants during the EEG testing stimulated the attention and alertness of participants. Analysis of the electrical brain activity revealed that there was a significant decrease in alpha, beta, and mu bands for the density measure and the number of connections measure. The significant decrease in results from pre- to post- in the density and number of connections measures could be attributed to the participants being more focused on a single task, therefore requiring less need for integration and more focus on the task at hand. By reducing the number of connections, the unnecessary connections were removed, which created a more efficient and well organized network. Consuming 135 mg of caffeine showed significant changes in brain

functional connectivity, and improved the cognitive state of participants, increasing their attention and alertness.

The study used 135 mg of caffeine as a variable since it is the average caffeine intake for young adults between the ages of 18-26 [7]. To determine if response time and functional connectivity were impacted by more than the average daily milligrams of caffeine, testing was repeated in session two using the same processes as session one, but with 200 mg of caffeine.

Data collected and analyzed from session two showed no significant change in response time or functional connectivity for the caffeine consumption level of 200 mg, thus suggesting that young adults experience greater impacts from caffeine when less than 200 mg is consumed. The findings from this study support literature that suggests that there is a connection between caffeine consumption and cognitive performance [15], [16]. A lower amount of caffeine consumption commonly has more effect on cognitive function and reducing anxiety. An intake of larger amounts of caffeine can have a higher potential for increasing general anxiety [59], [60].

Most participants attended the required session one and session two testing sessions. There were 17 participants that completed both sessions. Two additional participants completed session one, but not session two. Scheduling two sessions with college-age students was challenging. Within the study time frame, session times had to work around university classes, student course meetings, weather delays, student work schedules, and mid-terms. In multiple instances the testing schedule had to be adjusted based on participant availability, which was subject to change given student commitments in college events.

There was an issue with the EEG headset mid-semester, which created a delay in testing for some participants though results yielded accurate results for most sessions. One participant completed session one, however testing results were inconclusive with technology errors, therefore the participant could not continue. Full data sets were collected and analyzed using results of 17 participants (n=17).

While the population size was slightly less than the ideal n=20, patterns and statistical significance were able to be analyzed; however, the results would be more reliable and would provide easier detection of key differences if the population size was larger. A larger sample size would provide more data to examine the variability of response time.

Through informal conversations with participants during testing sessions, it became apparent that some participants were regular caffeine drinkers, while other participants rarely consumed caffeine, which evoked curiosity of whether long-term caffeine usage had an impact on study results of response time or functional connectivity.

Chapter 7. Limitations and Recommendations

The experiment was implemented according to the proposed plan and delivered in the expected time frame. However, this study was not without limitations. Four limitations emerged in the study.

The first limitation was the sample size. The sample size n=20 was calculated through the Minitab Statistical Software using the ‘Sample Size for Estimation’. The population size for this study was sufficient in producing statistical results; however, it was slightly decreased due to the inability of two participants to complete session two. If the study were repeated, it is suggested to increase the population size to N=30.

The second limitation was that the study was designed to be completed in two sessions. This criterion required participants to return for a second session at least 24 hours after the first session. While participants agreed to a two-session study, in two instances the participants did not return to complete the study. Additionally, having participants perform the same task during both sessions could have impacted the results, due to task familiarity. If the study were repeated, an increase in total population size to N=30 would address this limitation and increase the likelihood that there would be at least 20 full sets of data.

A third limitation was that some participants were regular caffeine drinkers, while other participants rarely consumed caffeine. The study was designed to control the variable of caffeine intake within a 24-hour period; however, it is possible that long-term caffeine usage could influence results. If this study were repeated, it is suggested to include daily caffeine usage on the initial screening questionnaire to help the researcher select participants with similar daily caffeine intake.

A fourth limitation that emerged in the study design was the ability to control participant caffeine usage prior to the study. Participants agreed to the caffeine restriction before completing the study and self-acknowledged that they had not consumed caffeine prior to session one through a survey; however, the questionnaire was not readministered prior to session two. If this study were repeated, it is recommended to readminister the questionnaire prior session two to minimize the likelihood of caffeine intake prior to testing. It is also recommended for the researcher to send a text reminder to participants 24 hours in advance of completing both sessions to encourage participants to refrain from caffeine intake prior to testing.

Based on the study findings, future related research would include addressing a limitation, building on the study findings, and continuing data collection. Future research can be conducted that aligns with the limitation to determine if there is a difference in cognitive function between regular and non-regular caffeine drinkers. Exploring the response time using a more complex decision-making task, builds on the study findings. This would determine if changing the task would result in similar or different response time findings.

It is recommended that future research continues data collection with a third session of 265 mg of caffeine. This would examine if the same trend of response time and function connectivity continues with a higher consumption level. Additionally, it is suggested to change the caffeine level order during the sessions. If the caffeine amounts were randomly assigned for each session, this would minimize the possibility of task familiarity and show the findings based on amounts of caffeine rather than the sessions.

Chapter 8. Conclusion

Research shows that adults make 35,000 decisions per day [19]. College-age students are challenged with making many of these decisions on their own. Response time in making decisions is important. This purpose of this study was to examine the effects that specific amounts of caffeine had on college-aged students by performing two different tasks to show the connection to response time and functional connectivity. Current research examines the effects that caffeine has a general well-being; with some studies including cognition and response time; however, lacking focus on the young adult population where caffeine usage is most prevalent. In addition, there is limited research related to this topic that studies the impacts of specific amounts of caffeine consumption or the association of caffeine and response time for 18-26 year old young adults.

This study was conducted in two sessions. Testing included the use of the GNGT to record reaction time based on participant response to visual stimuli and the EEG to show ERPs formed when participants reacted to varying stimuli. The two testing methods were repeated following 135 mg of caffeine consumption and 200 mg of caffeine consumption. A pre- and post- process was used in each session.
Findings from the study were used to conclude that there was a statistically significant difference in functional connectivity and response time with 135 mg of caffeine consumption in young adults.

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Appendix A: IRB Approval Document

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board
Willis Building · Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** ·
rede.ecu.edu/umcirb/

Notification of Initial Approval: Expedited

From: Biomedical IRB
To: Sunghan Kim
CC: Taylor Everett
Date: 10/30/2025
Re: UMCIRB 25-001541
The Effects of Caffeine on Response Time in Young Adults as Related to Decision-Making

I am pleased to inform you that your Expedited Application was approved. Approval of the study and any consent form(s) is for the period of 10/30/2025 to 10/29/2026. The research study is eligible for review under expedited category # 1,4,7. The Chairperson (or designee) deemed this study no more than minimal risk.

As the Principal Investigator you are explicitly responsible for the conduct of all aspects of this study and must adhere to all reporting requirements for the study. Your responsibilities include but are not limited to:

1. Ensuring changes to the approved research (including the UMCIRB approved consent document) are only initiated with UMCIRB review and approval except when necessary to eliminate an apparent immediate hazard to the participant. All changes (e.g. a change in procedure, number of participants, personnel, study locations, new recruitment materials, study instruments, etc.) must be prospectively reviewed and approved by the UMCIRB before they are implemented;

2. Where informed consent has not been waived by the UMCIRB, ensuring that only valid versions of the UMCIRB approved, date-stamped informed consent document(s) are used for obtaining informed consent (consent documents with the IRB approval date stamp are found under the Documents tab in the ePIRATE study workspace);

3. Promptly reporting to the UMCIRB all unanticipated problems involving risks to participants and others;

4. Applying for continuing review and receive approval of continuation of the study prior to the study's current expiration date. Application for continuing review should be submitted no less than 30 days prior to the expiration date. Lapses in approval (i.e. study expiration) should be avoided to protect the safety and welfare of enrolled participants and liability to the University; and

5. Submission of a final report when the study meets the UMCIRB criteria for closure. Study approval should not be allowed to expire simply because the study is completed, rather the UMCIRB should be formally notified of study completion via the final report process.

The approval includes the following items:

Name	Description
Informed Consent	Consent Forms
Initial Screening Questionnaire	Surveys and Questionnaires

Name	Description
Questionnaire	Surveys and Questionnaires
Research Flyer	Recruitment Documents/Scripts
Thesis Proposal Paper	Study Protocol or Grant Application

For research studies where a waiver or alteration of HIPAA Authorization has been approved, the IRB states that each of the waiver criteria in 45 CFR 164.512(i)(1)(i)(A) and (2)(i) through (v) have been met. Additionally, the elements of PHI to be collected as described in items 1 and 2 of the Application for Waiver of Authorization have been determined to be the minimal necessary for the specified research.

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418

Appendix B: Informed Consent Document

East Carolina University

ECU

Informed Consent to Participate in Research

Information to consider before taking part in research that has no more than minimal risk.

Title of Research Study: The Effects of Caffeine on Response Time in Young Adults as Related to Decision-Making

Principal Investigator: Sunghan Kim (Person in Charge of this Study)
Institution, Department or Division: Engineering
Address: 238 Slay, Greenville, NC 27858
Telephone #: (252) 737-1750

Researchers at East Carolina University (ECU) study issues related to society, health problems, environmental problems, behavior problems and the human condition. To do this, we need the help of volunteers who are willing to take part in research.

Why am I being invited to take part in this research?

The purpose of this research is to study the response time and brain waves of college-aged students after consuming specific amounts of caffeine through caffeinated beverages. Brain waves are recorded from the scalp and are based on visual images that influence the waves. The results of this study can be used to help educate college-aged students about positive and negative impacts that caffeinated beverages can have on physical, behavioral, and cognitive performance. You are being invited to take part in this research because you are between 18-26 years old and are considered a healthy volunteer. The decision to take part in this research is yours to make. By doing this research, we hope to learn the effects that caffeine has on response time in young adults.

If you volunteer to take part in this research, you will be one of about 20 people to do so.

Are there reasons I should not take part in this research?

You should not take part in this research if you are under 18 years of age or older than 26 years of age, pregnant, or have known neurological conditions (ex. stroke, insomnia, epilepsy, brain tumor, etc.), use of psychiatric medications (ex. antidepressants, antipsychotics, mood stabilizers, stimulants, etc.), traumatic brain injuries, kidney diseases, substance abuse (ex. harmful or excessive drug, alcohol, or medication use in ways that are not intended), heart conditions (ex. arrhythmias, tachycardia, high blood pressure, heart attack, etc.), or are visually impaired and do not have corrected vision with contacts or glasses.

What other choices do I have if I do not take part in this research?

You can choose not to participate. There are no alternatives.

Where is the research going to take place and how long will it last?

The research will be conducted at ECU in the Science and Technology Building. You will need to come to room 134 two times during the study. The total amount of time you will be asked to volunteer for this study is two and a half hours (75 minutes per visit) over the next 6 months.

What will I be asked to do?
You will be asked to do the following: The first task will be to complete a short questionnaire regarding your wellness before completing the two session research study. Following, you will take a Go/No-go Visual Reaction Time Test (GNGT), taking approximately 2 minutes to complete. Then, a researcher will place a cap with 64 electrodes on your head. You will be prompted to look at visual images on a screen in front of you and respond by pressing a corresponding key on a keyboard. The images will indicate you to either press the key or not. The cap is safe and painless, sitting on the scalp of the head. The cap is connected to a computer monitor that records brain waves.
Once the task is completed, you will consume a specific amount of caffeine provided by the researcher and wait 45 minutes after consumption. You will be randomly selected to consume 1 of 2 amounts of caffeine based on the average consumption young adult's intake daily, and remaining below the safe amount of caffeine per day provided by the U.S. Food and Drug Administration (FDA). After the wait period, you will complete the same GNGT and brain activity recording.
The second session will occur at least 24 hours after the first session is complete. You will be asked to complete the same tasks as in the previous session. You will be informed of the amount of caffeine you receive and the amount of caffeine the FDA cites is a safe amount for most healthy adults, once you have completed the tests.

What might I experience if I take part in the research?
We don't know of any risks (the chance of harm) associated with this research. Any risks that may occur with this research are no more than what you would experience in everyday life. The caffeine amounts do not exceed the FDA approved safe limit of 400 mg for most healthy adults; however, caffeine can cause anxiety, insomnia, irregular heartbeat, stress, digestive issues, headaches, and restlessness. We don't know if you will benefit from taking part in this study. There may not be any personal benefit to you, but the information gained by doing this research may help others in the future.

Will I be paid for taking part in this research?
We will be able to pay you for the time you volunteer while being in this study. Each participant will receive a $10 gift card after completing the second session.

Will it cost me to take part in this research?
It will not cost you any money to be part of the research.

Who will know that I took part in this research and learn personal information about me?
ECU and the people and organizations listed below may know that you took part in this research and may see information about you that is normally kept private. With your permission, these people may use your private information to do this research:

- Any agency of the federal, state, or local government that regulates human research. This includes the Department of Health and Human Services (DHHS), the North Carolina Department of Health, and the Office for Human Research Protections.
- The University & Medical Center Institutional Review Board (UMCIRB) and its staff have responsibility for overseeing your welfare during this research and may need to see research records that identify you.

How will you keep the information you collect about me secure? How long will you keep it?
The information collected during this research study will remain confidential from anyone that is not trained to work on the research. Each participant will be given an identification number for data collection purposes, rather than using their name. The only form containing participants' names will be a hard paper copy of this consent form. After 6 years of completing the study, the paper copies with personal information will be shredded. Electronic data records will be stored through East Carolina University's data server. Data collection will take place and remain on a password protected computer for secure keeping.

What if I decide I don't want to continue in this research?
You can stop at any time after it has already started. There will be no consequences if you stop and you will not be criticized. You will not lose any benefits that you normally receive.

Who should I contact if I have questions?
The people conducting this study will be able to answer any questions concerning this research, now or in the future. You may contact the Principal Investigator at 252-737-1750 (Monday-Friday between 9:00 am and 5:00 pm).
If you have questions about your rights as someone taking part in research, you may call the ECU University and Medical Center Institutional Review Board (UMCIRB) at phone number 252-744-2914 (days). If you would like to report a complaint or concern about this research study, you may call the Director for Human Research Protections, at 252-744-2914.

Is there anything else I should know?
Your information or biospecimens collected as part of the research, even if identifiers are removed, will not be used or distributed for future studies.

I have decided I want to take part in this research. What should I do now?
The person obtaining informed consent will ask you to read the following and if you agree, you should sign this form:

- I have read (or had read to me) all of the above information.
- I have had an opportunity to ask questions about things in this research I did not understand and have received satisfactory answers.
- I know that I can stop taking part in this study at any time.
- By signing this informed consent form, I am not giving up any of my rights.
- I have been given a copy of this consent document, and it is mine to keep.

_____ _____

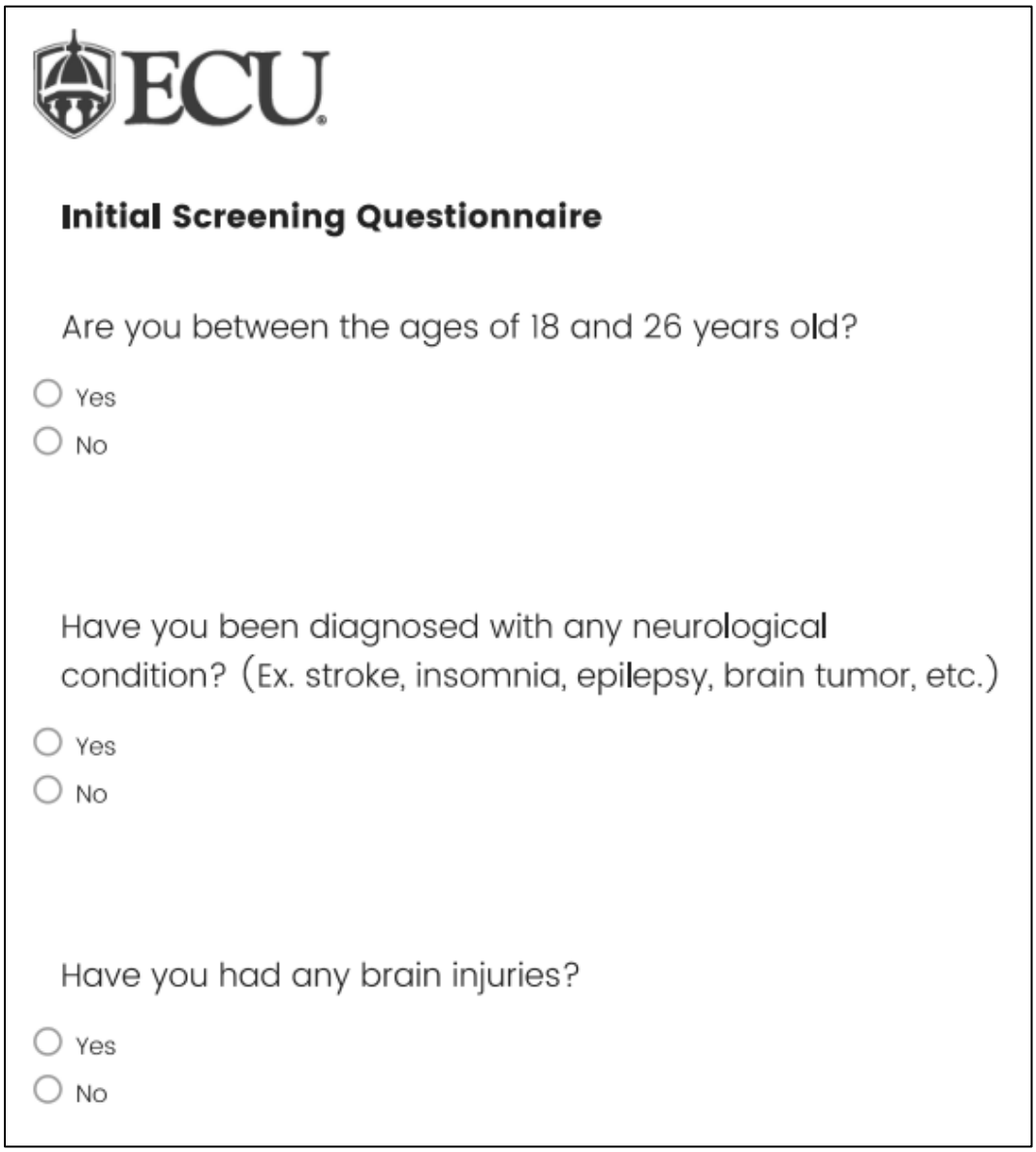
Participant's Name (PRINT) **Signature** **Date**

Person Obtaining Informed Consent: I have conducted the initial informed consent process. I have orally reviewed the contents of the consent document with the person who has signed above, and answered all of the person's questions about the research.

_____

Person Obtaining Consent (PRINT) **Signature** **Date**

Appendix C: Screening Questionnaire



Initial Screening Questionnaire

Are you between the ages of 18 and 26 years old?

- ○ Yes
- ○ No

Have you been diagnosed with any neurological condition? (Ex. stroke, insomnia, epilepsy, brain tumor, etc.)

- ○ Yes
- ○ No

Have you had any brain injuries?

- ○ Yes
- ○ No

Have you been diagnosed with any kidney disease?

- ○ Yes
- ○ No

Do you have any heart conditions? (Ex. arrhythmias, tachycardia, high blood pressure, heart attack, etc.)

- ○ Yes
- ○ No

Are you currently taking any psychiatric medications? (Ex. antidepressants, antipsychotics, mood stabilizers, stimulants, etc.)

- ○ Yes
- ○ No

Are you currently struggling with substance abuse? (Ex. harmful or excessive drug, alcohol, or medication use in ways that are not intended)

- ○ Yes

- ○ No

Do you have normal or corrected-to-normal vision?

- ○ Yes
- ○ No

Are you currently pregnant?

- ○ Yes
- ○ No

Please enter your name and email address if you are willing to participate in this research study.

Appendix D: Questionnaire

East Carolina University

Questionnaire

ECU

Title of Research Study: The Effects of Caffeine on Response Time in Young Adults as Related to Decision-Making

Principal Investigator: Sunghan Kim (Person in Charge of this Study)
Institution, Department or Division: Engineering
Address: 238 Slay, Greenville, NC 27858
Telephone #: (252) 737-1750
Study Coordinator: Taylor Everett
Telephone #: (252) 737-1750

This questionnaire is designed to gather information about you that can allow us to decide whether you are fit for the study or if the data we gather from you will be of sufficient quality for the study. For each question below, please circle the answer that best fits you.

Caffeine Usage

I drink caffeinated beverages for the physical effect.

Strongly Agree Agree Disagree Strongly Disagree

I drink caffeinated beverage more often when I am feeling overwhelmed or stressed.

Strongly Agree Agree Disagree Strongly Disagree

Caffeine consumption makes me feel better.

Strongly Agree Agree Disagree Strongly Disagree

Caffeine consumption helps me to perform better on daily tasks.

Strongly Agree Agree Disagree Strongly Disagree

I am aware of potential impacts of caffeine consumption.

Strongly Agree Agree Disagree Strongly Disagree

Have you consumed any caffeinated beverages in the past 24 hours?

YES NO

Appendix E: Session One Statistics

Table 3. Statistics for all frequency bands and graph measures for session one.

Graph Measures	Alpha Effect Size	Alpha P-value	Beta Effect Size	Beta P-value	Mu Effect Size	Mu P-value	Theta Effect Size	Theta P-value
Strength	-0.391	0.137	-0.276	0.330	-0.382	0.125	-0.219	0.476
Average Degree Centrality	-0.404	0.112	-0.190	0.426	-0.355	0.133	-0.426	0.171
Community	0.439	0.165	0.453	0.120	0.448	0.156	0.221	0.510
Modularity	0.503	0.0539	0.454	0.0685	0.471	0.0602	0.407	0.200
Path Length	0.243	0.343	0.245	0.289	0.256	0.337	-0.175	0.531
Eccentricity	0.321	0.252	0.119	0.641	0.325	0.253	0.00985	0.970
Radius	-0.131	0.576	0.224	0.390	-0.0875	0.717	-0.0844	0.758
Global Efficiency	-0.133	0.524	0.0129	0.945	-0.0965	0.621	0.0130	0.961
Assortativity	0.222	0.356	0.0231	0.918	0.278	0.213	-0.00656	0.984
Global Clustering Coefficient 1	-0.356	0.230	-0.0794	0.775	-0.269	0.352	-0.351	0.196
Global Clustering Coefficient 2	-0.567	0.0551	-0.0351	0.898	-0.451	0.130	-0.269	0.367
Density	-0.808	0.00646	-0.526	0.0396	-0.695	0.0213	-0.534	0.0955
Number of Connections	-0.808	0.00646	-0.526	0.0396	-0.695	0.0213	-0.534	0.0955

Appendix F: Session Two Statistics

Table 4. Statistics for all frequency bands and graph measures for session two.

Graph Measures	Alpha Effect Size	Alpha P-value	Beta Effect Size	Beta P-value	Mu Effect Size	Mu P-value	Theta Effect Size	Theta P-value
Strength	0.173	0.572	0.486	0.144	0.205	0.529	0.00497	0.988
Average Degree Centrality	-0.114	0.709	0.314	0.359	-0.124	0.685	0.0375	0.903
Community	-0.109	0.710	-0.523	0.127	-0.227	0.367	0.269	0.440
Modularity	0.368	0.230	0.049	0.859	0.363	0.216	0.171	0.649
Path Length	0.105	0.785	0.499	0.151	0.219	0.582	0.0867	0.790
Eccentricity	0.508	0.116	0.632	0.0587	0.446	0.130	0.168	0.603
Radius	0.406	0.143	0.480	0.165	0.456	0.133	0.276	0.385
Global Efficiency	0.216	0.272	0.0127	0.957	0.165	0.374	0.0519	0.813
Assortativity	0.068	0.853	0.0931	0.789	0.123	0.735	0.0692	0.855
Global Clustering Coefficient 1	-0.297	0.180	0.0595	0.816	-0.239	0.288	-0.315	0.220
Global Clustering Coefficient 2	-0.356	0.114	0.0333	0.889	-0.326	0.174	-0.388	0.155
Density	-0.147	0.544	0.00514	0.986	-0.196	0.418	-0.0880	0.711
Number of Connections	-0.147	0.544	0.00514	0.986	-0.196	0.418	-0.0880	0.711