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ORIGINAL RESEARCH ARTICLE

Evaluating numerous techniques for the effects of electromagnetic waves on the Electro Cardio Gram (ECG)

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ABSTRACT

Nowadays, due to the widespread use of mobile phones and the proliferation of mobile towers the human body parts especially the heart are getting affected. Furthermore, these waves are ubiquitous in our modern society, with various sources emitting these waves in our environment. As medical devices become more prevalent and wireless technologies continue to advance, concerns have been raised regarding the potential impact of electromagnetic waves on human health. It is important to monitor the condition of your heart. With the increase in the number of mobile phones, there is also an increase in electromagnetic radiation, which can affect the human heart. The heart is an important component of the human body and an electrocardiogram (ECG) can provide valuable information about its condition. ECG parameters can show how well the heart is working. In this paper, the author proposes how ECG parameters change under the influence of mobile phones in three different situations. A comprehensive experimental setup was devised. A group of healthy human subjects volunteered to participate in the study, with each subject undergoing ECG recording under controlled conditions. The subjects were exposed to varying intensities and frequencies of electromagnetic waves generated by a standardized source. Statistical analysis was performed to compare the ECG measurements obtained during exposure to electromagnetic waves with those obtained in a controlled environment without electromagnetic wave exposure. This study contributes to the growing body of research on the potential health effects of electromagnetic waves. By specifically focusing on the ECG signal, which is vital for cardiovascular diagnostics, this research provides valuable insights into the safety and reliability of using ECG in environments with electromagnetic wave exposure. The findings will help inform healthcare professionals, engineers, and policymakers to establish appropriate guidelines and safety measures concerning the use of medical devices and wireless technologies in proximity to patients or individuals with cardiac conditions.

Keywords: cardiac conditions; electromagnetic radiation; ECG parameters; ECG signals; electromagnetic wave; Electrocardiography (ECG); human health; heart rates; mobile phone

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1. Introduction

The use of mobile phones is becoming more and more widespread, resulting in high levels of electromagnetic radiation (EMR) in our daily lives. Although EMR from mobile phones is classified as non-ionizing and does not have the same harmful effects as ionizing radiation, there may be health risks associated with long-term exposure[1]. Research has shown that EMR can cause thermal and non-thermal effects and induce oxidative stress in animal brains and heart tissue. Mobile phones are a ubiquitous part of modern life, but their use has increased EMR in our surroundings. While EMR from mobile phones is not ionizing and does not have the same harmful effects as X-rays or gamma rays, prolonged exposure to this radiation can pose a health risk. Studies have found that EMR can cause both thermal and non-thermal effects and can cause oxidative stress in the brain and heart tissues of animals.

Considering the findings of previous studies on the harmful effects of mobile phone waves on the one hand and the inevitable need to use mobile phones in daily life on the other hand, this research was conducted to study the effects of mobile phone waves on electrocardiograms in different age peoples. It should be stated that few studies have been conducted on the effects of these waves on the heart[2].

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) has established guidelines for Specific Absorption Rate (SAR) in mobile phones. SAR measures how much energy the body absorbs from RF waves emitted by a mobile phone. The Department of Telecommunications (DoT) has approved a maximum SAR value of 1.6 W/kg for mobile phones. The heart, being an important organ responsible for blood circulation throughout the body, can be monitored through electrodes placed on the chest to assess electrocardiogram (ECG) parameters. It is important to acknowledge that the effects of electromagnetic radiation (EMR) on the heart are still being researched, and further studies are needed to fully understand the potential long-term health risks associated with prolonged exposure to EMR from mobile phones[3].

In light of these considerations, it is recommended to limit the use of mobile phones and take necessary precautions to reduce the potential health risks associated with EMR. These may include using hands-free devices, reducing the duration of calls, and avoiding mobile phones being close to the body or in pockets for long periods of time[4].

1.1. Electrocardiography (ECG)

Depolarization of the left and right atria, and the resulting atrial contraction, is represented by the P wave. It should be noted that the atria contract a fraction of a second after the onset of the P wave[5]. The QRS complex, consisting of the Q wave, R wave, and S wave, occurs in rapid succession and reflects the propagation of the electrical impulse through the ventricles, indicating ventricular depolarization. Similar to the P wave, the QRS complex begins just before the ventricular contraction[6]. After the QRS complex, a T wave appears, indicating ventricular repolarization, as shown in **Figure 1**.

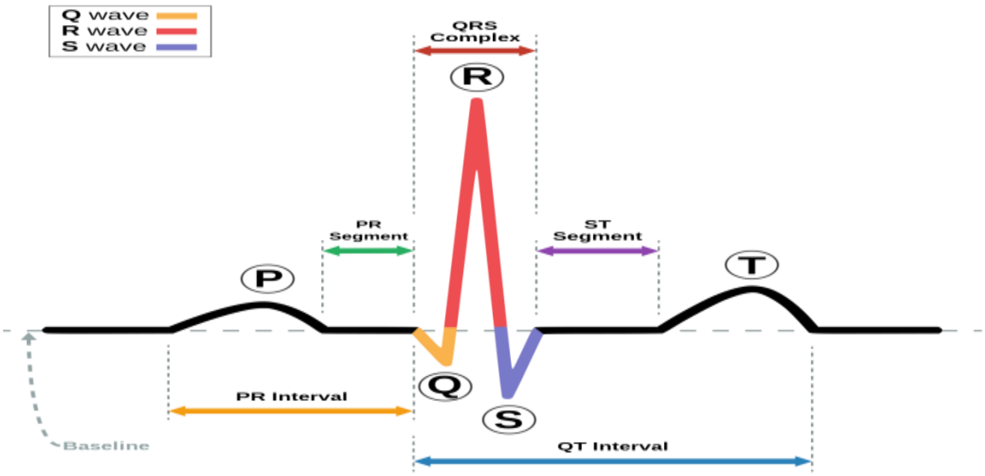

Figure 1. Basic of ECG.

1.2. Electromagnetic sources

An electromagnetic source is an object or device that emits electromagnetic radiation (EMR) in the form of waves or particles. Electromagnetic radiation is a type of energy that is transmitted through space at the speed of light. It consists of two components: an electric field and a magnetic field that rotates perpendicular to each other and the direction of propagation[7].

There are many sources of electromagnetic radiation in our environment, both natural and man-made. Here are some examples given in **Table 1**, **Table 2** gives their frequency and transmission power details[8].

Table 1. Common electromagnetic sources.

Sr. No	Frequency range	Common uses
1	30 kHz–300 GHz	Radio and TV, mobile phones, Wi-Fi, Bluetooth
2	300 MHz–300 GHz	Microwave ovens, radar, satellite communications
3	300 GHz–400 THz	Heat lamps, remote controls, some communication
4	400 THz–800 THz	Lighting, optical communication
5	800 THz–30 PHz	Tanning beds, black lights, sterilization
6	30 PHz–30 EHz	Medical imaging, security scanning
7	30 EHz–300 EHz	Cancer treatment, radiation therapy

There are many sources of electromagnetic radiation in our environment, both natural and man-made. Here are some examples given in **Table 1**, **Table 2** gives their frequency and transmission power details[8].

Table 2. Electromagnetic sources and their frequency & transmission power.

S. No.	R. F Source	Operating Frequency	Transmission Power	Numbers
1	AM/FM tower	540 KHz–108 MHz	1 KW–300 KW	380
2	TV tower	48 MHz#814 MHz	10–500 Watt	1201
3	Wi-Fi	2.4–2.5 GHz	10–100 mW	-
4	Cell towers	800, 900, 1800, 2450 MHz	20 W	5.4 Lacs
5	Mobile phone	GSM#1800/CDMA GSM#900	1 W–2 W	700+ Million

1.3. The radio frequency sources

Differences in voltage create electric fields, higher voltages create stronger fields. Magnetic fields are created when electric current flows, strong currents create strong fields. The combination of electric and magnetic fields creates an electromagnetic field (EMF). In telecommunications, commercial land mobile services generate electromagnetic radiation, including EMF, and can have potential effects on public health. Mobile phones emit radiation that can potentially affect public health. Characteristics associated with EMF radiation include frequency, strength, duration, and exposure from other sources[9].

1.4. Radiation effect

EMF radiation can be examined from two perspectives: biological effects and health effects. Biological impacts are measurable responses to stimuli or changes in the environment that are not necessarily harmful to human health[10]. On the other hand, health effects can be short-term or long-term changes that can stress the system and be harmful to human health.

Radiofrequency radiation (RFR) exposure can cause biological effects in two distinct ways. First, holding a mobile phone close to the body causes thermal effects, which can heat tissues. Second, there may be potential nonthermal effects from both the phone and the base station, which are unrelated to tissue heating but may still influence biological systems. Both types of effects should be considered in the study of EMF radiation[11].

1.5. Thermal effect

Microwave radiation can cause dielectric heating, which refers to the heating of any dielectric material, including living tissue, induced by an electromagnetic field. The thermal effect is mainly due to the absorption of EMF radiation. When a person uses a cell phone, most of the heating effect occurs on the surface of the head, causing a slight increase in temperature. Excess heat is disposed of by increasing local blood flow to the brain, but the cornea of the eye lacks a temperature regulation mechanism. This thermal effect can cause rise in body temperature[12].

1.6. Non-thermal effect

It is important to note that while there is a lack of conclusive evidence linking long-term exposure to wireless technology and adverse health effects, precautionary measures are recommended. The World Health Organization (WHO) has classified radiofrequency electromagnetic fields as carcinogenic to humans based on some limited evidence of a possible increase in brain tumors from mobile phone use[13]. The Indian Council of Medical Research (ICMR) has also recommended that precautionary measures should be taken to minimize exposure to EMF radiation. It is also worth noting that the effects of EMF radiation can vary based on individual factors such as age, health status, and duration and intensity of exposure. Therefore, it is important to continue research and studies on the potential health effects of EMF radiation and to promote awareness and precautionary measures to reduce exposure[14].

1.7. Related work

There is a substantial body of scientific literature on the subject of the effect of electromagnetic radiation on the electrocardiogram. Here are some examples of studies and reviews on this topic:

The research paper titled “Effect of Cell Phone Radiation (940 MHz) on the Learning and Memory of Bulb/C Mice” aims to investigate the effect of cell phone radiation on learning and memory in mice[15]. The study was conducted on Balb/c mice, which were exposed to 940 MHz frequency radiation for 2 hours per day for 35 days, the study found that exposure to cell phone radiation significantly decreased learning and memory in the mice. The authors suggested that this may be due to oxidative stress caused by cell phone radiation, which can damage cells and tissues in the body, including the brain. It is important to note that this study was conducted on animals and may not directly translate to the effects of cell phone radiation on humans. However, this study raises concerns about the potential long-term effects of cell phone radiation on brain function and the need for further research in this area[16].

The study by Lekawa-Raus, Dąbrowski, and Karpowicz aimed to systematically review the evidence on electromagnetic interference of mobile phones on ECG recordings. The study reviewed 22 articles published between 2004 and 2017 that investigated the effect of electromagnetic interference from mobile phones on ECG recordings. The authors found that electromagnetic interference from mobile phones can cause significant changes in ECG recordings, including changes in P-wave, QRS complex, and T-wave morphology, as well as heart rate and rhythm. The degree of interference varies depending on several factors, such as the distance between the phone and the ECG electrodes, the frequency and intensity of the phone signal, and the type of ECG equipment used. The authors concluded that mobile phone electromagnetic interference can significantly affect the accuracy and reliability of ECG recordings, which may have clinical implications for patient care. They suggested that further research is needed to develop guidelines on the safe use of mobile phones during ECG recording to reduce the risk of electromagnetic interference[17].

Another study aimed at reviewing the effects of electromagnetic radiation on the electrocardiogram (ECG) was conducted by Wang et al.[18]. The study reviewed 45 articles published between 2000 and 2019 that investigated the effects of electromagnetic radiation on the ECG. The authors found that electromagnetic radiation can cause significant changes in ECG recordings, including changes in heart rate, heart rate variability, and ECG waveform morphology. The degree of interference varies depending on several factors, such as the frequency and intensity of electromagnetic radiation, the distance between the radiation source and the ECG electrodes, and the duration of exposure. The authors concluded that electromagnetic radiation may have a negative impact on the accuracy and reliability of ECG recordings, which may have clinical implications for patient care. They suggested that further research is needed to better understand the mechanisms underlying the effects of electromagnetic radiation on the ECG and to develop guidelines for safe exposure limits to reduce the risk of interference[19].

The electromagnetic wave spectrum covers a wide range of frequencies spanning from 300 MHz to 300 GHz, with corresponding wavelengths varying from 1 mm to 1 m. Mobile phones emit waves in this frequency range, typically 900 MHz to 1 GHz[20]. The increasing use of mobile phones that emit electromagnetic waves has raised concerns about their potential effects on human health. Numerous reports in recent years have highlighted the teratogenic effects of these waves on various developmental processes, prompting researchers to investigate their effects on human health[21]. Some surveys have found symptoms such as sleep disturbances, headaches, anxiety, depression, and fatigue in individuals living near mobile phone antennas. However, other studies have found no association between these symptoms and exposure to mobile phone radiation. Epidemiological studies have shown that mobile waves with a power density of less than 1 mV/cm^2 can cause symptoms such as headache, ear irritation, memory loss, and fatigue. Moreover, there is a significant relationship between the duration and frequency of phone conversations in a day and the onset of these symptoms[22].

Andrzejak and colleagues studied the effects of mobile phones on the heart rate variability (HRV) of students with natural electrocardiograms and echocardiograms. They recorded HRV changes before, during, and after mobile phone use. Results showed significant differences in HRV during incoming calls and after the conversation compared to the pre-talk period[23]. Colak et al. conducted a study titled “Effects of Electromagnetic Radiation from 3G Mobile Phones on Heart Rate, Blood Pressure and ECG Parameters” in the Journal of Toxicology[24]. In 2011, this study aims to investigate the effect of electromagnetic radiation emitted by 3G mobile phones on heart rate, blood pressure, and electrocardiogram (ECG) parameters in rats[25]. In a case-control study examining long-term mobile phone use and brain tumor risk, results from the United States and five European countries after ten years of follow-up indicated that regular mobile phone users had a higher risk of brain tumors than those who rarely or never used mobile phones[24,26].

2. Materials and methods

2.1. Hardware

An ECG machine is important to ensure accurate and reliable readings of ECG parameters. By measuring heart rate, PR interval, QRS interval, QT interval, and QTc interval, you can get a comprehensive understanding of the heart’s electrical activity and identify any abnormalities or irregularities. Interpreting ECG results in the context of the patient’s medical history, symptoms, and physical examination is important for making an accurate diagnosis and developing an appropriate treatment plan[27].

Electrodes: Electrodes are placed at specific points on the skin to measure the electrical activity of the heart. Electrical impulses generated by the heart are conducted through the body and detected by electrodes[28]. These impulses are then amplified and recorded by an ECG machine to create a visual representation of the heart’s activity, which can be used to diagnose various heart conditions. A standard 12-lead ECG typically uses 10 electrodes, which are placed on the chest, arms, and legs. A standardized ECG machine is used to accurately measure these parameters and provide readings for each of the 40 subjects under test. Overall, electrocardiography is a valuable tool for diagnosing various heart conditions and monitoring heart health[29].

ECG Machine: An ECG machine, or electrocardiogram machine, is a medical device used to measure and record the electrical activity of the heart. It works by detecting the electrical signals produced by the heart as it beats and then converting these signals into a graphical presentation on paper or a computer screen[30]. An ECG machine usually consists of several leads (wires with electrodes attached to them) that are attached to the patient's chest, arms, and legs so that the electrical activity of the heart is taken from different angles. The machine then amplifies and filters these signals, and records them as a series of waves and intervals representing the heart's electrical activity (**Figure 2**). The resulting ECG recordings can be used by doctors to diagnose a wide range of heart conditions, including heart attacks, heart attacks, and heart failure[31].

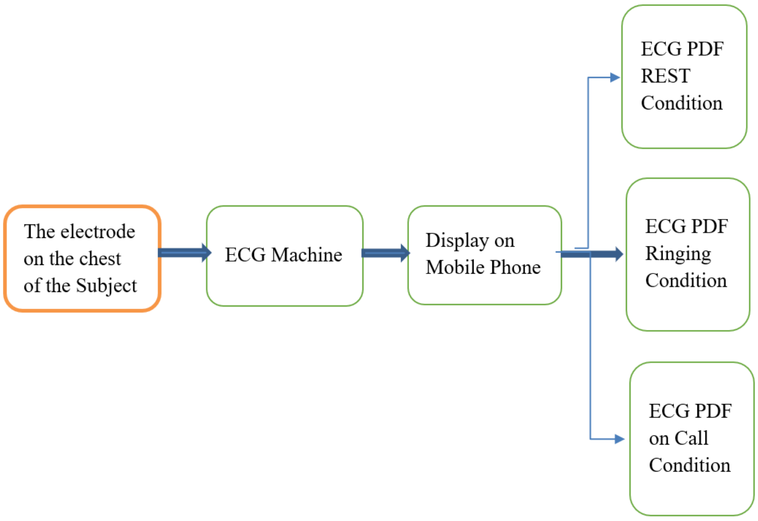

Figure 2. Block diagram of experimental work.

2.2. Experimentation methods

To examine the effect of mobile phone electromagnetic radiation on human electrocardiography (ECG), we experimented on 40 individuals, students, teachers, and non-teaching staff at Marathwada Institute of Technology, Aurangabad (Chhatrapati Sambhaji Nagar). My study involved taking ECG readings under different conditions and at different ages. The purpose of my research is to present our findings on the potential effects of mobile phone radiation on the human ECG.

Three conditions were considered for the use of mobile phones and analyzed their effect on electromagnetic radiation[32]. These are the three conditions

Three mobile phone conditions are considered for the analysis:

1) Silent mode or resting position with normal ECG without using a mobile phone;
2) Ringing status;
3) On-call status on the receiver side.

In modern times, the number of people using mobile phones in their daily lives has increased rapidly. Therefore, I am considering a mobile phone as a possible source of electromagnetic radiation and analyzing its effects on ECG parameters.

2.2.1. First condition (rest condition): Method 1

The following are the steps for the first condition that the mobile phone is in silent mode or resting state:

- The subject is instructed to either lie down or sit in a relaxed position.
- ECG electrodes are carefully attached to the person's chest, arms, and legs.
- The subject is advised to remain calm and breathe normally during the recording.
- The ECG machine is turned on, and its functionality is verified to ensure accurate readings.
- The mobile phone is switched to silent mode or placed in rest mode. It is located at a distance of 1 meter from the subject.
- The electrical activity of the heart is recorded with the help of an ECG machine.

- The collected ECG data is then analyzed to determine the values of various parameters including PQ interval, QRS interval, QT interval, and QTc interval, which are indicative of the heart's performance.
- The results are carefully documented and scrutinized if there are any significant changes or abnormalities in the ECG parameters due to the presence of the mobile phone in silent mode or at rest.
- Finally, an ECG report is generated, which includes the recorded heart rate and other relevant information. This report is then shared with the research participants for their review and record.

2.2.2. Second condition (ringing condition): Method 2

For the second condition involving the mobile phone being in ringing mode, the steps are as follows:

- Connect the ECG device to the subject at specific locations on the chest, arms, and legs using disposable electrodes.
- At a predetermined distance from the subject, set the subject's mobile phone to ringing mode.
- Initiate a call to the person's mobile phone from another phone while the ECG device is actively recording the subject's ECG signal.
- Record the ECG signal for a specific duration during the ringing phase of the subject's mobile phone.
- After the ringing phase ends, stop recording the ECG signal.
- Save the recorded ECG data for further analysis.
- Analyze the collected ECG data to extract various parameters including heart rate, PQ interval, QRS interval, QT interval, and QTc interval.
- Compare the ECG parameters obtained in the ringing phase with the parameters obtained in the resting state (as established in the previous state) to assess the possible effects of mobile phone radiation on the ECG signal.
- Assess any differences or abnormalities observed in ECG parameters between the ringing phase and resting state.
- Document findings and store analyzed data for future reference and analysis.

2.2.3. Third condition (on-call condition): Method 3

The following steps are followed for the third condition, i.e., when the mobile is on call mode at the receiver side.

- Connect the disposable electrodes to the specified locations. Right arm (RA) and left arm (LA) and clip electrodes to ground.
- Start the test by pressing the 'Start Test' button
- Ask another person to call the subject while the ECG measurement is in progress
- Readings of the PQ interval, QRS interval, QT interval, and QTC interval parameters of the human heart can be taken within seconds while the subject is under test and receiving a call on their smart mobile phone.
- Save the ECG report in PDF format
- After conducting the ECG test and analyzing the results, an ECG report is generated. This report includes ECG parameters such as PQ interval, QRS interval, QT interval, and QTc interval as well as the heart rate of the participant.
- Send ECG reports to research participants for their reference and to record their ECG readings.
- Note all ECG parameters in the Excel sheet for analysis purposes for the third condition
- Save the ECG report in PDF format.

After obtaining consent and agreement forms from participants, I explain the experimental procedure to them before taking their ECG readings. A PDF file of normal ECG readings is generated and sent to each participant, recommending to consult a doctor for further clarification if any abnormalities are found[33]. However, two of each participant's readings are not shared with them because they are used for research purposes only.

After taking the readings, a PDF file is created and shared with the participants along with the general ECG report. I note all ECG parameters including heart rate (HR), PQ interval, QRS complex, QT interval, and QTc interval of all subjects. I conducted this procedure for approximately 40 participants in three different conditions: a normal (resting) condition without a mobile phone, a ringing condition with a mobile phone, and an on-call reading from the receiver side. This results in a total of 120 ECG readings[34].

3. Results

After collecting 120 ECG readings, my next step involved examining the effect of electromagnetic radiation emitted by mobile phones on ECG parameters under three different conditions. I created individual graphs for each participant, showing changes in ECG parameters such as heart rate, PR interval, QRS interval, QT interval, and QTc interval—across different age groups. This graphical representation not only sheds light on the effect of mobile phone radiation on the human heart but also helps in understanding the potential risks associated with mobile phone use.

3.1. Heart rate (HR)

Figure 3 below displays the changes in Heart Rate (HR) of all the subjects under three different conditions. The waveform of HR shows that the Heart Rate of all the subjects varies during the Ringing and On-Call conditions in comparison to the Rest or Normal conditions. The major changes in HR are observed during the Ringing and On-Call conditions[35].

The following Formula is used to determine Deviation,

$$\text{Mean Deviation} = \frac{\sum_{1}^{n}(x-x1)}{n}$$

where,

n = Sample Number,

x = value in the dataset,

*x*1 = the mean value of the data set.

Table 3 and **Figure 3** present the differences in heart rate (HR) between the resting, ringing, and on-call states of the mobile phone. The mean HR values were 83 in the resting condition, 82 in the ringing condition, and 86 in the on-call condition. The percentage change in HR for the resting condition for the ringing condition is −1.23% and for the on-call condition, it is 4.04%. The percentage change in the standard deviation of HR for the ringing condition is 9.30% concerning the rest condition, while for the on-call condition; it is negligible (0.020%). These results are also illustrated in **Figure 3**. Findings suggest that the ringing position of a mobile phone placed close to the heart has a significant effect on HR[36].

Table 3. Heart Rate (HR) variation during Rest, Ringing, and On-Call condition.

Parameters	Factors	HR Rest	HR Ringing	HR On-Call	Change of HR Ringing w.r.t HR rest	Change of HR On-Call w.r.t HR rest
Sample	39	39	39	39	NA	NA
Mean	20	83	82	87	−1.23	4.04
SD	11	12	13	12	9.30	0.20
Minimum	1	59	58	59	−1.69	No change
25% of samples	11	76	72	78	−4.64	3.31
50% of samples	20	82	80	88	−2.44	7.32
75% of samples	30	90	93	94	3.35	5.03
Maximum	39	108	106	108	−1.85	No change

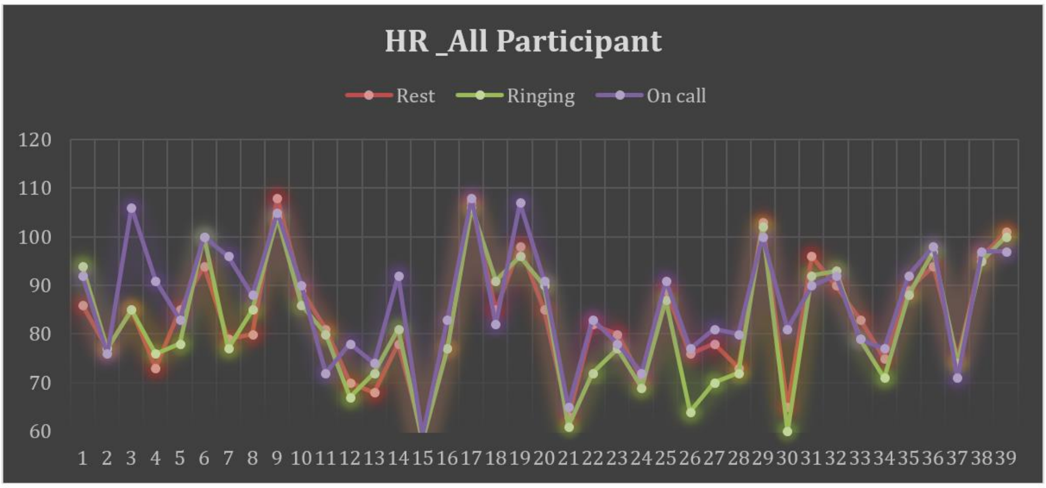

Figure 3. PR Interval variation during Rest, Ringing, and On-Call condition.

3.2. PR interval

The PR interval is the segment of the ECG waveform that represents the time from the beginning of atrial depolarization (P wave) to the beginning of ventricular depolarization (QRS complex). It is measured from the beginning of the P wave to the beginning of the QRS complex and reflects the time it takes for the electrical impulse to travel from the atria to the ventricles. The normal range of the PR interval is 120–200 milliseconds, and any deviation from this range can indicate certain heart conditions[37].

Table 4 and **Figure 4** present the differences in PR interval between resting, ringing, and on-call states of mobile phone use, where the mean PR interval is 138ms during resting, 136ms during ringing, and 138ms during the on-call state. The percentage change in PR interval during the ringing condition was −1.59% concerning the rest condition and the percentage change in PR interval during the on-call condition was -0.63%. Additionally, the percentage change in the standard deviation of the PR interval during the ringing condition is −6.47% concerning the rest condition, while the percentage change in the PR interval during the on-call condition is −1.71%, which is insignificant[38]. These findings, illustrated in **Table 4** and **Figure 4**, indicate that electromagnetic waves have a greater effect on the PR interval during the ringing condition than during the on-call condition.

Table 4. PR Interval Change in three different conditions.

Parameter	Factors	PR Rest	PR Ringing	PR On-Call	% Change of PR Ringing w.r.t HR rest	% Change of PR On-Call w.r.t HR rest
Samples	39	39	39	39	NA	NA
Mean	20	138	136	138	−1.59	−0.63
SD	11.40	17.72	16.57	17.41	−6.47	−1.71
Minimum	1	113	108	112	−4.42	−0.88
25% sample	11	126	126	125	0.00	−0.40
50% of the sample	20	135	132	135	−2.22	0.00
75% of the sample	30	149	145	142	−2.69	−4.38
Maximum	39	183	178	185	−2.73	1.09

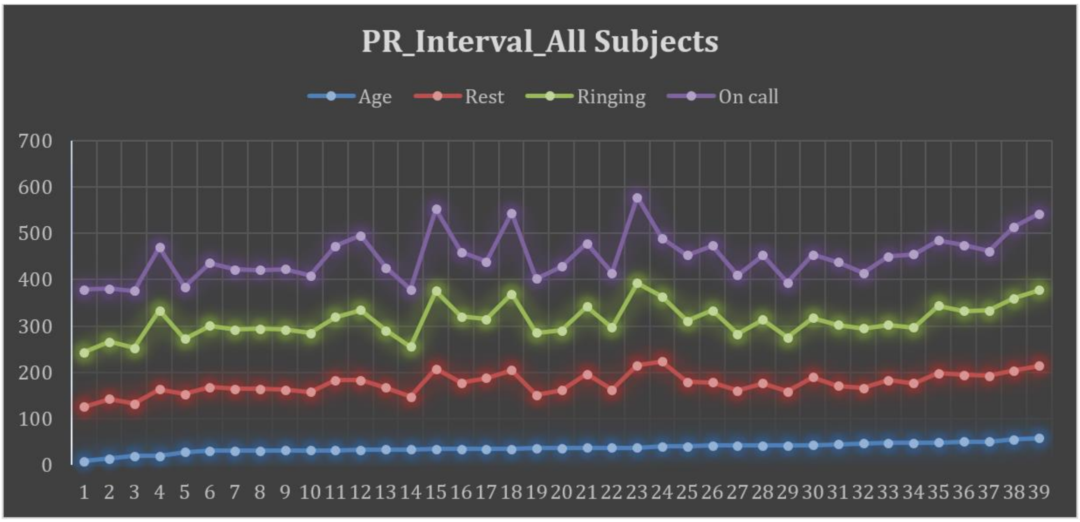

Figure 4. PR Interval variation during Rest, Ringing, and On-Call condition.

3.3. QRS interval

The QRS interval is a measure of the duration of the QRS complex on an electrocardiogram (ECG). It represents the time it takes for electrical impulses to travel through the heart's ventricles, which are responsible for pumping blood around the body. Abnormal QRS intervals can indicate various heart conditions such as bundle branch block, ventricular hypertrophy, and ventricular tachycardia[39].

Table 5 and **Figure 5** display the QRS interval differences of the study participants during the resting, ringing, and on-call states of the mobile phone. Mean QRS intervals in resting, ringing, and on-call conditions were 98, 99, and 98, respectively. The percentage changes in QRS interval for the ringing and on-call conditions were 1.18% and −0.18%, respectively. The standard deviations of QRS intervals for the three conditions were 11.40, 22.19, and 21.37, respectively. The percentage change in QRS during ringing concerning QRS at rest was −3.73% and the percentage change in QRS during on-call was −18.21% concerning QRS. Minimum, maximum, and quartile values are also given in the table. Regarding my study, it appears that there was a difference in the QRS interval of the subjects under different conditions of mobile phone use.

Table 5. QRS Interval variation during Rest, Ringing, and On-Call condition.

Parameters	Factors	QRS Rest	QRS Ringing	QRS On-Call	% Change of QRS Ringing wrt QRS rest	% Change of QRS On-Call wrt QRS rest
Samples	39	39	39	39	NA	NA
Mean	20	98	99	98	1.18	−0.18
SD	11.40	22.19	21.37	18.15	−3.73	−18.21
Minimum	1	72	75	73	4.17	1.39
25% of samples	11	85	86	87	1.18	1.76
50% of samples	20	91	93	92	2.20	1.10
75% of samples	30	105	104	108	−1.43	2.38
Maximum	39	192	188	165	−2.08	−14.06

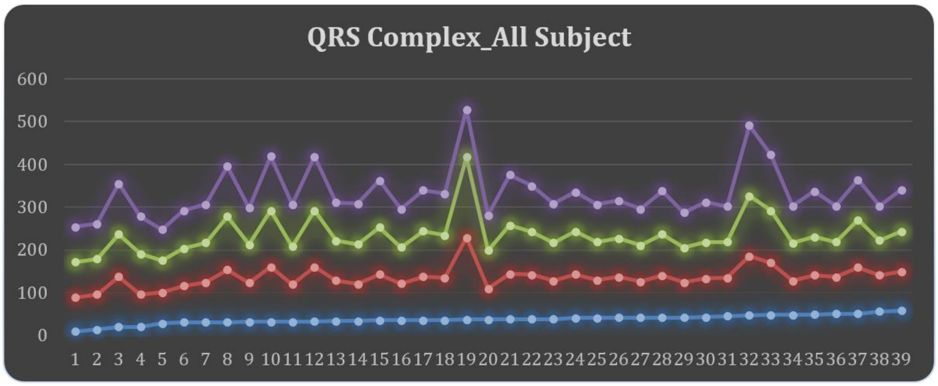

Figure 5. QRS Interval variation during Rest, Ringing, and On-Call condition.

3.4. QT interval

The QT interval is a measure of the time it takes for the ventricles of the heart to contract and then recover and is an important parameter used in electrocardiography (ECG) analysis. It represents the duration of ventricular depolarization and repolarization and can be affected by various factors, including medications, electrolyte imbalances, and certain medical conditions. Prolonged QT intervals have been associated with an increased risk of cardiac arrhythmia, which can be life-threatening. Therefore, monitoring the QT interval is an important part of ECG analysis and can provide valuable information about a patient's cardiac health.

The QT interval is the time it takes for the ventricles to contract and then relax.

Below **Table 6** and **Figure 6** present information on the QT interval, which is a measure of the time between the start of the Q wave and the end of the T wave in the heart's electrical cycle. Here is what each column means:

- Parameters: This column lists the different factors used to calculate the QT interval
- Factor: This column lists the different conditions under which the QT interval is being measured: resting, ringing, or On-Call
- QT Rest: This column lists the mean, standard deviation, minimum, maximum, and quartile values for the QT interval during relaxation.
- QT On Call: This column lists the mean, standard deviation, minimum, maximum, and quartile values for the QT interval during on-call.
- % Change of HR Ringing with QT Rest: This column shows the percentage change in heart rate (HR) during the ringing state concerning the QT interval at rest.
- QT% change of call on-call with HR relaxation: This column shows the percentage change in the QT interval during the on-call condition.

Table 6. QT Interval variation during Rest, Ringing, and On-Call condition.

Parameters	Factors	QT Rest	QT Ringing	QT On-Call	% Change of HR Ringing w.r.t QT rest	% Change of QT On Call w.r.t HR rest
Samples	39	39	39	39	NA	NA
Mean	20	370	370	365	No Change	−1.27
SD	11	34.28	33.63	31.15	−1.89	−9.14
Minimum	1	319	308	323	−3.45	1.25
25% of samples	11	350	348	345	−0.57	−1.43
50% of samples	20	361	367	359	1.66	−0.55
75% of samples	30	380	384	380	1.05	−0.13
Maximum	39	471	473	473	0.42	0.42

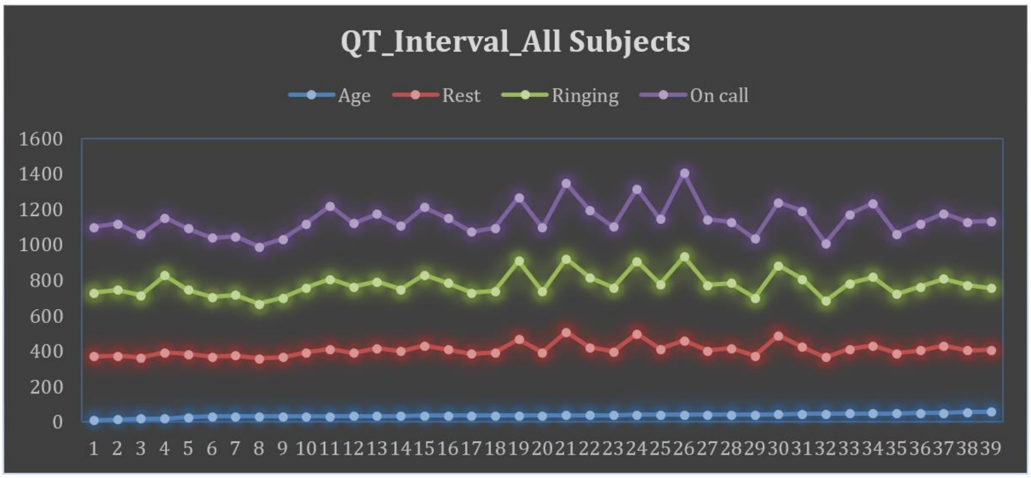

Figure 6. QT Interval variation during Rest, Ringing, and On-Call condition.

In general, the table indicates that there is no significant difference in QT interval between resting, ringing, and on-call conditions. The mean QT interval was similar in all three conditions with no change in QT interval during ringing and only a slight decrease (−1.27%) during on-call compared to rest. Standard deviation values are also similar across the three conditions, indicating similar variability in QT interval measurements.

3.5. QTc interval

QTc (corrected QT interval) is a measure of the time between the start of the Q wave and the end of the T wave on an electrocardiogram (ECG) recording. It is corrected for heart rate, allowing for more accurate comparisons between individuals with different heart rates. The QTc interval is important because a long QTc interval may indicate an increased risk of arrhythmias, including torsade de pointes, a potentially fatal ventricular tachycardia.

The QTc interval is calculated using the formula:

$$QTc = QT/sqrt(RR)$$

where, QT is the QT interval measured on an ECG recording and RR is the interval between two consecutive R waves, indicating the length of the cardiac cycle. The normal QTc interval ranges from 350 to 440 milliseconds, depending on age, sex, and other factors. A prolonged QTc interval is generally defined as greater than 450 milliseconds in men and greater than 460 milliseconds in women. Factors that can affect the QTc interval include drug use, electrolyte imbalances, genetic factors, and certain medical conditions such as congenital long QT syndrome.

Table 7 and **Figure 7** show the QTc interval data for three different conditions—at rest, while the phone is ringing, and during a call. The data is based on a sample of 40 individuals.

The mean QTc interval during rest was 427 ms, while it was 424 ms during ringing and 430 ms during calls. The percentage change in heart rate (HR) during ringing compared to rest was -0.72%, indicating a slight decrease in HR. The percentage change in QTc interval during calls compared to rest was 0.59%, indicating a slight increase in QTc interval. The standard deviation (SD) for the QTc interval was highest (38 ms) during ringing and lowest (26 ms) during calls. The minimum QTc interval during relaxation was 378 ms, while the maximum during relaxation was 552 ms.

Based on these data, it is unclear whether mobile phone use has a significant effect on the QTc interval. However, it may still be advisable to limit mobile phone use to reduce overall exposure to electromagnetic radiation.

Table 7. QTc Interval variation during Rest, Ringing, and On-Call condition.

Parameters	Factors	QTc Rest	QTc Ringing	QTc On-Call	% Change of HR Ringing w.r.t QTc rest	% Change of QTc On Call w.r.t HR rest
Samples	39	39	39	39	NA	NA
Mean	20	427	424	430	−0.72	0.59
SD	11	32	38	26	16.04	−20.17
Minimum	1	378	336	382	−11.11	1.06
25% sample	11	411	402	409	−2.19	−0.49
50% of sample	20	422	421	429	−0.24	1.66
75% of sample	30	439	439	448	−0.11	1.94
Maximum	39	552	560	480	1.45	−13.04

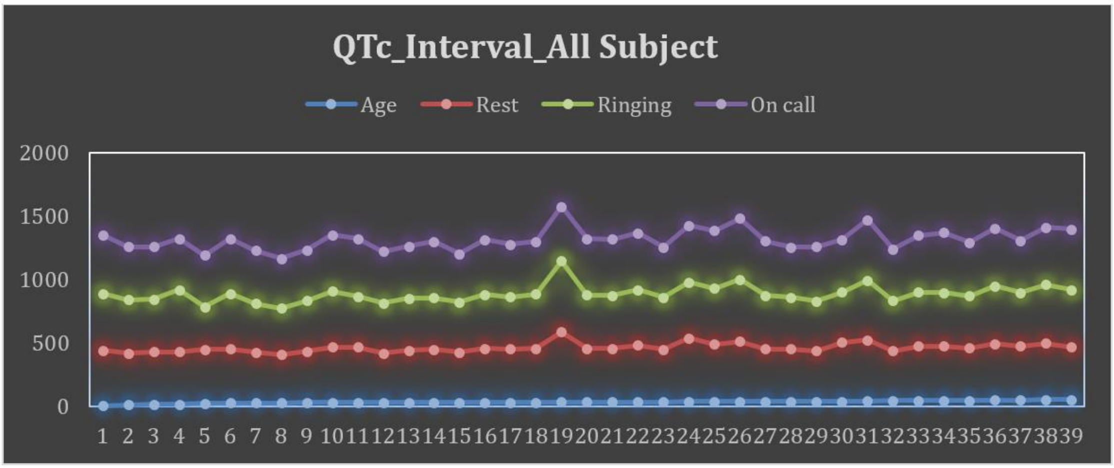

Figure 7. QTc Interval variation during Rest, Ringing, and On-Call condition.

Based on the results of the study, it may be reasonable to recommend the following criteria to reduce potential harm from mobile phone use:

- Limit mobile phone use to no more than one hour per day to reduce overall exposure to electromagnetic radiation.
- When using a mobile phone, use a microphone or hands-free technology such as Bluetooth to keep the phone away from the ear and reduce the direct effect of radiation on the head.
- Minimize the duration of phone calls as much as possible to minimize exposure.

4. Discussion

Our findings suggest that the ringing position of a mobile phone placed close to the heart has a significant effect on HR. HR during the ringing condition was significantly different from the resting and calling conditions. Regarding the PR interval, our observation suggests that electromagnetic waves emitted by mobile phones have a greater effect on the PR interval during the ringing condition than during the call condition.

Regarding the QRS interval, we observed differences between subjects in different mobile phone use conditions. Although the exact reason for this difference is unclear, it suggests that mobile phone use may affect this ECG parameter. However, our study did not reveal any significant difference in QT interval between resting, ringing, and on-call conditions. These results suggest that mobile phone use has little effect on QT interval. However, it is important to note that the effect of mobile phone use on corrected QT (QTc) interval is significantly changed concerning rest and ringing conditions.

5. Conclusions

Preliminary results indicate that exposure to electromagnetic waves has a minimal effect on the ECG waveform. The amplitude and frequency characteristics of the ECG signals remained largely unaffected, and the morphological features of the waveform exhibited no significant alterations. However, certain specific frequencies or intensities of electromagnetic waves showed subtle changes in specific ECG parameters, warranting further investigation.

The research findings suggest that exposure to electromagnetic radiation from mobile phones can affect the heart's electrical activity and heart rate, as measured by electrocardiography. Specifically, the study found significant changes in heart rate, PR interval, and QTc interval, which is the time between contraction and relaxation of the ventricles and the time it takes for electrical impulses to travel from the atria to the ventricles. Although studies have not provided definitive evidence regarding the effect of mobile phone use on QRS and QT interval, it may be advisable to limit mobile phone use to reduce overall exposure to electromagnetic radiation. However, further research is needed to confirm these results and to better understand the mechanisms underlying these effects. Meanwhile, individuals should take precautions to minimize exposure to mobile phone radiation. This study provides valuable insight into the potential cardiovascular effects of mobile phone radiation, which should be considered in future research and public health policy.

Author contributions

Conceptualization, TS; methodology, AS; formal analysis, AS; writing—original draft preparation, TS; writing—review and editing, TS and AS. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

Abbreviations

ECG	Electrocardiography
EMR	Electromagnetic Radiation
EMF	Electromotive Force
SAR	Specific absorption rate
ICNIRP	International Commission for Non-Ionizing Radiation Protection
DoT	Department of Telecommunication
RFR	Radiofrequency Radiation
WHO	World Health Organization
ICMR	Indian Council of Medical Research
OTG	On The Go adapter
RA	Right Arm
LA	Left Arm
HR	Heart Rate
AM	Amplitude Modulation

FM	Frequency Modulation
GSM	Global System for Mobile Communication
RF	Radio Frequency

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