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Effects of Mobile Telephone Electromagnetic Field on Electroencephalogram Recordings and Auditory Information Processing Speed in Undergraduate Students

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Abstract

This study aimed to examine the effect of a mobile telephone electromagnetic field (MP- EMF) on human brain bioelectric activity at the T3 location and information processing speed. Human brain bioelectric activity was assessed by calculating power spectral density (PSD) values from electroencephalogram (EEG) recordings, and information processing speed was assessed by the Paced Auditory Serial Addition Test (PASAT). Eighty-four people (ages 18-25) participated in this study. Each subject had two consecutive 15 minute single-channel EEGs (baseline and treatment) taken with either a T3/T5 or T3/CZ monopolar montage configuration. The treatment EEGs consisted of either exposure to a MP-EMF or a placebo mobile telephone (MP) with no electromagnetic field. The MP or placebo MP was held by the test subjects and against their left ear for the duration of the 15 minute treatment EEG. The PASAT is subject to practice effect, so a Solomon four-group design was implemented. A three-way mixed analysis of variance (ANOVA) was used to analyze the PSD values, and a meta-analytic approach was used to analyze the PASAT scores. Neither set of data, PSD measurements, or PASAT scores, produced statistically significant results. These results indicated that 15 minutes of exposure to a MP-EMF does not produce a statistically significant effect on human brain bioelectric activity at the T3 location. While the PASAT scores also indicated no effect on cognitive functions from MP-EMF exposure, many confounding factors, like the sensitivity and the time of the administration of the PASAT and duration of MP-EMF exposure, may have influenced the statistics. Further research controlling for these factors is suggested.

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Chapter I

Introduction

Mobile telephones (MPs) have become a primary avenue for communication in our current society. The first MP, commonly referred to as a “cell phone,” was invented in 1973, and since its creation, the number of MP users around the globe has grown exponentially. Current statistics are stating that in 2017, there will be an estimate of “6.3 billion mobile users worldwide” (The Radicati Group, Incorporated, 2017, p. 2). MPs can be found anywhere, from the pockets of adolescents to the hands of senior citizens. They are used for a range of purposes, from communication during emergency situations to casual conversations with friends. By the end of the year 2021, researchers have projected the number of mobile phone users will increase from 6.3 billion to over 7.1 billion (The Radicati Group, Incorporated, 2017, p. 2).

MPs operate as full-duplex radios, meaning they receive incoming signals in one frequency and send out signals in another (Klemens, 2013). This allows for individuals to talk and hear each other at the same time. MPs transmit data and calls through the emission and retrieval of these signals, which are called “radio waves.” These radio waves take the form of oscillating electric and magnetic fields, known as an electromagnetic field (EMF) (Klemens, 2013). With MPs traditional placement being against a user’s ear, the skull and brain are in the direct line of a mobile telephone electromagnetic field (MP-EMF). Over the past few decades, findings have revealed that a MP-EMF is partially absorbed by the skull and brain (Schöborn, Burkhardt, & Kuster, 1998). Specific absorption rate (SAR) is the term given to this occurrence. SAR is the measurement of how much radio frequency energy is absorbed into bodily tissue and is expressed by the amount of energy absorbed per unit of tissue, W/kg (Bernardi, Cavagnaro, Pisa, & Piuzzi, 2000). Every MP has a specific SAR value that can be found either on the device, in the MP's software, or on the manufacturer's website. With the knowledge of SAR, there has been a proliferation in concern for one's health and the potential adverse effects caused by a MP-EMF. This concern is exacerbated by the notion that a MP is placed near the skull when on a phone call, so one's brain has the potential to be impacted by a MP's SAR. Consequently, studies concerning the technology have increased.

Studies are continually emerging with conflicting results as to whether or not a MP-EMF affects human brain bioelectric activity, also known as "brain waves," and a person's cognitive functions. In 2007, research from the University of Essex showed that exposure to an EMF for 40 minutes does not produce an adverse effect on an individual's performance in an order threshold task (Cinel, Boldini, Russo, & Fox, 2007) and in 2016, researchers from Sir Seewoosagur Ramgoolam (SSR) Medical College, Vacoas-Phoenix, Mauritius and University College of Medical Sciences (UCMS), Delhi, India and Guru Teg Bahadur (GTB) Hospital, Delhi, India revealed that chronic MP usage did not result in a decline in a user's cognitive function (Mohan, Khaliq, Panwar, & Vaney, 2016). Conversely, research from the University of Keele, Newcastle, UK has shown that people that have been exposed to MP-EMF had a higher chance of improved immediate verbal working and immediate visuospatial memory capacity and sustained attention (Edelstyn & Oldershaw, 2002). However, research from Brain Sciences

Institute, Swinburne University, Melbourne, Australia revealed that exposure to EMF caused a decrease in test subject's simple and choice reaction times (Keetley, Wood, Spong, & Stough, 2006). While studies from Maastricht University, Maastricht, The Netherlands and Deenbandhu Chhotu Ram University of Science and Technology, Haryana, India reported that MP-EMF altered electroencephalogram (EEG) recordings of brain wave activity (Roggeveen, Os, Viechtbauer, & Lousberg, 2015; Tyagi, Duhan, & Bhatia, 2011). Whereas, a study from Institute of Pharmacology and Toxicology, University of Zurich, Zurich, Switzerland exposed children to different levels of EMF and reported no statistically significant changes in EEG recordings (Loughran et al., 2013). Such diversity in findings delineates the need for further research to obtain more conclusive data.

Statement of Problem

This study was designed to investigate the effect of mobile telephone electromagnetic field exposure on human brain bioelectric activity at the International 10/20 T3 location, using a single-channel EEG, and information processing speed, assessed by the Paced Auditory Serial Addition Test (PASAT).

Research Questions

1. How does MP-EMF exposure affect brain wave activity at the T3 location when compared to the T5 location?

2. How does MP-EMF exposure affect brain wave activity at the T3 location when compared to the CZ location?

3. How does MP-EMF exposure affect the cognitive function of information processing speed?

Definitions of Terms

10/20 International Positioning System: An internationally acknowledged system that is used to define different locations on the scalp for the purpose of EEG recordings (Trans Cranial Technologies, 2012).

Electroencephalogram (EEG): A device that records the electrical activity of the brain by placing electrodes on the scalp that measure changes in voltage. These recordings are then displayed as oscillating lines on a screen or piece of paper (Shubham & Goel, 2017).

Fast Fourier Transformation (FFT): The transformation of a signal as a function of time to one as a function of frequency (Bergland, 1969).

Mobile Phone Electromagnetic Field (MP-EMF): Mobile phones operate by emitting and receiving signals in the form of non-ionizing radio waves (Bolt, Maynard, Smith, & Kent, 2010).

Power Spectral Density (PSD): The measure of a signal's strength as a function of frequency (Dressler, Schneider, Stockmanns, & Kochs, 2004).

Practice Effect: The increase in one's score on a cognitive test due to the repeated administration of the cognitive test (Collie, Maruff, Darby, & McStephen, 2003).

Solomon Four-Group Design: A specific study design that enables researchers the ability to test for practice effects (Solomon, 1949).

Specific Absorption Rate (SAR): The amount of energy emitted from a mobile telephone that is absorbed into bodily tissues (Bernardi et al., 2000).

Overview of Study

Chapter I is comprised of the introduction, statement of the problem, research questions, definition of terms, and an overview of the study. Chapter II will examine previous research that investigates the effects of MP-EMF exposure on the bioelectric activity of the brain and different cognitive functions. A description of the conflicting research findings will be presented. Chapter III will include the study design, methodology, procedures, and materials used. Chapter IV will describe the analysis of the data and results of the study. Chapter V will provide a discussion, summary, conclusions, limitations of the study, and recommendations for future research.

Chapter II

Literature Review

How Mobile Telephones Work

MPs are designed to allow people the capability of communicating globally. In his book, *The Cellphone: The History and Technology of the Gadget That Changed the World*, Guy Klemens (2013) provides an in-depth illustration regarding how MPs operate and how they make phone calls. In essence, MPs could be described as advanced walkie-talkies. A walkie-talkie is a half-duplex device, meaning it operates at only one frequency. With a half-duplex device, only one person can speak at a time. On the other hand, MPs are full-duplex devices. Full-duplex devices operate at two different frequencies, allowing for communication from both sides at the same time. To further delineate, when people speak, their voices cause particles to move, which creates sound waves. When speaking into a MP, these sound waves come into contact with the microphone inside. The microphone is constructed to convert sound waves into radio waves (radio waves are a subcategory in the electromagnetic spectrum, which leads to the terms “radio waves” and “electromagnetic waves” to be seen interchangeably in most research articles written on MPs). These radio waves are beamed out from the MP’s antenna and to the nearest cell tower. The signal then travels through a switch station and to the cell tower nearest the MP with whom the person is on a call. The cell tower then sends the signal to the receiving MP, where it converts the radio waves back into sounds waves to be heard by the user. This process occurs almost instantaneously as these signals travel in waves at the same speed as light (Klemens, 2013).

Specific Absorption Rate

Understanding how a MP makes a call is critical to understanding specific absorption rate (SAR) and why there are growing health concerns for MP users. When radio waves are transmitted and received by a MP, if placed in the traditional position against the user's ear, the skull is in the direct path of that signal's transmission. Research has shown that the human skull and brain partially absorb these electromagnetic waves (Schöborn, Burkhardt, & Kuster, 1998). The measurement of the rate of this absorption is a SAR value, which is the amount of energy emitted from a mobile telephone that is absorbed into bodily tissues (Bernardi, Cavagnaro, Pisa, & Piuzzi, 2000). As of 2016, the United States' governmental limit on SAR values for public exposure from a mobile telephone is 1.6 W/kg (Federal Communications Commission, 2016). The MP that was used in this study had a SAR value of 1.18 W/kg to exposed tissue, as reported in the online manual (Apple.com, 2014).

Electroencephalograms (EEGs)

An electroencephalogram (EEG) is a device that records the electrical activity of the brain by placing electrodes on the scalp that measure changes in voltage. These recordings are then displayed as oscillating lines on a screen or piece of paper (Shubham & Goel, 2017). This study employed the single-channel EEG acquisition software on the BioPac MP36 device. A single-channel EEG is a recording that registers only one raw signal. This signal is then separated into each brain frequency based on filters inputted into the program. This type of EEG is easier to execute and obtain at an undergraduate level; however, they are more susceptible to noise in data because data is being acquired from only one location.

10/20 International Positioning System

The 10/20 International Positioning System (Jasper, 1958) is an international standard for electrode placement. It is now commonly used in research and clinical settings that require EEG recordings to examine the bioelectric activity of the brain. The "10/20" part of the name was given because this system determines locations by dividing the surface of the skull into points that are either 10 percent or 20 percent of the width or length of the skull away from each other.

Each location name is a description of where it can be found. The location names, such as T3, are divided into two parts. The first part of a location name is the letter: T, C, O, P, or F. Each letter identifies which brain lobe or region resides underneath that area of the skull at that location. The "T" represents the area above the temporal lobe, the "C" represents the area above the central sulcus, the "O" represents the area above the occipital lobe, the "P" represents the area above the parietal lobe, and the "F" represents the area above the frontal lobe. The second part of the name is the number. The odd numbers indicate a location on the skull's surface above the left hemisphere of the brain, and the even numbers indicate a location over the right hemisphere of the brain. However, a few of the location names have a "Z" where a number is normally placed. Each location with a "Z" refers to a location along the centerline of the skull, so neither over the left or right hemisphere (Jasper, 1958). This study utilized the T3, T5, and CZ locations. Both the T3 and T5 location fall on the left side of the skull over the temporal lobe, while the CZ location is the most central 10/20 location found at the top of the head (Jasper, 1958; Demos, 2005).

The Effects of MP-EMF on Brain Waves

Measurable Effects

Around the time MPs were becoming more widely available, Reiser, Dimpfel, and Schober (1995) created a study to examine the effects of electromagnetic fields on brain wave activity. After testing 36 individuals, they discovered that the presence of an EMF caused an increase in fast alpha brain waves and all beta brain waves. While no cognitive effects from this change were determined, alpha brain waves have been associated with alertness and readiness, and beta brain waves have been associated with thinking, focus, and hyper-alertness (Demos, 2005). A change in these brain frequencies may affect their related traits or functions, but this research did not test those functions. A year later, Mann and Röschke (1996) demonstrated that exposure to a pulsed EMF while sleeping caused an increase in the power spectral density measurements of the alpha brain frequency bandwidth in the 14 males they tested. These researchers later went on to publish articles similar to this study that looked at the effects of high-frequency EMF on sleep (Wagner, Röschke, Mann, Hiller, & Frank, 1998; Mann & Röschke, 2004). Although in 1998, they could not replicate the original results of their 1996 study, in their 2004 study, they did indicate, as in the original study, that EMF exposure caused an increase in alpha brain wave activity in test participants. However, they drew no conclusions regarding the actual effects to one’s health due to exposure. Alpha brain waves have been associated with alertness and readiness (Demos, 2005), so these traits may be affected by changes in alpha brain waves, but that was not determined in this study. In 2002, Croft et al. reported that exposure to MPs affected resting EEGs. They indicated that the exposure not only caused an increase in alpha waves, like the previous studies, but also a decrease in delta waves, 1-4Hz frequency bandwidth, in the right hemisphere. Delta waves have been associated with sleep and complex problem solving (Demos, 2005), so changes in this frequency bandwidth may affect those processes. However, no effect was tested or determined by this study. Three years later, Curcio et al. (2005) performed a study on 20 healthy subjects and reported that the most notable effect from exposure to MP-EMF was the increase in the 9-10Hz alpha frequency band during exposure. Though there was a change in brain waves, no health effects were determined.

Research from ten years later still supported what was found in the early 2000s: EMF exposure affects brain wave activity. In 2015, Ghosn et al. researched how EMF affects a resting EEG. However, their findings were different than previously reported studies. While they determined that the alpha brain waves were affected, their results showed a decrease rather than an increase in power spectral density measurements. A couple of months later, research by Roggeveen et al. (2015) showed that a MP placed against a subject's ear for 15 minutes caused a statistically significant increase in alpha, beta, and gamma brain wave frequencies in all regions of the brain. Alpha brain waves have been associated with alertness and readiness, beta brain waves have been associated with thinking, focus, and hyper-alertness, and gamma brain waves have been associated with cognitive processing and learning (Demos, 2005). While no changes in these functions were determined, Roggeveen et al. (2015) suggested further research to determine the possible physiological effects associated with their findings. In 2017, Yang, Chen, Lv, and Wu used a “closed eye” approach to determine if current long-term MP-EMF exposure affects the bioelectric activity of the brain. They used the term “closed eye” to explain that they recorded each of the 25 male test subjects while they kept their eyes closed during EEG acquisition. This was to help control for any visual stimuli that could have affected the EEGs. They controlled for multiple other variables as well, and their results showed a decrease in alpha and beta brain wave frequencies.

Researchers are still investigating what kind of impact a change in brain wave activity can cause. Each of these studies suggests further research to determine if a decrease or increase in brain wave activity cause a change in cognitive functioning, mental processes, or the physical landscape of the brain.

Statistically Non-Significant Effects

While Mann and Röschke published many articles on the effects of EMF on sleeping EEGs, they went on to research the effects of EMF on awake EEGs. Their work in 1997 showed that there was not an effect on power spectral density measurements on an individual’s awake EEG after three and a half minutes of EMF exposure. One year later, both Mann et al. (1998) and Wagner, Röschke, Mann, Hiller, and Frank (1998) conducted research that revealed that exposure to EMF did not affect EEG measurements. Both studies had a sample size of 24 males, exposure frequency of 900mHz, and EEGs for data acquisition. Two years later, Wagner et al. (2000) conducted yet another study on the effects of EMF on EEG recordings during sleep. The results indicated that of the 20 males they tested, the spectral density measurements of the EEG recordings had no significant fluctuations. Kleinlogel et al. (2008) examined the effects of MP exposure on the brain by exposing 15 males to EMFs and sham exposure while monitoring brain wave activity. Each test subject was tested five times over the course of five weeks. Each was identified as a regular MP user and did not indicate having any specific sensitivity to EMFs. They were exposed to an EMF at designated intervals while an EEG recording took place. Dissecting each EEG taken and analyzing them, it was determined that the exposure to EMF did not have a significant effect on the EEGs. Trunk et al. (2013) evaluated the effects of MP exposure by exposing test subjects to 30 minutes of MP-EMF. Their results also indicated, like previous studies, that the exposure did not affect the power spectral density measurements of the EEGs.

Curcio et al. (2012) examined MP's effect on the brain as some of the first researchers to use functional magnetic resonance imaging technologies for this type of study. Functional magnetic resonance imaging is a type of brain imaging that inspects the brain by examining brain metabolism. This is accomplished by looking at the blood flow. Determining where the blood is flowing and concentrating illustrates where activity in the brain is occurring (Glover, 2011). The researchers ran scans on twelve healthy individuals and reported finding no significant changes in brain wave activity due to the presence of a MP-EMF. Deviating from previous approaches found in literature, like Curico et al. (2012), Loughran et al. (2013) focused primarily on adolescents instead of adults but still tested the effect of MP-EMF on their brains. They designed their study to determine if adolescents were more sensitive to EMF exposure and if the exposure had an effect on their brain wave activity. They tested 22 children who were 11-13-year-olds and exposed them to different EMF levels while taking an EEG recording. The results revealed that there were no significant changes in EEG measurements. This study's results supported the notion that adolescents are not more sensitive to EMF exposure than adults, and that EMF exposure does not have an effect on either age group's brain wave activity. However, with such a small sample size, further research with an increased sample size is suggested to obtain results with more power.

The Effects of MP-EMF on Cognitive Functions

Positive Effects

A study by Koivisto, Krause, Revonsuo, Laine, and Hämäläinen (2000) revealed that exposure to a MP's radio field caused a measurable, and an actual positive, influence on test subjects' cognitive abilities. They tested 48 individuals by exposing them to pulsed EMFs while testing response time and working memory with an n-back task. An n-back task is a test that examines working memory and memory capacity. The task required test subjects to view different letters on a screen and determine if the letter on the screen is the same letter that was "n" letters previous. For example, the 3-back task required subjects to determine if the letter they looked at is the same letter that was shown to them three letters before (Jaeggi, Buschkuehl, Perrig, & Meier, 2010). Koivisto et al. (2000) had each test subject perform the 0-back, 1-back, 2-back, and 3-back task twice, once in the presence of an EMF and once without. They then compared the results with the control group and improved response times were revealed in the 3-back test results. The researchers noted that the accuracy of results was not diminished with the increase in response time, further supporting the notion that EMF exposure facilitates cognitive functions. However, when these researchers attempted to replicate this study with a few improvements (Haarala et al., 2004), they were unable to produce the same results. Their new experimental design included using a double-blind setup and two independent laboratories for executing the research protocols. They tested 64 volunteers using the same n-back tasks and EMF exposures as before. However, the replication indicated that exposure to the EMF did not affect short-term memory.

In 2003, Lee, Lam, Yee, and Chan showed, like Koivisto et al.'s study, that exposure to EMFs improved cognitive functions. They tested 78 volunteers' cognitive abilities by having them perform the Trail Making Task (TMT) and the Sustained Attention and Response Task (SART). The TMT is a two-part test. The first part consisted of a piece of paper with numbered circles randomly placed across the page. The test subject was asked to draw a line from one circle to the next in numerical order all the while the researcher timed how long the task took. The second part consisted of a similar test; however, instead of just numbered circles, lettered circles were also added. The subject was then asked to draw a line from a number and a letter, alternating back and forth, but continuing in numerical and alphabetical order. The score produced by the TMT was the length of time it took to complete both of the tests. The SART is a task that measured sustained attention. It was performed by having a test subject sit in front of a digital screen while numbers, one through nine, were momentarily displayed. The test subjects were given a button to press and directed to press it for every number except the number "3." There was a total of 225 numbers that were displayed, and only 11% of them were the number "3." The researchers determined their scores by measuring the accuracy of the test subjects' responses and their response times. After performing a two-way repeated measures ANOVA on the results, the researchers' results suggested that extended exposure to EMF increased the test subjects' scores. These findings indicated that increased exposure to EMF may facilitate better attention.

In 2012, Vecchio et al. tested the effects of 45 minutes of EMF exposure on EEG recordings and reaction times. They tested 11 healthy participants by acquiring two EEG recordings that were taken one week apart. In one session, test subjects were exposed to an EMF and in the other, they were exposed to a placebo condition. Test subjects were unaware of the placebo condition. During exposure, they were asked to perform a visual go/no-go task. The visual go/no-go task consisted of test subjects sitting in front of a computer screen that displayed either a red or green visual. The test subjects were given a computer mouse and directed to click the left button when the green stimulus appeared. Vecchio et al. (2012) saw a decrease in high alpha, but more saliently, they saw a significant increase in reaction times after EMF exposure when compared to sham conditions and pre-EMF conditions. These results indicated that the exposure to MP-EMF does have an effect on cognitive function since Jakobsen, Sorensen, Rask, Jensen, and Kondru (2011) conducted a study that validated using reaction time as a method to examine cognitive functions.

Negative Effects

Contrary to previously discussed studies, research by Keetley, Wood, Spong, and Stough (2006) resulted in data that showed a decrease in cognitive function due to MP-

EMF exposure. Their study consisted of 120 test subjects. They exposed each subject to an actual MP or a sham phone and had each subject perform eight different neuropsychological tests. The neuropsychological tests that were utilized were the Rey's Audio-Visual Learning Test (AVLT), Digital Span (DS), Digital Symbol Substitution Test (DSST), Speed of Comprehension Test (SCT), Trail Marking Task (TMT), Reaction Time (RT), Choice Reaction Time (CRT), and Inspection Time (IT). The AVLT tested immediate recall, verbal learning, and long-term memory and was performed by having test subjects verbally recall a list of words. The DS test looked at attention and working memory and was performed by having test subjects recall a series of numbers in sequential or reverse order. The DSST tested attention and response speed and was performed by having test subjects pair numbers with a particular symbol while being timed. SCT tested language comprehension and psycho-motor speed and was performed by having test subjects determine if a presented phrase was true or false in an allotted amount of time. The TMT tested response latency and visual motor tracking and was performed in the same manner that is was in Lee et al.'s (2003) study. The RT task tested response latency and was performed by having test subjects press a button on a keyboard immediately after an image appeared on the screen. The CRT tested perception and discrimination between selections and was performed by having test subjects press the keyboard key that corresponded with the part of the display screen that turned the color yellow. The IT task tested information intake speed was tested by presenting test subjects with two parallel lines on a screen, quickly covering up the bottom portion, and then having them disclose which line length was longer. After all of the test subjects' results from each task were analyzed, the final findings showed that the presence of the EMF caused a significant decrease in simple and choice reactions times indicated by the decrease in scores for the CRT task.

During the same year as Keetley et al.'s (2006) study, Eliyahu et al. (2006) conducted an experiment that tested participants' cognitive functions by subjecting them to different radio frequency radiation conditions while performing four different cognitive tasks. Participants performed a spatial item recognition task ("FACE"), verbal item recognition task ("LETTER"), and two spatial compatibility tasks ("SPAT" and "SIMON") while being exposed to either radio frequency radiation or sham exposure on the left or right side of the head. The "FACE" task required test subjects to determine if the "face" presented on the screen was in the same location as the initial three "face" locations. The "LETTER" task presented test subjects with a series of uppercase letters followed by a singular lowercase letter. The test subjects were to determine if the lowercase letter was one that was previously shown in the series of uppercase letters. The "SPAT" task had test subjects move their left or right hand according to the side of the screen that a stimulus appeared. Lastly, the "SIMON" task had test subjects respond by either moving their left or right hand when the corresponding left and right-hand symbols appeared on the screen. After the task results were analyzed, a statistically significant interaction was found between EMF exposure on the left side of the head and a decrease in reaction time from the left hand. These results indicated that exposure to an EMF had a negative effect on a person's reaction time when the left side of the head was exposed to an EMF.

No Effect

Different studies have shown that exposure to a MP-EMF does not affect an individual's cognition. Hinrichs and Heinze (2004) decided to implement magnetoencephalograms over EEGs in their study when they tested the effects of EMF exposure. A magnetoencephalogram is a type of non-invasive brain imaging technique. It focuses on tracking intercellular currents (Velmurugan, Sinha, & Satishchandra, 2014). Hinrichs and Heinze (2004) tested the effects of EMF by having the 12 test subjects perform encoding-retrieval tasks while in the presence of EMF and inside of a magnetoencephalogram. Test subjects were exposed to EMF for 30 minutes. For the encoding-retrieval task, test subjects were presented with different words on a screen and were directed to discern between animate and inanimate objects. For animate objects, they were told to press one button, and for inanimate objects, they were told to press a different one. Their results showed an effect on one of the early encoding-retrieval tasks; however, they could not draw conclusions about the adverse effects of EMF exposure from their results and sample size.

Haarala et al. (2004) performed a study on 64 test subjects to examine if exposure to 902 MHz affected short-term memory. They had their participants perform the n-back task and tested reaction times. The n-back task was performed in the same manner as it was in Koivisto et al.'s (2000) research. Haarala et al. (2004) reported that there were no ill effects from the exposure. Maier, Greter, and Maier (2004) conducted a study that same year that examined how EMF exposure affected scores on an auditory order threshold task. To execute this task, test subjects were seated and were given specialized headphones that were placed over their ears. Two sounds were presented to the test subjects with a specific inter-stimulus interval. Test subjects were directed to determine which side the first sound originated from. They reported their answers with a two-button device. If a subject's answer was incorrect, the inter-stimulus interval increased, and if a subject's answer was correct, the inter-stimulus interval decreased. This task was done before subjects were exposed to 50 minutes of an EMF or 50 minutes of placebo exposure, and then directly following. Maier et al. (2004) tested eleven individuals with this protocol and reported that over 80% of the participants' scores decreased as a result of the EMF exposure. However, Cinel, Boldini, Russo, and Fox (2007) replicated the study done by Maier et al. (2004) three years later but performed it with a much larger sample size of 168 participants, which produced more powerful results. The researchers found that 40 minutes of exposure to a MP-EMF did not significantly affect a test subject's order threshold task performance, thereby disputing the results of the previous study. However, the researchers did note that EMF exposure may affect different auditory functions that were not tested in their study.

Eltiti et al. (2009) tested individuals who reported sensitivity to EMFs and examined the cognitive functions of attention and memory. They tested 44 self-reported EMF sensitive individuals and 114 control subjects. Eltiti et al. (2009) began by collecting data on each test subject's cognitive functions by having them perform the Wechsler Adult Intelligence Scale-Revised (WAIS-R) Digit Span forward and backward test, mental arithmetic (MA), the DSST, and the DS. The researchers used the WAIS-R to measure test subject's short-term memory. The MA consisted of different two-digit numbers that the test subjects would have to either add or subtract. The DSST and the DS tasks were performed in the same manner as they were in Keetley et al.'s (2006) study. To reduce noise from practice effects, different versions of each task were presented each time an individual repeated a task. The results of the study revealed no significant effects on attention and memory in either group when exposed to EMF.

Since 2010, research has continued to support the theory that EMF exposure does not affect cognitive functions. Trunk et al. (2014) designed an experiment to examine the interaction and effects of MP-EMF exposure and caffeine intake on reaction times and EEG recordings. They did so by testing 25 healthy individuals that were divided into four separate groups based on caffeine intake or MP-EMF exposure. Participants performed a reaction time task while their reaction times and brain wave activity were recorded. This task consisted of test subjects sitting in front of a screen with a button in front of them. Different geometrical shapes were presented before them, and when the target shape, a circle, appeared, they were directed to press the button. Although their results revealed an effect caused by caffeine on reaction times, no effect was reported in the groups that had been exposed to MP-EMF. Two years after this study, Mohan, Khaliq, Panwar, and Vaney (2016) examined the effects of chronic MP exposure on cognitive functioning. They tested 90 subjects and divided them into three groups according to the number of years each had spent using a MP. Each group was asked to perform an auditory discrimination task in which subjects would listen to auditory stimuli presented and respond by pressing a button with their dominant hand. After looking at different aspects of the EEGs, Mohan et al. (2016) determined that the amount of years someone had used a phone did not affect their cognition. A year later, research on the topic was conducted by Zubko et al. (2017). Their research dissected ten previous studies that focused on the effects of EMF on cognitive functions. After running a meta-analysis on the information obtained from each study, their findings revealed that exposure to EMF did not have a significant effect on an individual's working memory during each of the n-back, digit-span, and substitution tasks.

Inconsistencies in Findings

An analysis of previous literature elucidates the inconsistencies evident in research findings that test the effects of MP-EMF exposure on human brain bioelectric activity and cognitive functions. With such diversity in findings and methodology, a need for more conclusive research is needed. In the following section, the researcher's methodology for conducting the study is discussed.

Chapter III

Methods

This study was presented to the Oral Roberts University Institutional Review Board and approved on January 27, 2017. Each test subject gave their verbal and written informed consent before participation.

To conduct the statistical analyses in this research, version 22 of the International Business Machines Statistical Package for the Social Sciences (IBM SPSS 22) was utilized. A three-way mixed ANOVA was employed to analyze the EEG PSD values. This statistical test examined if there was an effect on the dependent variable (EEG PSD values) across three different independent variables (MP-EMF presence, electrode placement, and time) (Laerd Statistics, 2013). To examine the PASAT scores, a meta-analytic approach outlined by Walton Braver and Braver (1988), was utilized. A 2x2 ANOVA, a main effect test, an ANCOVA, a t-test, and the Stouffer Method (Stouffer, Suchman, Devinney, Star, & Williams Jr., 1949) were all utilized to determine if the administration of a pre-PASAT test caused a practice effect and if the presence of the MP-EMF had an effect on the PASAT scores.

Research Design

This study was conducted using a randomized controlled trial research design. The independent variables were the presence of a MP-EMF, electrode placement, and time. The dependent variables were the EEG PSD values and the PASAT scores.

Participants

Before any data collection was performed, each test participant answered a brief, in-person, demographics questionnaire with the researcher. Eighty-four people, ranging in age from 18-24 years old, participated in the experiment. There were 61 females (M = 20.6, SD = 1.6 years) and 23 males (M = 20.7, SD = 1.6 years). Each participant was randomly allocated to one of eight different groups to determine which test procedures the individual was to follow. The groups were differentiated based on treatment, electrode placement, and PASAT setup (Table 1). Each group consisted of a single treatment style (placebo telephone or mobile telephone), one electrode placement configuration (T3/T5 or T3/CZ), and one PASAT administration setup (pre- & post-test or post-test only).

Recruitment Procedures

The researcher presented her study to multiple psychology classes at Oral Roberts University to recruit test participants for her research. Additionally, many professors in the psychology department at her university offered extra credit to each student who participated in the study. Promotion of the study through word of mouth also aided in increasing the number of test subjects who participated.

BioPac MP36 Programing

The BioPac MP36 was used for all EEG data collection. The device's software could be manually programmed for different physiological tests. For this research study, the researcher manually programmed the software for the EEG recordings. To program, the BioPac Student Lab was opened and "create/record a new experiment" and "create empty graph" was selected. In the new dialog box, the label was changed to "EEG" to distinguish the type of test recording being performed. The preset was adjusted to "Electroencephalogram (EEG) .5-35Hz" and the sampling rate of 2.000kHz was not changed.

Delta waves. Under the calculations tab, the "acquire" box next to the "C1" was selected. In the additional window that appeared, "integrate" was changed to "EEG Delta" by scrolling through the list of options. By selecting this, an Infinite Impulse Response (IIR) acquisition filter was programmed in to separate out the delta waves from the entire EEG recording and into a different channel. The source channel of "CH 1, Analog input" remained unchanged and the "plot" box remained selected. In the original window, the label was changed to "EEG Delta," and the channel sampling rate was set at 2.000 kHz.

Theta waves. Next, the "acquire" box for "C2" was chosen. "Integrate" was changed to "EEG Theta," while the source channel remained the same and the "plot" box was left automatically checked. This selection added an IIR acquisition filter to separate out the theta waves into their own channel. Then, with the "EEG Theta" line active, the "Setup…" button was selected to adjust the IIR filters for the theta frequency range. Under the section "high frequency," next to "fixed at," the value "8" was changed to "7.5." This change decreased the IIR high-pass filter to match the researcher's intended frequency range for theta, 4.0-7.5Hz.

Alpha waves. Once saved, "acquire" on the C3 line was chosen. "Integrate" was adjusted to "EEG Alpha (8-13Hz)," while the source channel and plot box remained unchanged. This selection added an IIR acquisition filter to separate out the alpha waves into a different channel. “Setup…” was selected while the C3 line was active and under the “low frequency” heading, the “8” was changed to “7.5.” This change decreased the IIR low-pass filter to match the researcher's intended frequency range for alpha, 7.5-13.0Hz.

Slow beta waves. Subsequently, the C4 “acquire” was chosen and “integrate” was changed to “EEG Beta (13-30Hz).” This selection added an IIR acquisition filter to separate out all beta waves into a different channel. With C4 line selected, the “Setup…” button was pressed and the label “EEG Beta” was changed to “EEG Slow Beta.” Under the “high frequency” section and next to “fixed at,” the “30” was changed to “20.” This change decreased the IIR high-pass filter to match the researcher's intended frequency range for slow beta, 13.0-20.0Hz.

Fast beta waves. “Acquire” was selected in the C5 line, and “integrate” was adjusted to “EEG Beta (13-30Hz).” This selection added an IIR acquisition filter to separate out beta waves into a different channel. With line C5 active, “Set up…” was opened and the label “EEG Beta” was changed to “EEG Fast Beta.” Under “low frequency” and next to “fixed at,” the value “13” was changed to “20.” This change increased the IIR low-pass filter to match the researcher's intended frequency range for high beta, 20.0-30.0Hz.

Checking Filters. Once saved, on the “Data Acquisition Settings,” all sampling rates were selected at 2.000kHz, and all the presets had been automatically altered to read “Filter IIR,” except for the top one that read “EEG Delta (0.5-4Hz).” This was because the IIR filter values for the “EEG Delta (0.5-4Hz)” already matched the set values the researcher used for the delta frequency bandwidth, so no alterations needed to be made. These ranges correlated with the ranges used in the research conducted by Roggeveen, Os, Viechtbauer, and Lousberg (2015). Subsequently, the "Length/rate" tab was selected to adjust the EEG acquisition length. This was done by changing the "30.0000000 seconds" to "60.0000000 minutes." This alteration allowed for the ability to perform longer EEGs without any disruptions.

EEG Acquisition

Test subjects were placed in a stationary chair approximately two feet from a video screen. They were told to relax but remain as still as possible for the entire duration of the EEG recording. Limited accessible equipment allowed for only a single-channel EEG with a monopolar montage design, which was taken of each participant using a BioPac MP36 with shielded leads (BioPac EL258S). Shielded leads were used to decrease chances of the MP-EMF interfering with the EEG recording. Ag-AgCl electrodes were used and placed using the 10/20 International System (Figure 1). Four of the eight groups had the active electrode (Vin^+) at the T3 location and reference electrode (Vin^-) at the CZ location. The other four groups had the Vin^+ electrode at the T3 location and the Vin^- at the T5 location. The T3/CZ design was chosen by the researcher to determine if there was an effect on brain bioelectric activity at the T3 location when in reference to the most centralized 10/20 position (Demos, 2005). The T3/T5 design was selected to determine if the effects were concentrated at the T3 position, or if the effects expanded to the entire temporal lobe. Like Papageorgiou et al. (2006), the ground electrode was placed on the forehead for all conditions. Rubbing alcohol and electrode gel was used to prepare the skin and remove any debris that could have obstructed the signal, and conductive paste was used to adhere each electrode to the scalp.

During EEG signal acquisition, a 60Hz notch filter was used as well as a 38.6Hz and a 66.5Hz low-pass IIR filter. Each of these filters came initially programmed onto the BioPac MP36 EEG software and were kept by the researcher to ensure cleaner data. Impedance was kept below 20 kOhms, which was measured by the BioPac MP36. The researcher performed this measurement by moving the electrode lead adapter (BioPac SS1LA) from the “CH 1” port to the “Electrode Check” port. Under the MP36 tab, "Electrode Checker" was selected, and a graph was produced. From the graph, the impedance level was determined.

Once the equipment was set up, a 15 minute baseline EEG was collected before exposure to either a MP-EMF or a placebo telephone with no EMF. Test subjects were asked to remain as still as possible and to refrain from making any overt movements. Subsequently, the treatment exposure was introduced. This was done by pausing the EEG recording, handing the MP or placebo telephone to the test subjects, and having them place it against their left ear. They were asked to hold it there for the duration of the second EEG. Following placement, the 15 minute treatment EEG was obtained by restarting the recording. The software automatically added a marker each time the EEG recording was paused, which allowed for the researcher to differentiate between the baseline and treatment EEG. For the treatment with the MP, the same MP was used for each participant and had a specific absorption rate of 1.18 W/kg to exposed tissue, as reported in the online manual (Apple.com, 2014). The MP was turned on, in talk mode, with the volume turned down. To ensure consistency with the MP, an Extech RF EMF Strength Meter was used to monitor EMF levels. The placebo telephone groups held a counterfeit MP that was modeled to the same weight and specification of an actual MP but emitted no EMF. Additionally, during EEG signal acquisition similar to research conducted by Roggeveen et al. (2015), each subject viewed the same neutral documentary about animals and the earth.

EEG Signal Analysis

A Fast Fourier Transformation (FFT) was performed on each subject's two EEG data sets (baseline and treatment) to determine the power spectral density (PSD). In a book by Freeman and Quiroga (2012, p. 25-26), the authors described FFTs and their application to EEGs. They explained that an FFT is an algorithm that is performed on a time-dependent digital signal, which is how EEG data is categorized. The algorithm takes the data that is given over a time domain and transforms it into one over a frequency domain. This allows a researcher to see the distribution of each frequency (Freeman & Quiroga, 2012 p. 25-26). In a paper presentation, Unde and Shriram (2014, p. 871-872) explained, "Power spectral density describes how the power of a signal or time series is distributed with frequency" and that it "shows the strength of the variations as a function of frequency."

The absolute PSD, meaning the PSD of the entire signal, for each EEG recording was established through the integration of the 0.5Hz-30.0Hz bandwidth. The 0.5Hz-30.0Hz bandwidth was selected for it encompassed delta (0.5-4.0Hz), theta (4.0-7.5Hz), alpha (7.5-13.0Hz), slow beta (13.0-20.0Hz), and fast beta (20.0-30.0Hz) brain wave frequencies, which allowed for the assessment of the overall effect of a MP-EMF on the main human brain wave frequencies. To calculate the integral of the total 0.5Hz-30.0Hz bandwidth, each frequency range had to be analyzed. The individual ranges of 0.5-4.0Hz, 4.0-7.5Hz, 7.5-13.0Hz, 13.0-20.0Hz, and 20.0-30.0Hz were filtered into separate channels on the BioPac MP36 software, which is why the researcher took additional steps to determine the overall effect. The researcher selected this design to allow her to extend her research if she later decided to examine the effects the MP-EMF had on the individual brain waves rather than on the effects overall.

To calculate the PSD values on the BioPac MP36, multiple steps were required. To begin, the researcher selected the “EEG Delta” channel from the EEG data displayed on the screen. She selected the first 15 minutes, which was the baseline EEG, by using the “control+ shift + =” shortcut ("Biopac Student Lab PRO Manual," 2010). This shortcut allowed the researcher to perform calculations on only the baseline EEG and not the entire 30 minutes of EEG data. To perform the calculation, “Power Spectral Density” was selected in the calculations tab. A Hanning window was used in the analysis to mirror the design of the research done by Jung, Makeig, Stensmo, and Sejnowski (1997). The "automatic" window size was selected. For the FFT width, "32,768 samples" was inputted. The researcher selected this amount for it divided every 15 minutes of data into approximately 55 epochs. For the "overlap length," the researcher manually inputted "16,384 samples." This value was chosen to implement the Welch's method of 50% overlap, which was also used in research done by Polat and Salih Güneş (2007). Once all the data were submitted, a PSD graph was generated. The graph produced displayed the data over an interval of frequency rather than of time. The researcher used the "control+ shift + =" shortcut again to select the 0.5-4.0 Hz delta frequency range. The integral was then computed. This was achieved by selecting the current channel in the calculations toolbar, which was found in the ribbon. Then, the box that read "none" was selected and changed to "integral." The integral value was subsequently given and manually transferred into a spreadsheet document where all the data was stored. A separate spreadsheet was used because the BioPac MP36 system lacked the capability to store each integral value within the system. The previous steps were repeated for each channel, adjusting the frequency bandwidth to match each brain wave frequency range. Once all of the PSD values had been calculated for the first 15 minute baseline EEG, the same procedures were repeated for the second 15 minutes for the exposure EEG. Lastly, the absolute PSD value was calculated by adding all the individual brain wave PSD values. This was done by using calculations within the spreadsheet document.

Cognitive Assessment Procedures

Since its origination, research has shown that the Paced Auditory Serial Addition Test (PASAT) is a suitable way to examine an individual's information processing speed (Forn et al., 2008; Gronwall, 1977). However, the PASAT has been said to be subject to practice effects, meaning an individual's score may increase due to repeated administration of the test. Therefore, a Solomon four-group design was used in this study. A Solomon-four group design is a specific experiment arrangement that measures the influence of a study's pre-test on the post-test scores (Solomon, 1949). The Solomon-four group design acts by taking a two-group study design and adding two additional groups. The two additional groups consist of only the pre-test and treatment and only the pre-test and no treatment. To follow the design, only half of the groups performed the PASAT at two points during the study: before the initial baseline EEG and directly following the treatment EEG. The other half of the groups performed the PASAT only in the latter condition (Table 2). The PASAT is a test that is administered via an audio recording of numbers, one through nine, that are specifically distributed at a constant inter-stimulus interval. The individuals are asked to add the previous number they heard to the current number they just heard and verbally speak out the answer.

In this research study, the PASAT that was administered was formatted with 50 numbers and an inter-stimulus interval of three seconds. The pre- and post-test both consisted of different numbers; however, the math skills required for each test was consistent between them. Test subjects had two practice PASATs consisting of four numbers before the initial test was conducted. This was done to acclimate them to the format of the test. The researcher sat next to the test participant while he or she spoke each answer aloud. The researcher then manually recorded each answer on a physical copy of the PASAT test. During each subject's EEG recording, the researcher remained in the room and assessed the PASAT results.

Chapter IV

Results

EEG Results

Absolute PSD measurements for the baseline and treatment EEGs were analyzed using a three-way mixed ANOVA with the two between-subject factors being the treatment (MP vs. placebo telephone exposure) and electrode placement (T3/T5 and T3/CZ), and one within-subject factor being time (baseline PSD values and treatment PSD values). This three-way ANOVA was conducted to understand the effect of MP-EMF on human brain bioelectric activity at the T3 location. PSD values were moderately positively skewed. A square root transformation was performed to normalize the data sets. There were 11 outliers in the data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. Each outlying data set was removed from further analysis. Extreme and outlying values were assumed to be due to limitations in EEG filtering on accessible software, which was determined by further inspection of each outlying data set. For all groups but one, data were normally distributed as assessed by Shapiro-Wilk's test ($p > .05$). However, given that ANOVA is considered robust to violations of normality (Laerd Statistics, 2013), all data were retained for further analysis. Mauchly's test of sphericity was assumed given there were only two levels of the within-subjects factor. There was homogeneity of variance for both the baseline measurements ($p = .226$) and throughout the treatment measurements ($p = .355$) as assessed by Levene’s test for equality of variance. The three-way interaction between treatment, electrode placement, and brain waves was not statistically significant,

$F(1, 69) = .403$, $p = .528$, partial $\eta^2 = .006$. Additionally, all two-way interactions were not significant (time and treatment, $F(1, 69) = 1.738$, $p = .192$, partial $\eta^2 = .025$, and time and electrode placement, $F(1, 69) = 1.876$, $p = .175$, partial $\eta^2 = .026$).

PASAT Results

To accurately analyze the PASAT scores with a Solomon four-group design, a meta-analytic approach outlined by Walton Braver and Braver (1988), was utilized. To determine if there was a practice effect, a 2x2 ANOVA was run with the between factors being the treatment (MP vs. placebo telephone exposure) and pre-test (pre-test vs. no pre-test). There were two outliers in the data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. These scores were determined as genuinely unusual values because they were consistently the same distance from the boxplot for each level of the within subject factor, rather than falling at varying distances from each boxplot. These values were kept for further analysis. Data were not normally distributed as assessed by Shapiro- Wilk's test ($p > .05$); however, given that ANOVA is considered robust to violations of normality (Laerd Statistics, 2013), all data were retained for further analysis. There was homogeneity of variance, as assessed by Levene’s test for equality of variance, $p = .485$. There was no significant interaction between treatment and pre-test, $F(1,80) = .192$, $p = .662$, partial $\eta^2 = .002$, so to establish if the presence of a MP-EMF had an effect on test scores and to verify that there was no practice effect from the pre-test, a main effect test was run. There was no statistically significant main effect of treatment (MP vs. placebo telephone exposure) on post-test scores, $F(1,80) = 2.295$, $p = .134$, partial $\eta^2 = .028$, and there was no statistically significant main effect of pre-test (pre-test vs. no pre-test) on post-test scores, $F(1,80) = .154$, $p = .696$, partial $\eta^2 = .002$. These results indicated that there was no practice effect caused by the presence of the pre-test.

To determine if the presence of a MP-EMF had an effect on post-test scores, an ANCOVA was run on only the groups that performed both a pre- and a post-test, which were groups 2, 4, 6, and 8. These groups' post-test scores were analyzed with the covariate being the pre-test scores. To meet the assumptions, there was a linear relationship between pre- and post-test scores for both the MP and sham-phone conditions, as assessed by visual inspection of a scatterplot. There was homogeneity of regression slopes as the interaction term was not statistically significant, $F(1,38) = .005$, $p = .945$. Standardized residuals for the interventions were normally distributed as assessed by Shapiro-Wilk's test ($p > .05$). There was homoscedasticity, as assessed by visual inspection of the standardized residuals plotted against the predicted values. There was homogeneity of variance, as assessed by Levene's test of homogeneity of variance ($p = .379$). There were no outliers in the data, as assessed by no cases with standardized residuals greater than ± 3 standard deviations. After adjustment for the covariate, the pre-test scores, the ANCOVA was able to determine if there is a significant effect on the dependent scores, the post-test scores. The results indicated that there was not a statistically significant difference in post-test scores between MP and placebo telephone conditions, $F(1,39) = .145$, $p = .706$, partial $\eta^2 = .004$.

Since the ANCOVA resulted in non-significant results, an independent t-test was run on post-test scores in groups with only post-test scores (groups 1, 3, 5, and 7), as directed by Walton Braver and Braver (1988). To meet the assumptions, there were no outliers in the data, as assessed by inspection of a boxplot for values greater than 1.5 box-lengths from the edge of the box. Post-test scores for treatment conditions (MP vs. sham-phone) were normally distributed, as assessed by Shapiro-Wilks test ($p > .05$). There was homogeneity of variance as assessed by Levene's test for equality of variance ($p = .448$). There was not a statistically significant difference in mean post-test scores between the MP condition (*M* = 32.15, SD = 11.28) and placebo telephone condition (*M* = 32.05, SD = 9.52). Since both the ANCOVA and t-test results were non-significant, the meta-analysis approach, Stouffer Method (Stouffer, Suchman, Devinney, Star, & Williams Jr., 1949), was taken by combining the results of the ANCOVA and the independent t-test. The results from the meta-analysis were not statistically significant, $Z_{meta} = -.29$, $p = .77$.

Chapter V

Summary and Discussion

With the dramatic increase in MP usage worldwide, a vast number of people are concerned about the potential harmful effects MP-EMF exposure may have on their health, particularly their brains and different cognitive functions. This concern is augmented by the knowledge that a MP is generally positioned next to a person's ear when on a telephone call. While in this position, radio waves are being emitted and retrieved by the MP, all of which is occurring in the direct path of the human brain and skull. To address health concerns related to MP-EMF exposure, the researcher designed and conducted an experiment to test the effects of MP-EMF on human brain bioelectric activity at the T3 location and the cognitive function of information processing speed. Human brain waves were monitored using EEG technology and information processing speed was assessed by the PASAT.

EEG Discussion

A single-channel EEG using a monopolar montage setup was used to examine the effect of MP-EMF exposure at the T3 location. The T3/CZ design was implemented to investigate if there were changes in human brain bioelectric activity at the T3 location when in reference to the most central point on the skull (Demos, 2005), and the T3/T5 design was chosen to determine if 15 minutes of MP-EMF exposure had a localized effect at the T3 location. Results of the three-way mixed ANOVA revealed that 15 minutes of exposure to a MP-EMF did not have an immediate significant effect on human brain bioelectric activity at the T3 location when referenced to the T5 location and the CZ location. These results were comparable with the findings of Mann et al. (1998), Wagner et al. (1998), Wagner et al. (2000), Hietanen et al. (2000), Kleinlogel et al. (2008), Wu, Sajad, and Omar (2009), Trunk et al. (2013), Curcio et al. (2012), and Loughran et al. (2013). All of these studies indicated that MP-EMF did not have a significant effect on EEG recordings. These findings can aid in the efforts to diminish society's apprehension towards using MPs. However, possible confounding factors such as limitations in EEG equipment and the duration of MP-EMF exposure may have influenced the non-significant results that were produced in this study. The EEG equipment lacked extensive filtering capabilities; as a result of this limitation, if an artifact was discovered when an EEG recording was filtered, the entire EEG was rejected. Whereas, more detailed filtering would only reject the segment of time within the EEG that contained the artifact. Further research is suggested.

PASAT Discussion

Satisfactory performance on the PASAT has been shown to be associated with the different sections of the brain, including the left pre-frontal lobe (Rogers & Fox, 2012), which is why each subject held either a MP or placebo telephone next to his or her left ear only. A meta-analysis was performed to determine if MP-EMF exposure has an effect on information processing speed. The results of the meta-analysis indicated that the MP-EMF did not have a significant effect on information-processing speed. These findings similarly correlated with Papageorgiou et al.'s (2006) findings that suggested that a MP-EMF did not have a statistically significant effect on working memory. The results also reflected similar results with the research of Besset, Espa, Dauvilliers, Billiard, and Seze (2005). Their data suggested that daily MP use had no statistically significant effect on information processing speed, attention capacity, and memory and executive function. However, the non-significant results from the PASAT in this study may have been influenced by possible confounding factors such as the sensitivity and timing of the administration of the cognitive test and the duration of the MP-EMF exposure. Although the PASAT was primarily selected for its accessibility, a more sensitive test, such as the n-back task or the go/no-go task, may be more appropriate for identifying subtleties in cognitive fluctuations. Each of these tasks have been shown to be reliable measurements of cognitive fluctuations and are commonly used in cognitive research studies, while the PASAT is primarily used in clinical settings. Furthermore, mirroring the general setup of Edelstyn and Oldershaw's (2000) research, this study administered the cognitive test after MP-EMF exposure was removed. If there are cognitive variations that occur only while MP-EMF is present, this study's structure was not designed to detect them. Additional research that administers a cognitive test while test subjects are in the presence of MP-EMF exposure is advised. Lastly, the research conducted by Edelstyn and Oldershaw (2002) revealed that MP-EMF exposure increased test subjects' cognitive functions after 30 minutes of exposure. This study's MP-EMF exposure only measured 15 minutes in length, adding to the possible factors that may have influenced the non-significant cognitive test results. Supplementary research with an increased MP-EMF exposure length is recommended.

The study results indicated the exposure to MP-EMF for 15 minutes does not have a significant effect on brain wave activity at the T3 location and information processing speed. These results are aligned with previous research findings; however, further research is still suggested to control for different confounding factors.

Conclusions

1. The results of the three-way mixed ANOVA for the human brain bioelectric activity measurements indicated that 15 minutes of exposure to a MP-EMF did not produce a significant effect on human brain bioelectric activity at the T3 location when in reference to the T5 location. However, possible confounding factors may have attributed to the non-significant results.

2. The results of the three-way mixed ANOVA for the human brain bioelectric activity measurements indicated that 15 minutes of exposure to a MP-EMF did not produce a significant effect on human brain bioelectric activity at the T3 location when in reference to the CZ location. However, possible confounding factors may have attributed to the non-significant results.

3. The results of the meta-analysis for PASAT scores indicated that 15 minutes of exposure to a MP-EMF did not produce a significant effect on information processing speed. However, possible confounding factors may have influenced the results of the PASAT test.

Limitations

1. The available EEG program on the BioPac MP36 only allowed for a single-channel EEG. This limited the number of 10/20 positions that were monitored for the study.

2. The researcher was an undergraduate student with no prior knowledge of BioPac MP36 EEG acquisition and analysis, so the researcher had limited knowledge to draw from. Additionally, the researcher had a limited number of contacts, who also had a limited understanding of the topic, to discuss and solve problems when obstacles were encountered.

3. The filtering capabilities on the BioPac MP36 for the FFT and PSD measurements were generalized and unable to reject partial segments of an EEG recording that contained artifact. The BioPac MP36 filtered each EEG by examining the entire recording, and if an artifact was discovered, the entire EEG was rejected. Whereas, more detailed filtering would only reject the segment of time within the EEG that contained the artifact.

4. The BioPac MP36 was incapable of running an electromyography recording simultaneously with the EEG recording, which would have enabled the researcher to reject any artifact that was caused facial muscle movements.

Recommendations

1. Further research should include EEG recordings from multiple different channels. For a more comprehensive view of the brain, a 256 channel EEG is recommended.

2. Utilizing more advanced and precise EEG equipment that allows for epoch filtering and analysis and electromyography recording and artifact detection is recommended.

3. Further research that incorporates a more sensitive cognitive test, such as the n-back task or the go/no-go task, is recommended to detect any minor fluctuations in cognitive functioning that may occur due to MP-EMF exposure.

4. Increasing the length of MP-EMF exposure to more than 15 minutes in future research experiments is recommended to determine if an increase in exposure length causes a change in brain wave activity or cognitive functioning.

5. It is recommended that future research studies measure test subjects' cognitive functioning while in the presence of a MP-EMF.

6. A longitudinal study that examines the effects of MP-EMF exposure over the course of multiple years is suggested. A study that examines the effects of MP-EMF exposure across at least 10 years or more would be ideal to investigate if exposure has an accumulative effect.

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Vita

Laura A. Kaneta was born on November 30, 1995 in Las Vegas, Nevada. She attended Metro Christian Academy in Tulsa, Oklahoma but graduated in May 2014 from NorthStar Online Academy while living overseas. She is currently attending Oral Roberts University in Tulsa, Oklahoma where she anticipates to graduate in May of 2018. Laura plans to pursue her Ph.D. in clinical child psychology and specialize in neuropsychology. Her long-term goal is to conduct research on neurodevelopmental disorders and work towards more effective preventative measures and treatments. She is particularly interested in working with homeless communities and the foster care system.

Tables

Table 1

	Treatment		Electrode Placement		PASAT	
	Placebo Telephone	Mobile Telephone	T3/T5	T3/CZ	Pre- & Post-test	Post-test Only
Group 1	X		X		X	
Group 2	X		X			X
Group 3		X	X		X	
Group 4		X	X			X
Group 5	X			X	X	
Group 6	X			X		X
Group 7		X		X	X	
Group 8		X		X		X

Table 1: Each group's experimental design.

Table 2

		Viewing a Neutral Documentary		
Groups 1, 3, 5, & 7	N/A	15 minute baseline EEG	15 minute treatment EEG	Post-PASAT
Groups 2, 4, 6, & 8	Pre-PASAT	15 minute baseline EEG	15 minute treatment EEG	Post-PASAT

Table 2: Chronological illustration of each test subject's experimental procedures.

Figures

Figure 1

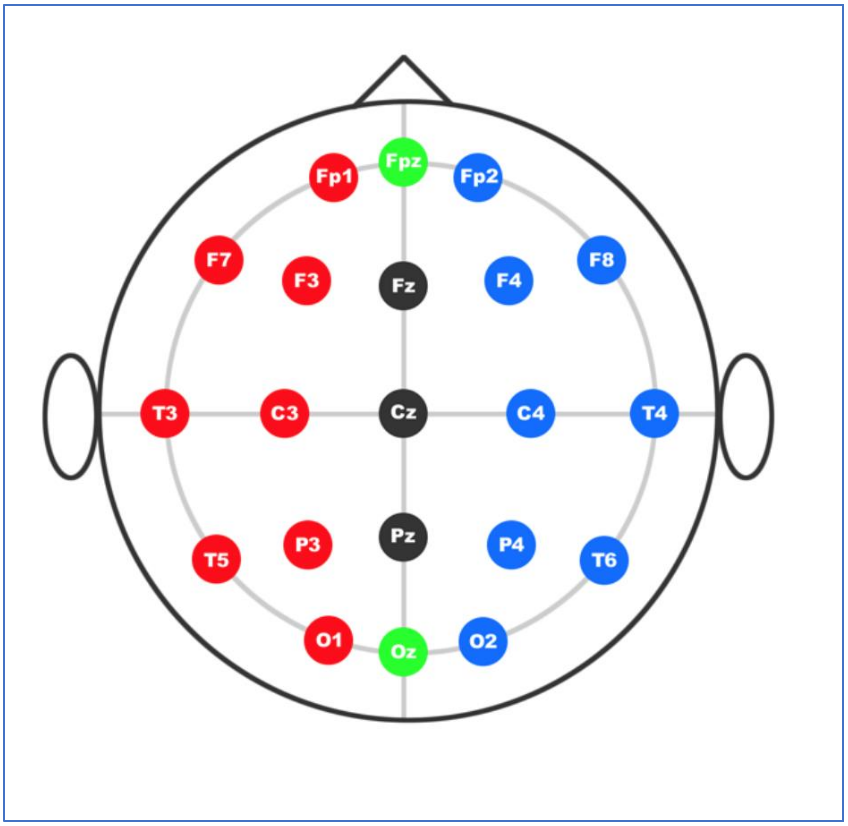

Figure 1: 10/20 International Positions (Trans Cranial Technologies, 2012).