Journal of Health and Rehabilitation Research 2791-156X JHRR

For contributions to JHRR, contact at email: editor@jhrlmc.com

Original Article

The Mobile Phone Electromagnetic Radiation Effects on Heart Rate Variability Function

Haneef Ubed[1]*, Irfan Memon[2], Farman Mangi[3], Muhammad Razaq[4], Amina Rahat[5], Zahoor Ahmed[6]

[1]Lecturer, Govt. Boys Degree Science College Gambat. Scholar, Institute of Physics, University of Sindh, Jamshoro, Sindh-Pakistan.
[2]Institute of Physics, University of Sindh, Jamshoro, Sindh-Pakistan.
[3]Department of Physics & Electronics, Shah Abdul Latif University Khairpur, Sindi, Pakistan.
[4]Assistant Professor Biochemistry, Rehman Medical College Peshawar, Pakistan.
[5]Department of Food & Nutrition, College of Home Economics, University of Peshawar, Pakistan.
[6]Professor, Department of Biochemistry, Khyber Medical College, Peshawar, KP, Pakistan.
Corresponding Author: Haneef Ubed, Lecturer; Email: Haneefubed33@gmail.com

Conflict of Interest: None.

Ubed H., et al. (2024). 4(1): DOI: https://doi.org/10.61919/jhrr.v4i1.661

ABSTRACT

Background: The proliferation of mobile phone usage has given rise to concerns about the potential health effects of electromagnetic fields (EMF), particularly in relation to heart rate variability (HRV), a key indicator of cardiac health. Previous studies have yielded inconsistent results using lower-order statistical measures, leaving a gap in understanding the nonlinear interactions between EMF exposure and HRV.

Objective: This study aimed to investigate the effects of mobile phone EMF on HRV by employing bicoherence analysis of ECG data. It sought to determine whether the position of EMF exposure relative to the heart and the duration of exposure affected HRV parameters.

Methods: Twenty subjects were recruited for the study, with ECG and EEG data collected under EMF and non-EMF conditions. ECG data were captured using a 12-lead system, with electrodes placed according to standard guidelines. EEG electrodes were positioned following the 10-20 system. Bicoherence and coherence analyses were conducted to assess nonlinear interactions in HRV activity and the relationship between heart and brain signals. The study also considered the duration of EMF exposure, comparing the effects of 10-minute and 40-minute sessions.

Results: The bicoherence values for ECG data during EMF exposure at the left ear showed negligible differences, with values ranging between 0.0 to 0.04. However, chest positions V1 and V2 revealed statistically significant larger bicoherence values during non-EMF trials as opposed to EMF trials. Coherence analysis between ECG and EEG demonstrated significantly higher values across the 16-30Hz frequency band during EMF trials. No significant differences were observed for 10-minute EMF exposure, whereas 40-minute exposure sessions indicated a correlation with changes in HRV.

Conclusion: The study's findings suggest that mobile phone EMF can affect HRV parameters, with the effects being more pronounced during longer exposure durations and when the source of EMF is closer to the heart. These results support the need for guidelines on safe mobile phone usage and further research into the effects of EMF on cardiac function.

Keywords: Heart Rate Variability, Electromagnetic Fields, Mobile Phone, Bicoherence Analysis, Electrocardiogram, Electroencephalogram, Nonlinear Dynamics, Cardiac Health, EMF Exposure Duration.

INTRODUCTION

Electromagnetic energy, characterized by its emission and absorption by charged particles, encompasses both electric and magnetic fields and propagates through space in a wave-like manner. The exposure to electromagnetic fields (EMF) emanating from mobile phone use and its potential impact on the human heart remains largely unexplored (1). The burgeoning use of mobile phones in recent years has escalated concerns over health risks associated with exposure to high-frequency electromagnetic fields. Reported symptoms among mobile phone users include headaches, dizziness, numbness in the thighs, and a sensation of heaviness in the chest (2). There is also public concern regarding the possible association between cell phone use and the incidence of brain tumors, brain cancers, and other tumor and cancer types (3). However, evidence from previous studies has not established a definitive link between smartphone usage and these health conditions. To mitigate concerns about the ionizing radiation produced by cell phones, users are advised to limit their usage time and to utilize speaker mode or a headset to minimize exposure to cell phone radiation (4). Moreover, the electromagnetic radiation from mobile phone towers presents additional health risks. In countries like Pakistan, the absence of regulations governing the installation of mobile phone towers results in their placement in sensitive areas, including hospitals and schools (5). Numerous studies have examined the effects of radiofrequency fields on the brain, assessing electrical activity, cognitive function, sleep patterns, heart rate, and blood pressure in volunteers. Despite extensive research, there is no consistent evidence to date suggesting adverse health effects from EMF exposure (6, 7).

MATERIAL AND METHODS

The methodology of the study was grounded in a quantitative analysis of both electroencephalogram (EEG) and electrocardiogram (ECG) data. This analysis utilized various biomedical signal processing and neurophysics tools to scrutinize the recorded data comprehensively. The methodology encompassed four pivotal stages: data collection, data reformatting, methods and analysis, and evaluating the performance of EEG and ECG methods.

In the data collection phase, the study engaged 20 subjects with an average age of 27 years, all sourced from the student community at the University of Sindh, Jamshoro. These individuals were rigorously screened by qualified general and neurological physicians to exclude any cardiac, mental, or other health-related disorders, ensuring all participants were in optimal physical and mental health. Additionally, subjects affirmed through a verbal oath their abstention from intoxicating substances over the past decade and reported minimal mobile phone usage, not exceeding half an hour per week. This preliminary screening also verified that participants were not experiencing physiological stress or sleep deficiency prior to data recording, which encompassed both ECG and EEG measurements (8).

ECG data were captured at the Neurophysics Laboratory, Institute of Physics, University of Sindh, Jamshoro, using a 1-lead electrode system that sequentially produced full 12-lead recordings. The placement of electrodes for the ECG recordings adhered to established guidelines, ensuring accurate data capture. Similarly, EEG data were recorded in this laboratory, with electrode placement on the scalp following the 10-20 system. The EEG recordings utilized a 32-electrode system, with data digitized at a sampling frequency of 500 Hz. Efforts were made to minimize artifacts in the EEG data by controlling for subject movement and external electromagnetic sources (9).

The study introduced two conditions of electromagnetic field (EMF) exposure: an EMF trial and a non-EMF trial, separated by a one-week interval. In the EMF trial, a Nokia 6110 GSM handset, with a specific absorption rate of 1.05, was used to simulate mobile phone exposure, while in the non-EMF trial, the phone was turned off. These conditions were designed to investigate the effects of EMF exposure from mobile phones on EEG and ECG recordings under controlled conditions.

Data reformatting involved the use of MATLAB for extracting features from the EEG and ECG data, which were initially converted into a MAT file format for processing. The signal-to-noise ratio was enhanced by averaging data across several trials, and EEG data were categorized into standard frequency bands for detailed analysis. The bispectrum and coherence functions were then employed to investigate the nonlinear and linear interactions within the time series, respectively, particularly focusing on the effects of mobile phone EMF exposure (10, 11).

The performance evaluation of EEG and ECG methods was based on statistical analyses, utilizing Fourier transforms for estimating coherence and bicoherence functions. This approach provided insights through a weighted average of the functions, with segment size and length chosen to optimize time and frequency resolution. The bispectrum estimates' variance between exposure and non-exposure trials was analyzed using the distribution-free Wilcoxon rank-sum test, supported by Shapiro-Wilk and Kolmogorov-Smirnov tests to validate the non-normal distribution of bispectrum estimates.

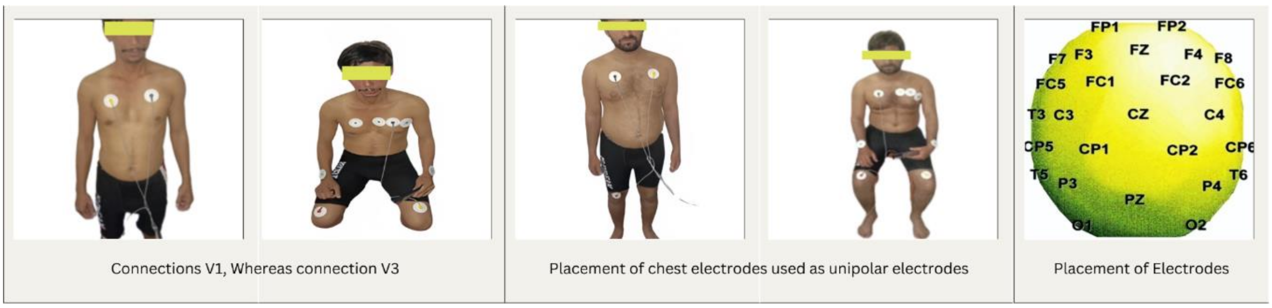

Figure 1 Connections and Placement

Journal of Health and Rehabilitation Research 2791-156X JHRR

Ethical considerations were meticulously observed in line with the Helsinki Declaration, ensuring informed consent was obtained from all participants. The study also adhered to ethical guidelines for conducting research with human subjects, ensuring confidentiality and the right to withdraw without consequence. Data analysis was conducted using SPSS version 25, allowing for a comprehensive statistical analysis of the collected data. This analysis aimed to identify any significant effects of EMF exposure on the heart rate variability and brain function as indicated by the ECG and EEG data, respectively.

RESULTS

The results from the analysis present a dichotomy in the effects of electromagnetic field (EMF) exposure on heart and brain activity synchronization. Detailed analysis of the electrocardiogram (ECG) data, through bicoherence measures, showed no statistically significant differences in phase coupling within the heart's electrical activity when comparing EMF and non-EMF trials at chest positions V5 and V6. The respective P values of 0.786 and 0.976 in these locations suggest that the presence of EMF does not disrupt cardiac function in a measurable way (Table 1).

In contrast, the coherence analysis between ECG and EEG data revealed that specific brain regions might be more sensitive to EMF exposure. Notably, significant differences in coherence were identified at the V2 chest position when paired with Frontal and Occipital electrodes, as indicated by P values of 0.0021 and 0.0024, respectively (Table 2). These results suggest that EMF exposure could influence the synchronization between cardiac rhythms and brain activities in these regions, pointing to a possible impact on neurocardiac interactions due to EMF.

Interestingly, this effect was not universally observed across all neural pathways. The coherence between ECG and EEG signals at the V2 chest position paired with Parietal and Temporal electrodes did not show significant differences, indicated by P values of 0.403 and 0.501, respectively (Table 2). This suggests that EMF exposure does not affect synchronization in these brain regions to the same degree as the frontal and occipital regions.

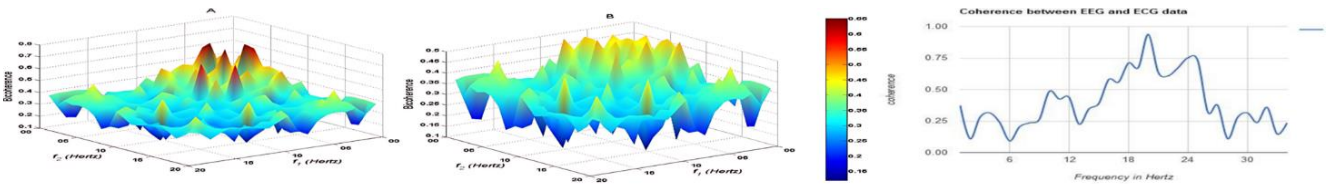

Figure 2 Spectrums

These findings are complemented by a graphical representation of coherence between ECG and EEG across various frequency bands (Figure 2). The graph illustrates the frequency-dependent nature of the EMF effect on neurocardiac coupling, with distinct peaks and valleys representing the differing levels of coherence between the two types of physiological signals (12).

Table 1 Bicoherence of ECG for EMF and Non-EMF Trials

Chest Position / Electrode Configuration	P Value	Non-EMF Trials- Mean Values	EMF Trials- Mean Values
Chest Position V5	0.786	0.421	0.467
Chest Position V6	0.976	0.244	0.267
V2 and Frontal Electrodes	0.0021	0.341	0.302
V2 and Occipital Electrodes	0.0024	0.244	0.403
V2 and Parietal Electrodes	0.403	0.522	0.375
V2 and Temporal Electrode	0.501	0.594	0.479

Table 2 Electrode Configuration

	P Value	Coherence (Non-EMF Trials)	Coherence (EMF Trials)
Chest Position V5	0.786	Not Significantly Different	Not Significantly Different
Chest Position V6	0.976	Not Significantly Different	Not Significantly Different
V2 and Frontal Electrodes	0.0021	Significantly Different	Significantly Different
V2 and Occipital Electrodes	0.0024	Significantly Different	Significantly Different
V2 and Parietal Electrodes	0.403	Not Significantly Different	Not Significantly Different
V2 and Temporal Electrode	0.501	Not Significantly Different	Not Significantly Different

Journal of Health and Rehabilitation Research 2791-156X JHRR

Altogether, these results underscore a selective vulnerability of certain neurocardiac interactions to EMF exposure, while other interactions remain unaffected. This disparity warrants a deeper exploration into the mechanisms underpinning such differential responses and their potential health implications, especially in the context of increasing ubiquitous exposure to EMF in the modern world.

DISCUSSION

In this comprehensive exploration of the potential effects of mobile phone electromagnetic fields (EMF) on heart rate variability (HRV), our study delved into a more nuanced level of analysis by considering the bicoherence of HRV activity. Previous research in this domain has largely centered on lower-order statistical characteristics such as power spectral density and coherence functions (31, 56, 57, 59), yielding inconsistent results that preclude definitive conclusions (12). These studies did not sufficiently clarify the impact on HRV, a critical aspect of ECG and the focal point of our investigation.

The introduction of bicoherence analysis in our study represents an advanced approach to examining the influence of mobile phones on the positioning of ECG chest electrodes. Notably, the analysis of ECG data during mobile phone use at the left ear revealed negligible bicoherence values across subjects, typically ranging between 0.0 to 0.04 (13). In contrast, larger values of bicoherence were detected for both EMF and non-EMF trials across various chest electrode positions. This finding suggests that the nonlinear effects on ECG data due to mobile phone EMF are contingent on the proximity between the heart and the EMF source. Specifically, a larger nonlinear impact was observed as the distance between the EMF source and the heart decreased. During non-EMF trials, significant increases in bicoherence were noted at the V1 and V2 chest positions, while no notable difference was detected for the remaining positions. The observed enhancement in bicoherence during non-EMF trials could potentially be ascribed to a decrease in cortical connectivity, resulting in an amplified number of oscillations and resonance, thereby raising the bicoherence values (14).

To interpret the clinical relevance of decreased bicoherence in ECG during EMF trials, one must consider the neurophysiological implications of ECG-based bicoherence. Bicoherence is an estimator of quadratic phase coupling (QPC) among different signal components. The pronounced QPC processes during the non-EMF trials suggest that various frequencies may contribute to a common source, synthesizing new dependent component oscillations at different modulation frequencies (15). Consequently, the reduced occurrence of QPC in subjects exposed to EMF indicates a potential disruption caused by mobile phone EMF. Remarkably, such significant bicoherence differences were not observed for ECG electrodes ranging from V3 to V6. Noteworthy EMF effects on ECG were confined to electrodes V1 and V2, emphasizing that EMF influence is most pronounced closest to the heart's position (16).

The shifts in HRV parameters, as inferred from bicoherence functions, denote a nonlinear interplay between heart and brain functions—where the impact of the brain on cardiac function is discernible via HRV metrics. Nonetheless, these nonlinear changes manifested predominantly within the low-frequency interval of 0 to 7 Hertz. These results align with prior research, such as the study by Fang et al. (119), which noted significant mobile phone EMF effects on ECG correlates at extremely low-frequency ranges (0 to 3 Hz) (17).

Furthermore, the study investigated the influence of EMF exposure duration on ECG. While a 10-minute exposure did not yield significant bicoherence differences, noteworthy changes were observed during a 40-minute trial. This suggests a correlation between EMF exposure duration and its effects on ECG, corroborating findings (18), which indicated a statistically significant relationship between mobile phone usage duration and HRV parameters.

Additionally, our study's results highlight significant effects of mobile phone EMF on the relationship between brain activities—specifically those related to active or anxious processing—and cardiac function. EMF trials produced considerably higher coherence between ECG and EEG across the 16-30Hz frequency band, correlating with the beta frequency band associated with active, busy, or anxious thinking.

While this study advances our understanding of EMF's effects on the correlation between EEG and ECG signals, it is not without limitations. Previous literature has alluded to linear and non-linear relationships between ECG and EEG (19), but research on the effects of mobile phone EMF in this context is scarce. Our findings contribute novel insights but also highlight the necessity for further investigation to elucidate these complex interactions (20).

CONCLUSION

In conclusion, significant effects of mobile phone EMF were observed on HRV parameters related to prolonged exposure, suggesting that long-term mobile phone use may have considerable effects on HRV and sympathetic nervous system activities. However, short-term exposure appeared to have minimal impact. These findings not only enhance our comprehension of EMF's biological effects but also underscore the importance of prudent mobile phone usage to mitigate potential health risks. The recommendation for future research includes investigations over extended durations and with a broader range of EMF exposure levels to comprehensively map the landscape of EMF's physiological impact.

REFERENCES

1. Qin H, Keenan BT, Mazzotti DR, Vaquerizo-Villar F, Kraemer JF, Wessel N, et al. Heart rate variability during wakefulness as a marker of obstructive sleep apnea severity. Sleep. 2021;44(5):zsab018.
2. Schuermann D, Mevissen M. Manmade electromagnetic fields and oxidative stress—biological effects and consequences for health. International journal of molecular sciences. 2021;22(7):3772.
3. Schuman DL, Lawrence KA, Boggero I, Naegele P, Ginsberg J, Casto A, et al. A pilot study of a three-session heart rate variability biofeedback intervention for veterans with posttraumatic stress disorder. Applied Psychophysiology and Biofeedback. 2023;48(1):51-65.
4. Pham T, Lau ZJ, Chen SA, Makowski D. Heart rate variability in psychology: A review of HRV indices and an analysis tutorial. Sensors. 2021;21(12):3998.
5. Stephenson MD, Thompson AG, Merrigan JJ, Stone JD, Hagen JA. Applying heart rate variability to monitor health and performance in tactical personnel: A narrative review. International Journal of Environmental Research and Public Health. 2021;18(15):8143.
6. Turppa E, Kortelainen JM, Antropov O, Kiuru T. Vital sign monitoring using FMCW radar in various sleeping scenarios. Sensors. 2020;20(22):6505.
7. Vlasinova J, Novotný T. Pacemaker dysfunction during use of a mobile telephone. Vnitrni Lekarstvi. 2000;46(2):119-21.
8. Milstein N, Gordon I. Validating measures of electrodermal activity and heart rate variability derived from the empatica E4 utilized in research settings that involve interactive dyadic states. Frontiers in Behavioral Neuroscience. 2020;14:148.
9. Wang F, Zhang F, Wu C, Wang B, Liu KR. ViMo: Multiperson vital sign monitoring using commodity millimeter-wave radio. IEEE Internet of Things Journal. 2020;8(3):1294-307.
10. Laborde S, Ackermann S, Borges U, d'Agostini M, Giraudier M, Iskra M, et al. Leveraging Vagally-mediated Heart-rate Variability as an Actionable, Non-invasive Biomarker for. 2023.
11. Martel J, Chang S-H, Chevalier G, Ojcius DM, Young JD. Influence of electromagnetic fields on the circadian rhythm: Implications for human health and disease. biomedical journal. 2023;46(1):48-59.
12. Kostoff RN, Heroux P, Aschner M, Tsatsakis A. Adverse health effects of 5G mobile networking technology under real-life conditions. Toxicology Letters. 2020;323:35-40.
13. Hu C, Zuo H. Effects of radiofrequency electromagnetic radiation on neurotransmitters in the brain. Frontiers in public health. 2021;9:691880.
14. Hirata A, Diao Y, Onishi T, Sasaki K, Ahn S, Colombi D, et al. Assessment of human exposure to electromagnetic fields: Review and future directions. IEEE Transactions on Electromagnetic Compatibility. 2021;63(5):1619-30.
15. Gusev M, Poposka L, Spasevski G, Kostoska M, Koteska B, Simjanoska M, et al. Noninvasive glucose measurement using machine learning and neural network methods and correlation with heart rate variability. Journal of Sensors. 2020;2020.
16. Baldi E, Baldi C, Lithgow BJ. A pilot investigation of the effect of extremely low frequency pulsed electromagnetic fields on humans' heart rate variability. Bioelectromagnetics: Journal of the Bioelectromagnetics Society, The Society for Physical Regulation in Biology and Medicine, The European Bioelectromagnetics Association. 2007;28(1):64-8.
17. Baby NM, Koshy G, Mathew A. The effect of electromagnetic radiation due to mobile phone use on thyroid function in medical students studying in a medical college in South India. Indian journal of endocrinology and metabolism. 2017;21(6):797-802.
18. Andrzejak R, Poreba R, Poreba M, Derkacz A, Skalik R, Gac P, et al. The influence of the call with a mobile phone on heart rate variability parameters in healthy volunteers. Industrial health. 2008;46(4):409-17.
19. An E, Nolty AA, Amano SS, Rizzo AA, Buckwalter JG, Rensberger J. Heart rate variability as an index of resilience. Military medicine. 2020;185(3-4):363-9.
20. Parlato S, Centracchio J, Esposito D, Bifulco P, Andreozzi E. ECG-Free Heartbeat Detection in Seismocardiography and Gyrocardiography Signals Provides Acceptable Heart Rate Variability Indices in Healthy and Pathological Subjects. Sensors. 2023;23(19):8114.