Radio Frequency Radiation Impact Analysis on ECG and HRV: A Review

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Abstract: The technological advancement has led to the exponential use of wireless devices leading to the concern for the analysis of their side effects on the human health. This paper presents the review of the researches conducted from time to time, in order to study the impact of radiations from mobile phones, base transceiver station (BTS), Wi-Fi etc. on the electrocardiogram (ECG), heart rate variability (HRV), blood pressure etc. The different parameters used to assess the HRV have also been reviewed. The various biological effects of these radiations are also discussed in this paper.

Keywords: Electrocardiogram, Radio Frequency Signals, Global System for Mobile Communication (GSM), Wide Band Code Division Multiple Access (WCDMA).

Introduction

Due to the rapid development of RF devices in recent years, radio frequency signals are prevailing all around [1]. The web of these radiations is considered to hazardous for the normal functioning of the human body when highly exposed to them [1, 2]. The major sources of these radiations are mobile phones, Wi-Fi devices, televisions etc.[3]. The electromagnetic fields (EMF) are also produced by the bioelectric signals inside our body. The strength of EMF of a heart is 100 times more than the EMF of a brain. The interaction of heart EMF and with the radiations from the mobile phones that are frequently being used and carried close to the body, interact and the effect of it need to be studied for the human interest [4]. It is reported that the impact of RF radiations on human health is mediated via dielectric heating or biological effects [5].The world health organization (WHO) has considered these radiations as carcinogenic [5]. Lin [6] has described about the partial report on the five year research that has been led by the American government on the effect of mobile phone exposure on male rats. It has been disclosed that two types of cancer malignant gliomas in the brain and schwannomas of the heart has been found in the exposed male rats [6]. The ICINRP has also put some guidelines to the mobile phone companies so that the specific absorption rate (SAR) value from these devices is put under control. According to the European guidelines the SAR is limited to 2W/kg over 10 grams of tissue for hand held devices. According to American guidelines the SAR limit is 1.6W/kg measured over 1gram of tissue. This SAR limit of1.6W/kg is actually for 6 minutes per day use. So a person should not use cell phone for more than 18 to24 minutes per day [7]. India is now following the American guidelines on SAR of BTS and Mobile phones with effect from September 2012 [8]. In the young generation, the mobile phone usages have become an addiction and hence they are exposed to the radiation from these mobile phones [9]. WHO has emphasized on the provocation study of RF-EMF field impact on young children to be a high priority in its 2010 agenda [10,11]. GSM and WCDMA are the mobile communication technologies that are majorly being employed. GSM operates at 900 MHz to 1800MHz frequency [12] and CDMA at 800MHz and 1900MHz [13,14]. Some of the electromagnetic energy radiated by mobile phone is absorbed into the tissues. Heating even up to 0.3ºCmay alter the expression of genes and proteins [5]. Evidences and the researchers report that there are subjective symptoms such as headaches, fatigue, memory loss, irritation, heating of the tissues etc. by the usage of mobile phones [7]. So the increasing health risk because of increase in mobile phones and BTS, the concern has increased to have extensive research [3].

In the ECG signal, R wave is of highest amplitude. The interval between the R to R waves constitutes the heart beat rate. The variation in these intervals is termed as heart rate variability (HRV). HRV is extracted from the ECG signal and then analyzed to know more information in detail regarding the cardiovascular diseases if any [15]. HRV analysis is the representation of the sympathetic and parasympathetic activities. Normally, there should be a balance between sympathetic and parasympathetic activities but imbalance in them, varies the heart rate [16]. So, HRV is commonly used to assess the influence of the autonomic nervous system (ANS)on the heart [17]. HRV parameters can be assessed to know the cardiac functioning and to know the impact of mobile phone radiations on the heart [2]. It is possible that EMF generated by mobile

phones may have an influence on the ANS and modulates the function of circulatory system [18]. Recent studies have shown that the decreased fluctuation of the R-R intervals may lead to an increased risk of arrhythmias and an increased mortality rate [19]. Frequency domain and time domain parameters have been recommended for HRV analysis with short-term i.e. 5 minutes recordings [20].

This paper presents the work that has been carried out by various researchers to know the possible effects of radiations on the heart. Their findings have been reported in this paper along with the experimental setups and the other issues related to it in the following sections.

Materials and Methods

After obtaining the approval from the local ethical board or committee, the research can be carried out either in a laboratory. The following sections review the various other preparations that need to be done for acquiring the data for the study.

Subjects

For the study of mobile phone radiations effect, the participants are selected. In the literature, study has been conducted on 100-150 healthy subjects [1]. Generally teenagers and adults both male and female are included in the study. Some subjects voluntarily participate and they are paid some amount for it [21]. In some cases, students and staff members of a college are taken who participate voluntarily [1]. The type of participant depends on the type of study that is being carried out and at which place it is being carried out. Only males are taken for study [16] and only femalesare taken as according to the authors[4], MPRS is more frequently encountered in females. The research has also been taken on the electromagnetic hyper sensitive (EHS) people. Similarly in [21] authors took 164 police persons as the subjects who were the actively prone to those radiations, to assess the effect of Terrestrial Trunk Radio (TETRA) effect. The age of the subjects is usually between 17- 35 years. If research is done on healthy subjects then those who are having any kind of heart problem or hyper sensitive to electromagnetic radiations are not included in the study. Subjects consuming alcohol and smoking are also excluded [1]. EHS subjects are excluded by using EHS screening tool developed by Eltiti et al. [11]. Clinical examination is also done before the acquisition of ECG signal [1]. Pretest preparations are informed to the subjects [1]. Subjects are asked to abstain from the caffeinated products, drugs that can affect the HRV and no gymnasium or sports one day or 12 hours before the experiment [1,11]. The study can be single blinded in which the motive of the experiment is not disclosed or can be double blinded [11] in which the subject is totally unaware about the study and the test. Subjects are made to relax for 10–20 min before starting the test. The breathing should be normal. Written consent is taken from all the subjects. That can also include some questionnaire regarding their biological data as well i.e. how many hours a day they use on mobile phones. The various subjective effects such as what they feel are also included in it. The authors have seen the effect of these radio frequency (RF) radiations on cardiovascular patients and ischemic patients also [5].

Protocol

The subjects are first allowed to relax for 5-15 minutes in a sitting or supine position and asked to breathe normally during the test also. The protocol of the experiment is adopted differently by the various authors. As the control group, the ECG is recorded without the mobile phone. The exposure is given either from a real mobile phone or from a dummy phone. The ECG signal is recorded when eyes of the subjects are open as well as in closed state [21]. The recording is done in the morning hours when the subjects are not exposed to any other radiation. The duration of the exposure may vary from 5 minutes to 40 minutes as reported in the literature. The recordings are taken before the exposure, during the exposure and after the exposure. In between the subjects are asked questions about any feeling of EMF effect or any other subjective effect on them [11]. Blood pressure is also being measured before during and after the test [2]. The placement of mobile phone is near to chest on the left pocket so that it is in close to the heart [16]. The exposure given is when the mobile phone is in the standby mode, handshaking mode, in silent mode, in ringing mode and in the transmitting or receiving of a call. Exposure is given by placing cell phone on the left side of the lower abdomen at the belt level and allowed a single ring of 40 sec and simultaneously the ECG signal is recorded also when mobile phone placed in the trouser pocket [22]. The mobile phone is made silent to avoid the effect of ring tone on the HRV of the subject.

Data Acquisition

The data is recorded in a laboratory or in a hospital room that is a semi- darkened, quiet and the temperature is controlled to 20°C- 26°C. It is exclusively used for this purpose and all other electrical equipments except those required in the experiment are unplugged to avoid any other interference in the recordings [11]. The background extremely low frequency electric and magnetic fields are measured so ensure that the subjects are not influenced by those fields [11]. The RF fields are also measured in the frequency range that is utilized in the experiment with the help of spectrum analyzer or radiation meter. Floor is covered with absorbers to reduce wave reflection [4]. Distance from BTS is also taken into consideration [23,24]. Heart rate, respiration rate and HRV collected in such a way that the worker was not visible to the subject [25]. In order to avoid the interference due to movement of subject hand, some mobile holders are arranged in the head phone. The SAR value of the

mobile phone is also taken into consideration. NOKIA X2 mobile phone having SAR 0.82 has been used in [1], mobile phone (Nokia 5220), WCDMA phones [11], CDMA phone [25], mobile phone of SAR 1.2W/kg is used [23] and 1.6W/kg SAR level dummy phone at WCDMA frequency [26] is used for all subjects. The ECG, respiration rate is recorded simultaneously [13]. BIOPAC recording machines, Holter machines and polyG1 computerized polygraph system have been used in by various authors in carrying out the work. The sampling rate is between 500-1000Hz. Ag-AgCl electrodes are used to acquire the ECG signal [18,27]. Care should be taken so that there is proper contact of electrodes made with the skin and the impedance should be low. The recorded ECG signal may contain artifacts in it due to the electrical power, mobile phone used for the exposure and even due to the muscles movement of the subjects. So the preprocessing of the ECG signal is done by using the band pass filters to remove those noises. HRV is extracted from the ECG signal. HRV and its power spectrum are extracted using the software Telescan version 2.8. HRV parameters have also been taken using Kubios software [13], Variowin-HR software [1] to obtain the time, frequency and non linear parameters [21]. All these measurements taken from the ECG and HRV are the taken as the mean value and then compared with the control or normal mode.

Data Analysis

The ECG signal recorded during different modes of exposure is then analyzed by the software to measure the time intervals of various waves. The heart rate, TP segment interval, time of T wave, PR interval, and time of QRS of the subjects are measured before and after the exposure3. ECG variables are studied such as heart rate (beats/min), R-R interval (msec), P-R interval (msec), QRS period (msec), QTm (measured) interval (msec), and QTc (corrected) interval (msec) [5]. The amplitude of R wave in lead V5 (mV), the amplitude of S wave in lead V1 (mV), and the voltage summation of R wave in V5 and S wave in V1 (mV) are also studied. Philips DXL ECG Algorithm software for analysis of various ECG variables such as QT interval [12] is being used. This measured QT intervals were corrected by Bazett's formula and defined as QTc, QTd was defined as the difference between longest QT interval and shortest QT interval. The heart rate variability extracted from the ECG signal into its time domain, frequency domain and non linear parameters. The various parameters of HRV that have been utilized by various authors and their significance are being discussed in the following sections.

Time Domain Analysis

Time Domain measures are simplest to calculate but do not quantify the sympathetic or parasympathetic activity or their balance [28]. They also do not give any information about the distribution of power. This analysis includes the mean normal-to-normal (NN) intervals based analysis and statistical measures of the variance between these NN intervals. The various parameters in this category are: standard deviation of the NN interval (SDNN) [29]. This index reflects the cyclic components responsible for the variations during the recording period [30], standard deviation of the average NN interval calculated over short periods, usually 5 min (SDANN) reflects ultralow frequency power [1], square root of the mean squared differences of successive NN intervals (RMSSD) [29], SDSD, NN50 count which is the number of interval differences of successive NN intervals greater than 50 ms, pNN50 is the proportion derived by dividing NN50 by the total number of NN intervals, and triangular interpolation of RR interval histogram (TINN) [1]. SDSD, RMSSD and ppN50 parameters of short-term variation estimate high frequency variations in HRV and both are related to the parasympathetic activity [1,30]. Triangular Index measurement is the number of all RR intervals divided by the number of RR intervals of the minimum RR interval length and is related to the regularity of the signal length30. TINN is related to the amplitude of cycle length variations [30]. In this paper, we further investigate the effects of the ELF-PEMF on the ECG signal using the hyperbolic T-distributions (HTD). This distribution was shown to be suitable for efficient amplitude and instantaneous frequency (IF) estimation of mono- and multi component FM signals. In this work, we introduce this distribution to the analysis of ECG signals [31].

Frequency Domain Analysis

Frequency-domain analysis of HRV provides quantitative and noninvasive measure of ANS activity [32]. The frequency domain analysis analyses the frequency components of the data. The main advantages of spectral analysis time domain measures is that it gives information about the distribution of power as a function of frequency. It also provides the quantitative measure of the ANS. Spectral analysis is performed using Auto Regressive (AR) model [30] and Fast Fourier Transform (FFT) models. Autonomic system variations in HRV include both sympathetic and parasympathetic activity, but there is a lot of overlap in the spectrum between these two divisions of the autonomic system. The power is calculated in low frequency (LF) band (0.04 Hz to 0.15 Hz), high frequency (HF) band (0.15 Hz to 0.4 Hz), and very low frequency (VLF) band (0.0033 Hz to 0.04 Hz) [18]. HF fluctuations in the HRV is generated by the process that is in synchronous with the respiration [30]. The HF power provides a quantitative measure of the effect of respiration on ECG signal and the vagal modulation of the sinus node30. High frequency power (HFP) is an index of parasympathetic system and reflects effect on the respiratory sinus arrhythmia. Low frequency power (LFP) reflects the effect on both sympathetic and parasympathetic nerve. LF/HF ration indicates the balance of sympathetic and parasympathetic nerves and also termed as sympatho-vagal balance [11].

Non Linear Analysis

For analyzing the hidden dynamics of HRV, non-linear analysis is done. It is significant to apply methods of non linear analysis on HRV as it will yield valuable information, because the effects that cause this variability are also nonlinear [15]. Under this, approximate entropy (ApEn) which is a measure of degree of randomness and hence gives information about the regularity of the signal is used [23]. ApEn is introduced by Pinacus [33] for analysis of physiological time series processing for complexity evaluation. Also detrended fluctuation analysis (DFA) in [23] was proposed to analyze long-term correlation in DNA nucleotides [16]. The DFA method helps in the detection of intrinsic self-similarity in nonstationary time series [16]. Another entropy related to approximate entropy (ApEn) called sample entropy (SampEn), is also measure of complexity, has been proposed that corrects the bias inherent in ApEn and is less dependent on the length of the time series [16]. Largest lyapunov exponent (LLE) measure is used [34], which quantifies the predictability of a system. The high predictability corresponds to lower chaotic degree [34]. The value of LLE increases as the degree of chaos becomes higher [34]. The computation of LLE requires an appropriate selection of control parameters apart from time delay and embedding dimension [34]. Also another measure correlation dimension (CD) is defined as a quantitative measure of the dimensions of the nature of the signal [15]. Different CD values are associated with particular diseases [15]. Hurst Exponent (H) is used to measure the self-similarity and also the correlation properties of the signal [15]. Fractal Dimension (FD) [15] measures the complexity of dynamic signals. FD is a powerful tool for transient detection. Capacity Dimension(CaD) [15] is a real number that represents the minimum number of open sets of diameter (D) less than or equal to ε, then is proportional to $\varepsilon - D$ as $\varepsilon \rightarrow 0$.

Statistical Analysis

Data is represented in the mean along with the standard deviation. To analyze the results, the statistical analysis is being done to find if the result has significantly changed from the baseline. For this, SPSS software has been used by various authors with different versions as 10, 11 20 etc. to compare the results of the exposed values with the sham or control group. First the normality of the data is determined by Kolmogorov–Smirnov test, Shapiro-Wilk test [18], Anderson Darling normality test [34] etc. The non-normally distributed parameters were corrected by logarithmic transformation or by exclusion of the outlier values [30]. For the comparison of the means the various test adopted in literature are two way multivariate analysis of variance [25] , one way ANOVA [1], student t-test [34], two tailed paired t-test [2] has also been performed. The p value of 0.05 is kept as the level of significance. $p<0.05$ means the null hypothesis is rejected and alternate hypothesis is accepted.

Results and Discussion

The research done so far is on the basis of HRV linear and non-linear analysis, P Q R S and T waves' interval, heart rate, respiration rate and biological effects. The various parameters of HRV have been compared as follows. Burgess et al. [21] studied the effects of terrestrial trunked radio (TETRA) radiations that are used by police personnel and found that there are neurophysiologic effects and the changes in the HRV are also noticed when the radiations given at the chest. Similarly, Vegas et al. [1] investigated the effect of mobile phone radiations and found the changes in the time domain and frequency domain parameters of HRV. There is increase in the sympathetic tone and decrease in vagal in case of female subjects whereas there is decrease in the vagal tone in male subjects. But, the nonlinear analysis is missing in the study. It has been experimented to find the long term effect of 3G mobile phones radiations on adults and teenagers on HRV [11,26]. The data is collected by using dummy mobile phone with head phone for 32 minutes. The results do not show any significant change in the experimented results and the subjective symptoms in all the subjects. Saini and Pandey[23] studied the effect of wireless network radiation. The subjects are kept near to the source of the radiations and the distance is varied to apply the varied levels of exposure as minimum, moderate and maximum. It has been found that there is significant increase in the DFA component with the exposure level but no change in the approximate entropy. Kodavanji et al. [19] studied and found no significant change in time domain parameters but in frequency domain VLF, LFP increases and HF decreases. The LF/HF ratio also increased. Thoratand Shelke [22] found no statistical change in the HRV, cardiac activity and no effect on autonomic nervous system. Saini and Pandey [24] studied the effect of Base Station on the HRV. The results show that there is decrease in the scaling exponent with the radiation and the values changes with the increase in the level of the radiation. Irfan et al. [20] experimented and found that there are no such variations in the parameters of HRV obtained during the usage of mobile phone as compared to baseline. Kwon etal. [13] studied the radiations of WCDMA mobile phones on electromagnetic sensitive (EHS) and non-EHS subjects. The heart rate, respiration rate and the LFP/HFP are analyzed. From the results it is found that there is no significant effect on any of the analyzed parameter in both the subjects. Al-hazimi et al. [9] studied the HRV parameters and the results show that standard deviation from normal to normal intervals (SDNN) increases significantly also in [18], VLF, HF increased and LF decreased significantly thus concluding the effect of radiations on the increase in parasympathetic and decrease in sympathetic activity of the heart. Talking on phone can increase the speed of breathing and, therefore, changes in respiratory frequency may have an influence on heart rate [18]. Nergui et al. [15] studied the effect of mobile phone radiations when placed near to chest and head. The results show that there is measureable change in the non linear parameters with the exposure but is small and statistically not significant to conclude their effect. Yilmaz et al. [34] analyzed HRV the largest lyapunov exponent (LLE) that increases slightly with the higher EMF level as

compared to the low level and found that there is a significant change in LLE value. In this paper, the level of EMF is very low compared with real exposure periods. Andrzejak et al. [18] experimented on healthy subjects and HRV is analyzed in time and frequency domain and the results show an increase in SDNN and SDANN. Also there was increase in VLF, LF and HF components and decrease in LF/HF ratio. Ahamed et al. [16] recorded the ECG signal in two modes of keeping phone near to chest and left ear. The HRV analyzed for scaling exponent and sample entropy. The results show that there is increase in the scaling parameter and heart rate when mobile phone is near to chest and decreases when the mobile phone is near to the ear. But the effect does not proved by the statistical analysis. Parazzini et al. [30] studied the effect of 2G mobile phone radiations and results are interpreted and found weak significant change in SDNN, TINN and the LF power.

Some authors have given analysis on the basis of variations in the intervals of various waves in the ECG signal. Saili et al. [35] experimented on rabbits to know the acute exposure effect of Wi-Fi at 2.45 GHz. The results showed that RR interval in the ECG signal reduces such that heart rate is increased. There is also increase in PR and QT intervals. Umar et al. [2] studied the effect on heart rate, QRS, PR, QTc intervals for all the states of exposure. The results show no significant variation in the values due to the RF exposure. Similarly, Devaysia et al. [12] studied the effect of mobile phone radiations on the heart rate, QT interval, QT corrected and QT dispersion. The experiment was conducted in a hospital for a year. The data was collected in state with no mobile phone, with phone but not ringing and the ringing phone placed close to heart. The results show that there is no significant difference in heart rate and QT intervals. Alhusseiny et al.[5] studied the effect of radiations on acute coronary syndrome (ACS) patients. ECG is recorded at baseline and during the exposure by placing mobile phone at the belt region and over the precordial region. The results showed the P-R period in Group I gets shortened. The other variables related to the cardiac conductive system; the QT period and the duration of QRS wave complex or to the voltage criteria did not significantly alter in both groups. The authors concluded that regular short term use of mobile during the recovery period of ACS is safe and does not impact upon ECG record. Komeiliand Nabizadeh [3] investigated and shown that there is increase in the heart rate and the other intervals of the ECG segments. But the results are different in males and females and it has been concluded that the EM RF radiations can affect the heart due to long usage. Alhusseiny et al. [5] studied on the patients with ischemic disease and found that there is enlargement in the QT interval in the ECG signal and also found that the radiations interfere with the voltage criteria of ECG record in male subjects as compared to the female subjects. Tamer et al. [27] evaluated the 12 lead ECG and BP. The results show no significant difference in any of the interval measured at any of the stage. Nam et al. [14,25] did a provocation study to know the effect of CDMA phone radiations on electromagnetic sensitive people. Study was conducted on two group as Electromagnetic hypersensitive (EHS) and non- EHS on HRV, heart rate, and respiration rate and also on the subjective or biological effects. The authors did not find any physiological or biological effect on any of the group. Mahmoud et al. [13] studied the effects of low frequency pulsed electromagnetic fields (EMF) on ECG and EEG of healthy subjects. The ECG is analyzed for the power level and also using hyperbolic-T distribution using quadratic time frequency distributions and stated there is small shift in the frequency domain of the signal after the exposure.

The various biological effects have also been reported in the literature. Acharya et al. [36] studied the effects on the college students grouped to urban and rural and found the effects in the urban subjects using mobile phones frequently. 96% students were very much using mobile phones. More than 50% students were reporting of headaches, tiredness, insomnia, irritatibility, lack of concentration, eye strain and insomnia are the common effects found. Aghav et al. [7] studied the effects of mobile phone tower and mobile phone handsets on the humans. The biological effects due to radiations from tower includes blood brain barrier, cell damage, effects to birds, plants and animals have been reported and also significant change in the heart rate of male and female subjects both. Furubayashi et al. [4] investigated the short term effects of WCDMA mobile phone radiations on women by a questionnaire on possible health effects. The psychological and cognitive parameters were measured before and after the exposure. The authors found no evidence of any effective effect of these radiations. The sample size for the study is very less to apply to the general population. Also the study should be conducted for the long term i.e. at least 24 hours.

Conclusion

This paper has presented the various aspects and the methods related to the experimental setup, subjects and the protocol of the study done by various researchers to assess the impact of mobile phone radiations on the ECG signal and the heart rate variability. The various parameters that have been utilized for the analysis have also been discussed. The results given are statistically analyzed and the different results are obtained in the experiments done by the various researchers. Some concludes that these Wi-Fi radiations affect the cardiovascular system directly or indirectly. Also, some authors could not effectively give any general conclusion about the effects of mobile phone radiations. It has been even concluded by some authors that the mobile phones do not alter the electrical activity of the heart or blood pressure of the user. The purpose of studies done is same by the differing effects may be due to the different pathological conditions of the subjects and the region also. The unseen other factors of the living conditions, thought process of a subject at the time of experiment cannot be overruled. Also, HRV is affected not only by many diseases but also physiological differences, such as age, sex, and the period of measurement. So the control group should be matched with the test group in these respects. The signal strength and

background radiations are not taken into consideration by all the authors. The signal strength, distance from the BTS also affects these results. But more or less the first hand effects i.e. biological effects, on humans are prevalent and exists in almost all the subjects. As the heart rate variability is non linear in nature, non linear parameters give more precise information regarding the signal characteristics along with time and frequency domain parameters. More studies may be conducted with more number of subjects and keeping in control all the possible parameters. So, a clear conclusion has not yet been made.

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