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A Comprehensive Study of Change in Heart Rate Variability Parameters Due to Radiations Emitted from GSM and WCDMA Cellular Phones

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Abstract

The growth of wireless technology has resulted in a large scale use of mobile phones. In the young generation, the mobile phone usage has become an addiction, leading to more exposure to the radiations. In order to see the impact of these Radio Frequency (RF) radiations from the mobile phones, analysis of Electrocardiogram (ECG) signal and Heart Rate Variability (HRV) have been done using various linear and non-linear parameters in this paper. The effects of the electromagnetic field (EMF) emitted from these devices, especially on young generation studying in colleges, have been studied using 18 parameters of HRV. Five different situations have been considered in Global System for Mobile Communication (GSM) and Wideband Code Division Multiple Access (WCDMA) modes and these are normal mode when no communication using mobile phone exists and the other four are the communicating mode- transmitting and receiving modes in both GSM and WCDMA networks. The subjects are not exposed to any external RF signals. The study has been carried out when the student is making their usual mobile calls. The results have also been verified statistically using Statistical Package for Social Sciences (SPSS) software. Distinct changes are observed in mean heart rate (HR), sympathetic, vagal and approximate entropy (ApEn) mainly in transmitting mode. This study can be used as a lead in order to explore further in the area of exposure therapy leading to improved medicare system.

Keywords: Heart rate variability, electromagnetic field, mobile communication, vagal, sympathetic.

INTRODUCTION

The growth of wireless technology has resulted in a large scale use of mobile phones. In 2011, the World Health Organization named mobile phone radiations as carcinogenic hazards [1]. In the young generation, the mobile phone usage has become an addiction and hence, they are exposed more to these radiations. Mobile phones operate in the range of 450 MHz to 2700 MHz [2]. The radiations from them considered to be non-ionizing that can affect the atoms in the exposed area and create vibrations in them, leading to heating effects [2]. However, this depends on duration of daily usage and field intensity of the exposure.

ECG signal is the pictorial view of the heart functioning. Heart rate variability signal (HRV) is the variations in the RR intervals of the ECG signal [3]. It helps in the diagnosis of heart problems and has become a popular method of studying the autonomic nervous system (ANS) and the balance of vagal and sympathetic nerves. The daily exposure to RF radiations from mobile phones put a great impact on our biological system. In this paper, in order to accurately examine the impact of these RF radiations, analysis of HRV signals have been done using various parameters. For the assessment of ANS activity, spectral analysis of HRV is a widely used approach [4]. For basic research, frequency domain analysis of HRV is done using parameters like power in very low frequency (VLF) (0-0.03 Hz), low frequency (LF) (0.03-0.15 Hz), high frequency (HF) (0.15-0.4 Hz) component [5]. LF component is influenced by both sympathetic and parasympathetic nervous system and HF component is influenced by the parasympathetic activity. Heart rate variations may be due to both the internal and external stimulated causes [6]. The linear analysis of the HRV signals, such as time and frequency related methods mainly show the complexity of signals, but may miss the useful information in them. Moreover, HRV is a non-linear and non-stationary complex signal which exhibits the fractal properties [7] so as to know the hidden complexities in it, non-linear methods have also been employed to better assess the changes occurred during the exposure. Geometrical Parameters of the time domain parameters are insensitive to the noise and includes HRV triangular index, the triangular interpolation of the histogram NN and logarithmic index etc. have also been considered [8].

This paper is organized as follows. Section1 gives the introduction about the motive of the research. Section 2 relates to the research done in this field so far. Section 3 presents the experimental setup, protocol, data acquisition and the methods of data analysis. Section 4 gives the results obtained and the discussion. Section 5 includes the conclusion, followed by the references.

RELATED RESEARCH

From last one decade a large number of researchers are engaged in studying the impact of RF radiations on human beings, animals, and environment. Vegad et al. [9] investigated the effects of mobile phone radiations on HRV and found an increase in the sympathetic tone. But, no non-linear analysis is taken up. Umar et al. [10] studied on heart rate (HR) and blood pressure and revealed no significant change in the parameters. Choi et al. [11] found no effect on the HR and HRV parameters. Devasia et al. [12] studied on healthy subjects and found no significant difference in HR, QT intervals in the ECG signal when exposed to mobile phone radiations. Saini et al. [13] studied the wireless network radiations on HRV and found no impact on Approximate Entropy (ApEn), but observed an increase in the detrended fluctuation analysis (DFA). Thorat et al. [14] also found no statistical change in the HRV, cardiac activity and ANS. Aghav et al. [15] reported significant change in the HR due to mobile phone and towers. Komeili et al. [16] investigated on young students and studied HR, PR interval, time of QRS and T waves, and voltage of R wave and reported an increase in the HR and the other intervals of the ECG segments. But the results varied for males and females. Alhusseiny et al. [17] found that QT interval of ECG signal was prolonged and the radiations interfered with the voltage criteria of ECG records in male patients, showing sign of myocardial ischemia. Tamer et al. [18] did not show any significant difference in any of the ECG wave's interval with the exposure. Andrzejak et al. [19] showed an increase in parasympathetic tone and decrease in sympathetic tone. The symptoms like headache, memory loss, fatigue, heating of ear, irritation and many other psychological, behavioural and biological effects have been reported by Repacholi [20]. Studies also showed the changes in the frequency components of the HRV [21, 22]. Largest Lyapunov Exponent (LLE) has also been analysed by Yilmaz et al. [23] and found that with the higher exposure to EMFs, the LLE values of the HRV increased, showing more chaos in the signal. Ahamed et al. [24] experimented by keeping phone near to chest and the left ear and reported an increase in the scaling parameter and HR when the phone was near to chest. Increase in HF and decrease in LF power were found by Al-hazimi et al. [25]. On the other hand, Barutcu et al. [26] experimented on healthy subjects and found no such variations in the parameters of HRV. Parazzini et al. [27] concluded that EMF RF does not produce any significant changes in the heart parameters of the user. Reports have also been published on the various guidelines imposing restrictions on the SAR values and power levels of the exposures from BTS as precautionary measures without specifically reporting on any significant effects.

The present work presents the rhythmic effects on the HRV due to the radiations from the mobile phone of second (2G) and third generation (3G) on the active users and analyses the parameters in time, frequency and nonlinear domain.

MATERIALS AND METHODS

The description of the recording setup, the procedures and the protocol followed during the acquisition of the ECG signal has been presented in the following sub-

sections. The ECG has been recorded in the presence of a cardiologist in a laboratory when the user used their mobile phone for the normal daily use to communicate.

SUBJECTS

For this study, 75 (57 males and 18 females) young and healthy students studying in post graduate courses in National Institute of Technical Teachers Training and Research, Chandigarh, India have been considered. The age, height, weight, BMI Index is almost same for all the subjects. The mean age of the subjects is 22.2 years with standard deviation of 2.27 years. The daily usage of mobile phones for all considered subjects is between 1-2 hours. No subject is taking any kind of medicine. The phones which are used by the subjects in the experiment are of Nokia, Samsung, Panasonic and Motorola companies and their specific absorption rate (SAR) values are in between 0.67-1.14 W/kg. No external RF exposure has been applied. Informed consents have been obtained from all individual participants included in the study. Intentionally the single blind study has been done so that the subject is made to feel at ease and all cares are taken to keep the subject free of stress.

EXPERIMENT FRAMEWORK

The ECG acquisition involves the natural process when the subject communicated using mobile phone in its daily routine. The subjects are instructed to take necessary precautions before the recording. The recording is done in the early morning between 6 to 8 a.m. when the subjects are having fresh mind and have not used mobile phone up to that time of the day and is labeled as 'Ideal'. During the day, under the normal usage, the ECG is acquired and classified as "2GRx" for 2nd generation phone (GSM) in the receiving mode and '2GTx'in the transmitting mode. Similarly, the ECG acquired while using 3rd generation network standard WCDMA is termed as'3GRx'for receiving mode and '3GTx'in the transmitting mode. However, the sequence of recording is not fixed and is random as the state comes. No direct EMF has been linked, however, the SAR values of the mobile phones have been considered. After the acquisition, ECG signal is preprocessed to remove the artifacts and then HRV is extracted using the Biopac system.

DATA ACQUISITION

The field strength measurement is performed all around the chair using a Boonton power meter Model number 52018 to see the power level available and to observe the variation in the field intensity in the defined sitting region. No appreciable field intensity variation is observed till 10 minutes. Hence the measurement carried out up to 5 minutes may therefore, assumed to be a non-varying situation. This study aims at users' realistic situation radiation study hence no dummy phones are used. ECG signal is acquired using Biopac MP100 system fixed at a 1 kHz sampling frequency and notch filter at 50 Hz. The recording has been done with three electrodes, positive polarity on left arm wrist (LA), negative polarity on right arm wrist (RA) and ground electrode at right leg ankle (RL). Three lead Biopac instrument has been used for ECG recording which follows Einthoven triangle. Three lead system is used mainly

for studying the rhythmic variations which is the focus of this research. The authors have studied all the three leads however, in this paper, the results of lead I have been presented. Proper grounding of the setup is done in order to avoid any other noise in the signal. Subjects are made to sit in a comfortable posture. The subjects are instructed to attend the calls through right ear only as in Figure and to avoid unnecessary body movements to prevent the effect of artifacts.

Figure. ECG acquisition.

No other phones are allowed inside the laboratory. The duration of the mobile use varies from subject to subject. However, for analysis purpose, this has been segmented to interval of 5 minutes in all different modes i.e. ideal, 2GTx, 2GRx, 3GTx, 3GRx with intermediate break.

DATA ANALYSIS

The clean HRV is then analyzed for various pre-defined parameters, as suggested by the medical consultant. The parametric analysis is done with the software Kubios HRV toolkit version 2.2. Eighteen parameters have been considered for the detailed analysis. Six time domain parameters that are Mean Heart Rate (Mean HR), root mean square of successive R-R interval differences (RMSSD) [16], Standard Deviation of Heart rate (STD HR), standard deviation of all normal sinus R-R intervals in ms (SDNN), RR Triangular Index, percentage of the number of R-R interval differences which are equal to or more than 50 ms [16] (pNN50) in beats per minute. STDHR, SDNN and RR Triangular Index give the number of all RR intervals divided by the number of RR intervals of the most frequent RR interval length [27]. Six frequency domain parameters include power at very low frequency (VLF), Low frequency (LF) and high frequency (HF) bands of the signal that is calculated using FFT method, vagal, sympathetic tone and their balance i.e. sympatho-vagal balance or

LF/HF ratio. Six non-linear parameters include correlation dimension (CD), approximate entropy (ApEn), determinism (DET), recurrence rate (REC), sample entropy (SamEn) and Shannon entropy (ShanEn) that indicate the amount of irregularity in a time series data [20].

STATISTICAL ANALYSIS

The statistical analysis is done using student's Paired Sample t- test in IBM SPSS version 20. The null hypothesis (H_0) shows no significant difference between the mean values of normal mode and the other modes. So, a p-value is less than 0.05 (p-value < 0.05) is considered statistically significant value to denote the effective difference between the means compared with the ideal mean. When p-value is less than 0.05, then alternative hypothesis (Ha) is accepted i.e. there is a significant difference in the mean values.

RESULTS AND DISCUSSION

The linear and non-linear analysis of the data is depicted in the corresponding tables. The normal mode values are written along with the parameter name with mean and standard deviation in the parenthesis. The communicating modes corresponding statistical values for 't' and 'p' have also been mentioned.

TIME DOMAIN

Time domain results tabulated in Table 1 show an increase in the mean HR in all the communicating modes, but not significant enough. RMSSD is less in the GSM mode and also in agreement with the heart rate. There is an increase in the STD HR in 2GTx and in both transmitting and receiving modes of WCDMA, but do not represent any significant change. SDNN shows the decreasing trend in the receiving modes of both GSM and WCDMA but is significant in GSM. RR triangular index, which is related to the periodical repetition of the cardiac cycle [27] has same effect as on the STD RR. pNN50 is low in all the modes due to effect of radiations but not very significant change is seen. RMSSD and pNN50 both are related to the parasympathetic activity [27]. The lower activity of parasympathetic represents a decrease in the level of relaxation and more towards the anxiety. But this may be due to other mental conditions as non-uniformity in variation is observed.

Table 1. Time domain parameter values.

N/w	Mean	SD	t-value	p-value	Mean	SD	t-value	p-value
Mean HR (bpm)			80.488 (11.394)		RMSSD (ms)		47.064 (25.80)	
2GRx	81.088	11.366	-0.768	0.450	39.51	21.24	2.125	0.044*
2GTx	80.744	11.376	-0.324	0.748	40.28	21.69	2.740	0.011*
3GRx	80.708	11.589	-0.333	0.742	47.43	25.53	-0.070	0.945
3GTx	80.642	11.602	-0.217	0.830	47.36	25.85	-0.077	0.939

STD HR(bpm)			5.134 (1.4316)		SDNN (ms) 54.666667 (15.834561)			
2GRx	4.850	1.488	1.270	0.216	55.4876	13.28	-0.398	0.695
2GTx	5.466	1.725	-1.019	0.318	55.7157	13.60	-0.390	0.700
3GRx	5.473	2.092	-0.879	0.388	55.4323	15.65	-0.188	0.853
3GTx	5.707	2.437	-1.249	0.224	56.9047	14.83	-0.535	0.599
RR Triangular Index			10.782 (3.386)		pNN50 (%)		18.67 (15.74)	
2GRx	9.953	2.89	1.275	0.215	12.54	11.57	3.404	0.002*
2GTx	10.81	3.262	-0.051	0.959	14.35	11.60	2.217	0.036*
3GRx	10.29	3.22	0.769	0.450	13.96	11.24	2.213	0.037*
3GTx	10.96	2.999	-0.274	0.786	12.48	10.05	3.249	0.003*

∗ Significant Values

FREQUENCY DOMAIN

The power contained in the various bands i.e. in VLF, LF, and HF band is shown in Table 2. VLF effectively represents only the parasympathetic activity. The results show less VLF power while receiving calls and high during the transmission of calls in both 2G and 3G networks. There is an increase in the LF component with highest value in the 2GTx mode but not significant in any mode. LF component is considered to be the reflection of both sympathetic and parasympathetic tone [27].

Table 2. Frequency domain parameter values.

N/w	Mean	SD	t-value	p-value	Mean	SD	t-value	p-value
Power in VLF Band (ms^2) 902.64 (1013.03)					Power in LF Band(ms^2)934.76 (1394.22)			
2GRx	631.32	662.80	1.343	0.192	1040.80	1443.41	-0.971	0.341
2GTx	1118.5	1202.5	-0.836	0.412	1274.20	2165.43	-1.483	0.151
3GRx	736.60	544.80	1.143	0.264	1185.80	1453.46	-1.146	0.263
3GTx	918.40	727.97	-0.063	0.951	1084.12	788.21	-0.837	0.411
Power in HF Band (ms^2) 1008.16 (1716.54)					Sympathetic 0.50959 (0.2038)			
2GRx	652.96	706.16	1.262	0.219	0.59396	0.17657	-2.578	0.016*
2GTx	703.12	647.82	1.192	0.245	0.56006	0.18547	-1.318	0.200
3GRx	953.40	830.67	0.173	0.864	0.54289	0.15339	-1.027	0.315
3GTx	1040.16	1274.74	-0.164	0.871	0.58096	0.18565	-2.215	0.036*
Vagal 0.49040 (0.17657)					LF/HF Ratio 1.6358 (1.8835)			
2GRx	0.40603	0.17657	2.578	0.016*	1.9814	1.4117	-1.015	0.320
2GTx	0.43994	0.18547	0.1318	0.200	1.8946	1.9608	-0.590	0.561
3GRx	0.45710	0.15339	1.027	0.315	1.5586	1.3306	0.425	0.675
3GTx	0.41904	0.18565	2.215	0.036*	2.0766	1.7775	-1.292	0.209

∗ Significant Values

The results show a decrease in HF power that lead to the conclusion of non-relaxation stage. With the increase in the exercise, the HF power increases. During dynamic exercise, there is an increase in sympathetic activity and reduction of parasympathetic activity, thus increases the HF power and decreases the LF power that leads to increase in the heart rate. The high frequency component is also influenced by the respiration [27]. The sympathetic tone is increased with the radiations and it is significantly higher in 2GRx mode. The increasing trend of sympathetic tone is in agreement with Kodavanji et al. [22]. The increased sympathetic value affects the HR and shifts the breathing rate towards the higher side. However, there is a significant decrease in the vagal tone in 2GRx and 3GTx. The increase in the vagal tone is beneficial for the heart as it regulates the HR and relaxes it [21].Sympathetic and vagal tone activity regulate the ventricular arrhythmias. The LF/HF ratio is sensitive to the stress in the body and the results show LF/HF ratio is higher as compared to the normal mode, but it is not significant in any mode. Leading to a conclusion, the present day phones do not lead to a sensible RF radiation effect due to less radiating power.

NON LINEAR PARAMETER

The correlation dimension (CD) values shown in the Table 3 is on the decreasing trend with the lowest value in the 3GRx mode. The low value of the CD goes with the high heart rate. Entropy refers to the regularity of the signal; low value represents regularity whereas, in healthy people the HRV signal is more irregular which is supported by Al-Angari et al. [29].

Table 3. Nonlinear parameter values.

N/w	Mean	SD	t-value	p-value	Mean	SD	t-value	p-value
CD		2.4868 (1.2695)			ApEn		0.9418 (.1465)	
2G Rx	2.4614	1.2276	0.104	0.918	1.01768	0.1381	-3.323	0.003*
2G Tx	2.4884	1.1801	-0.007	0.995	0.97668	0.1148	-1.133	0.268
3G Rx	2.3468	1.2011	0.568	0.575	0.9654	0.1328	-0.651	0.521
3G Tx	2.3710	1.2398	0.519	0.608	0.9356	0.09489	-1.746	0.094
DET (%)		97.380 (1.669)			Recurrence Rate		(%) 32.07 (12.10)	
2G Rx	97.940	1.0943	-1.539	0.137	34.64	13.09	-0.782	0.442
2G Tx	98.170	0.8486	-2.333	0.028*	35.55	11.694	-1.292	0.209
3G Rx	98.160	1.4031	-1.817	0.082	38.91	13.77	-1.730	0.096
3G Tx	98.561	1.0049	-3.360	0.003*	39.72	11.92	-2.439	0.022*
SamEn		1.531 (0.2477)			ShanEn		3.013 (0.3765)	
2G Rx	1.528	0.2837	0.037	0.971	3.0270	0.2966	-0.168	0.868
2G Tx	1.473	0.3203	1.016	0.320	3.1195	0.3286	-1.190	0.246
3G Rx	1.402	0.2971	2.021	0.055	3.1871	0.4018	-1.595	0.124
3G Tx	1.3776	0.2707	2.503	0.020*	3.256	0.3028	-3.179	0.004*

∗ Significant Values

Approximate Entropy (ApEn) is high in all the modes with highest in the receiving mode of 2G. The more regular and predictable the HR signal is, the low ApEn it shows [30]. This means that with the exposure, HRV has become complex as compared to normal. Madhavi et al. [31] studied ApEn and found that with the meditation, its value increases, showing more healthy and relaxed state of the heart. ApEn is a measure of disorder in case of heart rate signals, so the higher value represents a normal heart and low value points towards the abnormal cardiac functioning. ApEn introduces errors for dynamic signals so its modification i.e. sample entropy (SamEn) is used for the analysis [32, 33]. Determinism (DET) is said to be the determinant of the RR intervals as measured by the variables [34] and is significantly high in 2GTx as well as 3GTx modes. Recurrence rate is the quantitative measure of the recurrence plot (RP) and is the ratio of ones and zeros in the RP matrix [34]. Here its value is increasing with the exposure in both the modes GSM and WCDMA. SamEn is low in all the modes but not significant enough. SamEn is low in case of obstructive sleep apnea (OSA) patients [25] and in the presented results; it is low for 3G phones exposures. OSA patients have more regular HRV signal as compared to healthy ones [25]. Also, the higher value of SamEn denotes higher irregularity in heart rate. Shannon Entropy (ShanEn) is higher with the exposure to the radiations in the transmitting mode of 3G, but not significant enough to draw any inference.

COMPARISON OF GSM AND WCDMA

GSM and WCDMA parameters performance comparison has been shown in Table 4.

Table 4. Comparison of GSM and WCDMA parameters.

		GSM		WCDMA	
Parameter	Normal	2GRx	2GTx	3GRx	3GTx
Mean HR	80.488	81.0884	80.744	80.7084	80.642
RMSSD	47.8583	40.1833	40.8208	48.6166	47.575
STD HR	5.134	4.85	5.466	5.473	5.707
SDNN	54.279	47.883	54.370	52.683	55.25
LFP	934.76	1040.80	1274.20	736.60	918.40
HFP	1008.16	652.96	703.12	953.40	1040.16
Sympathetic	0.50959	0.59396	0.56006	0.54289	0.58096
Vagal	0.49040	0.40603	0.43994	0.45710	0.41904
CD	2.4868	2.4614	2.4884	2.3468	2.3710
ApEn	0.9418	1.01768	0.97668	0.9654	0.9356
SamEn	1.531	1.528	1.473	1.402	1.3776
ShanEn	3.013	3.0270	3.1195	3.1871	3.256

Mean HR decreases in WCDMA network, whereas RMSSD, STD HR, SDNN are high in WCDMA network. LF power is low in WCDMA and HF power is high in WCDMA network. Also, LF power is increasing with the exposure, with highest in the GSM transmission mode (2GTx). Sympathetic is high in transmission mode and low in the reception mode of WCDMA and vice versa in vagal. CD, ApEn and SamEn is high in GSM network, whereas ShanEn is higher in WCDMA with highest in the transmission mode.

CONCLUSION

In this paper, the variations observed in HRV trace while using GSM and WCDMA network mobile phones have been presented. The study has been carried out when the subjects use their mobile phones as normal users i.e. without any external exposure. The results show a change in parameters but not very significant. The distortion observed in the trace of heart rate is more or less matching with the trace of increased heart rate. This paper provides an extensive study of interaction of EMF radiation from mobile phones and HRV. The extensive study using linear, non-linear and statistical parameters on 75 healthy subjects show no significant changes. The discussion with cardiac consultant led to the conclusion that the study using long duration exposure in the clinical approach may come up with the answer for the effect of radiation from mobile phones on human heart. The present day mobile phones due to digital evolution use low input power. Hence, users having standard use hours may not have significant effect, as has been observed in this study.

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