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Brief Research Report

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The Effect of Mobile Telephone Electromagnetic Field on Human Brain Bioelectric Activity and Information Processing Speed

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ABSTRACT

Aim: 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.
Materials and Methods: 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 an MP-EMF or a placebo telephone with no electromagnetic field. The mobile telephone or placebo telephone was held by the test subjects and against their left ear for the duration of the 15 minute treatment EEG. Subjects were blind to the possibility of exposure to a placebo telephone. The PASAT is subject to practice effect, so a Solomon four-group design was implemented. Half of the groups received a pre-test and post-test, while the other half only received a post-test.
Results: 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.
Conclusion: These results indicate that 15 minutes of exposure to an MP-EMF does not produce a statistically significant effect on human brain bioelectric activity at the T3 location. While the PASAT scores also indicate 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.

KEY WORDS: Electromagnetic field; Paced Auditory Serial Addition Test; Information processing speed; Mobile telephones; Electroencephalogram (EEG); Mobile telephone electromagnetic field (MP-EMF); Solomon-four group design.

ABBREVIATIONS: MPs: Mobile telephones; MP-EMF: Mobile Telephone Electromagnetic field; EEG: Electroencephalogram; EMF: Electromagnetic field; PASAT: Paced Auditory Serial Addition Test; PSD: Power Spectral Density.

INTRODUCTION

Mobile telephones (MPs) have become a primary avenue for communication in our current society. They operate as two-way radios and transmit data and calls through the emission and retrieval of radio waves. These radio waves take the form of oscillating electric and magnetic fields, known as an electromagnetic field (EMF). With the understanding of the partial absorption of a mobile telephone electromagnetic field (MP-EMF) by the skull and brain,[1] there has

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been a proliferation in concern for one's health and the potential adverse effects caused by an MP-EMF. Consequently, studies concerning the technology have increased. However, studies are continually emerging with conflicting results as to whether or not an MP-EMF has an effect on human brain bioelectric activity and cognitive functions. In 2007, research from the University of Essex showed that exposure to an EMF for 40 minutes did not produce an adverse effect on an individual's performance in an order threshold task[2] 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.[3] Conversely, 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,[4,5] while 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.[6] Such diversity in findings delineates the need for further research to obtain more conclusive data.

This study was designed to investigate the effect of MP-EMF 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). This study takes a direct approach by focusing solely on the human brain bioelectric activity at the T3 location and the cognitive function of information processing speed. The T3 position is the closest 10/20 position to the MP's antenna when held against the ear, making it the central position focused on in the study. Each participant received a treatment of either exposure to an MP-EMF or a placebo telephone with no EMF while an EEG recording co-occurred to assess if the treatment affected human brain bioelectric activity. The PASAT was administered to examine information processing speed.[7,8] It was first introduced in 1974[9] as a way to evaluate cognitive functions of concussed individuals and is currently widely used in clinical settings on multiple sclerosis patients. The PASAT is subject to practice effects,[10] so a Solomon four-group design[11] was implemented in this research study to account for that.

MATERIALS AND METHODS

Subjects

Eighty-four people ranging in age from 18-24 years old participated in the experiment. There were 61 females (mean age 20.6±1.6 years) and 23 males (mean age 20.7±1.6 years). Participants were randomly allocated to one of the eight different groups, which were differentiated based on treatment, electrode placement, and PASAT setup (Figure 1).

Design

This study was presented to the Oral Roberts University Institutional Review Board (IRB) and approved on January 27, 2017. All test subjects gave their verbal and written informed consent before participation. Additionally, many psychology courses at Oral Roberts University offered comparable extra credit to students who participated.

Electroencephalogram (EEG) Acquisition

Test subjects were placed in a stationary chair approximately two feet from a video screen. Limited accessible equipment allowed for only a single-channel EEG with a monopolar montage design and it was taken of each participant using a BioPac MP36 with shielded leads (BioPac EL258S). Ag-AgCl electrodes were placed using the 10/20 International System. Half of the groups had the active electrode (Vin^+) at the T3 location and reference electrode (Vin^-) at the CZ location. The other half of the groups had the Vin^+ electrode at the T3 location and the Vin^- at the T5 location. The ground electrode was placed on the forehead for all conditions. Rubbing alcohol and electrode gel were used to prepare the skin, and conductive paste was used to adhere each electrode to the scalp. A 60 Hz notch filter was used as

Figure 1: Each Group's Experimental Design.

	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

PASAT: Paced Auditory Serial Addition Test.

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well as a 38.6 Hz and a 66.5 Hz low pass IIR filter. Impedance was kept below 20 kohms, which was measured by the BioPac MP36. During the EEG signal acquisition, each subject viewed the same neutral documentary. A 15 minute baseline EEG was collected before treatment exposure. Subsequently, the treatment (MP or placebo telephone exposure) was introduced, and an additional 15 minute EEG was obtained. 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 manual. It was held by the test subjects and against their left ear for the duration of the 15 minute EEG. The MP was turned on, in talk mode, with the volume turned down. 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.

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). Each 15 minute EEG was conducted at a sampling rate of 2000 Hz and subdivided into epochs of 32,768 samples, the width of each FFT. A Hanning window and Welch's method of 50% overlap was used in the calculations. The absolute PSD for each EEG was established through the integration of the 0.5 Hz-30.0 Hz bandwidth. The 0.5 Hz-30.0 Hz bandwidth was selected for it encompassed delta (0.5-4.0 Hz), theta (4.0-7.5 Hz), alpha (7.5-13.0), slow beta (13.0-20.0), and fast beta (20.0-30.0) brain frequencies, which allowed for the assessment of the overall effect of an MP-EMF on the main human brain wave frequencies.

Cognitive Assessment Procedures

Following the Solomon four-group 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 (Figure 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 just heard to the current number they 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 3 seconds. Test subjects had two practice PASATs consisting of four numbers in order to acclimate them to the format of the test before the initial test was conducted.

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, and each was removed from further analysis. 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. The three-way interaction between treatment, electrode placement, and brain waves was not statistically significant, $F(1, 69)=0.403$, $p=0.528$, partial $\eta^2=0.006$. Additionally, all two-way interactions were not statistically significant (time and treatment, $F(1, 69)=1.738$, $p=0.192$, partial $\eta^2=0.025$, and time and electrode placement, $F(1,69)=1.876$, $p=0.175$, partial $\eta^2=0.026$).

Paced Auditory Serial Addition Test (PASAT) Results

To accurately analyze the PASAT scores with a Solomon four-group design a meta-analytic approach, outlined by Walton Braver and Braver,[12] was utilized. To determine if there was a practice effect, a 2×2 ANOVA was run with the between factors being the treatment (MP *vs*. placebo telephone exposure) and pre-test (pre-test *vs*. no pre-test). Two outliers were found, but these scores were determined as genuinely unusual values and kept for further analysis. There was no significant interaction between treatment and pre-test, $F(1,80)=0.192$, $p=0.662$, partial $\eta^2=0.002$, so to establish if the presence of an 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, $F(1,80)=2.295$, $p=0.134$, partial $\eta^2=0.028$, and there was no statistically significant main effect of pre-test (pre-test *vs*. no pre-test) on post-test scores, $F(1,80)=0.154$, $p=0.696$, partial $\eta^2=0.002$. These results indicate that there was no practice effect caused by the presence of the pre-test. To determine if the presence of an MP-EMF had an

Figure 2: Chronological Illustration of each Test Subject's Experimental Procedures.

		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

PASAT: Paced Auditory Serial Addition Test.

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effect on post-test scores, an analysis of covariance (ANCOVA) was run on groups 2, 4, 6, and 8's post-test scores with the covariate being the pre-test scores. After adjustment for the pre-test scores, there was no statistically significant difference in post-test scores between MP and placebo telephone conditions, $F(1,39)=0.145$, $p=0.706$, partial $\eta^2=0.004$. Since the ANCOVA resulted in insignificant results, an independent *t*-test was run on post-test scores in groups with only post-test scores (groups 1, 3, 5, and 7). There was no statistically significant difference in mean post-test scores between MP condition (32.15±11.28) and placebo telephone condition (32.05±9.52). Since both the ANCOVA and *t*-test results were insignificant, the meta-analysis approach, Stouffer Method,[13] was taken by combining the results of the ANCOVA and the independent *t*-test. The results from the meta-analysis were not statistically significant, $Z_{meta}=-0.29$, $p=0.77$.

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, 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 3-way mixed ANOVA revealed that 15 minutes of exposure to an MP-EMF did not have an immediate effect on human brain bioelectric activity at the T3 location. These findings are comparable to the ones of Hietanen, Kovala, and Hämäläinen[14] and Wu, Sajad, and Omar.[15] Both studies indicate that MP-EMF does not have an effect on EEG recordings.

Satisfactory performance on the PASAT has been shown to be associated with the different sections of the brain, including the left pre-frontal lobe,[10] which is why subjects held either an MP or placebo telephone next to their left ear. The results of the meta-analysis indicate that the MP-EMF did not have an effect on information-processing speed. These findings similarly correlate with Papageorgiou's[16] findings that suggest that an MP-EMF does not have a statistically significant effect on working memory. The results also reflect similar results with the research of Besset, Espa, Dauvilliers, Billiard, and Seze.[17] Their data suggest that daily MP use has no statistically significant effect on information processing speed, attention capacity, and memory and executive function.

While it stands to reason that the lack of change in human brain bioelectric activity produce consistent cognitive functioning, it is important to note that in this study the insignificant results from the PASAT scores may have been influenced by possible confounding factors, such as the sensitivity and the timing of the administration of the cognitive test and the duration of the MP-EMF exposure. While the PASAT was primarily selected for its accessibility, a more sensitive test, such as the Go/No-Go task, may be more appropriate for identifying subtleties in cognitive fluctuations. Furthermore, mirroring the general setup of Edelstyn and Oldershaw's[6] 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 is advised. Lastly, the research conducted by Edelstyn and Oldershaw[6] 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 insignificant cognitive test results. Supplementary research with an increased MP-EMF exposure length is recommended.

CONCLUSION

The results of the three-way mixed ANOVA for the human brain bioelectric activity measurements and the results of the meta-analysis for PASAT scores indicate that 15 minutes of exposure to an MP-EMF does not produce a significant effect on human brain bioelectric activity at the T3 location or information processing speed. However, possible confounding factors may have influenced the results of the PASAT test. Further research that incorporates a more sensitive cognitive test, increases the length of MP-EMF exposure, and examines test subjects' cognitive functions while being exposed to MP-EMF is suggested to obtain more conclusive results that support the notion that mobile phones are innocuous.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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