

Heart Rate Variability Monitoring Due to 50 Hz Electromagnetic Field Exposure and Statistical Processing

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Abstract—This study investigates the influence of the 50 Hz electromagnetic exposure on heart rate variability (HRV). Thus, we recorded and preceded the ECG signals for 44 volunteers both in high and normal field exposure. The acquisition system and the QRS detection algorithm were developed by the authors with the view to be used in this study. Spectral measurements of the HRV revealed a significant increase (Student's t-test: $P_t=0.001$; Mann-Whitney U-test $P_U=0.001$; average difference $D=16.857$) in the power of the HF components and significant reduction in the power of the low-frequency (Student's t-test: $P_t=0.003$; Mann-Whitney U-test $P_U=0.003$; average difference $D=-14.906$) on volunteers exposed compared with unexposed one conditions.

Keywords - heart rate variability; electromagnetic exposure; statistical processing

I. INTRODUCTION

One of the most common sources of interference is due to the power line system (220 V, 50 Hz). Disruptive electric and magnetic fields resulted from this source are relatively strong and their frequency (50 Hz) is within the ECG spectrum and hence the difficulties with reduction of these disturbances [1], [2]. Studies indicate that adaptive filtering in these conditions can be a good solution [3], [4]. On the other hand the biological and health effects of electric and magnetic fields are an up to date theme [5], [6]. The aim of this work is to investigate the possible modification of HRV in case of electromagnetic field exposure.

II. HRV DETERMINATION

The ECG signal was acquired with a system developed by the author [7] (Fig. 1). The acquisition was performed using a single channel acquisition board from National Instruments NI USB-6009, sampling frequency of 500 Hz. The programming environment used was LabView 2009.



Figure 1. ECG acquisition system used in measurements.

We implemented a Wavelet Multi-Resolution Analysis (MRA) algorithm for the detection of the QRS complex in a high level of noise ECG recording, Fig. 2 [8].

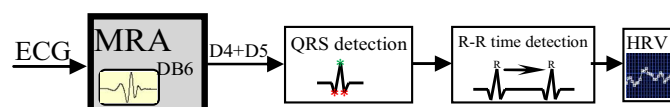


Figure 2. The algorithm to extract the QRS complex to obtain the HRV.

At this test 44 young volunteers were considered being exposed at relatively high level ($B = 67 \mu\text{T}$) of 50 Hz electromagnetic field exposure, but below the maximum level of exposure ($B = 100 \mu\text{T}$, conform ICNIRP), respectively at normal or low level exposure field (B of tens or hundreds of μT).

For this study a number of 32 ECG (14 exposed volunteers and 18 in normal conditions) recordings were utilized, because some ECG recordings were excluded due to movement artifacts, imperfect electrode contacts. The age of the volunteers was between 23 and 28 years, from which 13 women and 19 men.

Examples of ECG signal acquired in normal and field exposed conditions are shown in Fig. 3 (time domain representation) and Fig. 4 (frequency domain representation).

With the view to decrease the noise level in ECG recordings, we performed both an adaptive filtering in LabView and used a Wavelet denoised filtering [9].

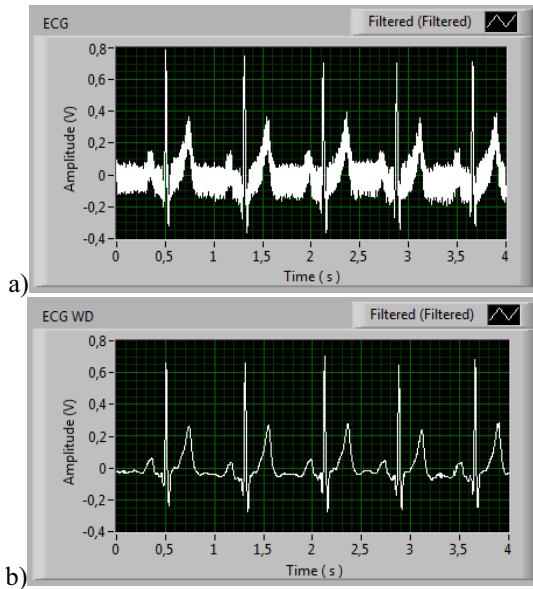


Figure 3. ECG signal.

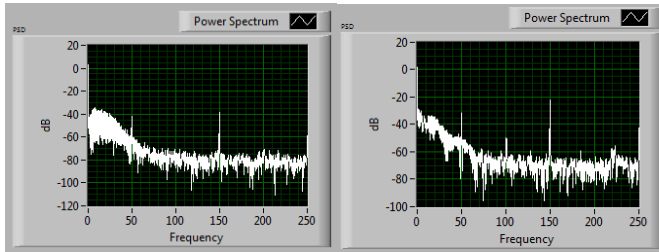


Figure 4. Power spectral density of the ECG signal:
a) In normal conditions; b) exposed.

III. HRV MODIFICATIONS

To highlight the modification of ECG during the exposure to electromagnetic field it we have extracted some feature in time domain and frequency representation of the HRV.

In time domain the extracted feature were the feature described by Task Force of the European Society of Cardiology, [10]: The mean N-N interval; SDNN, the standard deviation of the N-N intervals; pNN50, the number of interval differences of successive N-N intervals greater than 50 ms, divided by the total number of N-N intervals.

In frequency domain, the power spectral density (PDS) was divided in main used bands of frequency: high frequency (HF: 0.15 Hz - 0.4 Hz), low frequency (LF: 0.04 Hz - 0.15 Hz) and very low frequency (VLF: 0.003-0.04 Hz).

HRV is mediated by the activity of the sympathetic and parasympathetic branches of the autonomic nervous system. In general, the sympathetic branch acts to speed up heart rate and the parasympathetic branch acts to slow heart rate.

The continuous modulation of the sympathetic and parasympathetic innervations results in variations in both heart rate and blood pressure. The most conspicuous periodic component of HRV is the so-called respiratory sinus

arrhythmia (RSA) which is considered to range from 0.15 to 0.4 Hz [11].

A. Time - frequency representation

Since the Fourier transform it is not appropriate to apply a signal whose frequency structure varies over time, non-stationary signals, because is not localizing in time the signal changes, the representation is done in the time-frequency representation.

Time-frequency analysis of HRV is traditionally performed using short-term Fourier transform (STFT). Wavelet transform (WT) may however be better suited for analyzing non-stationary signals such as heart rate recordings.

In Fig. 5 it can be seen a comparison between power spectral density (PSD), spectrogram and scalogram and how the modification appear in time both in normal conditions and in field exposure cases.

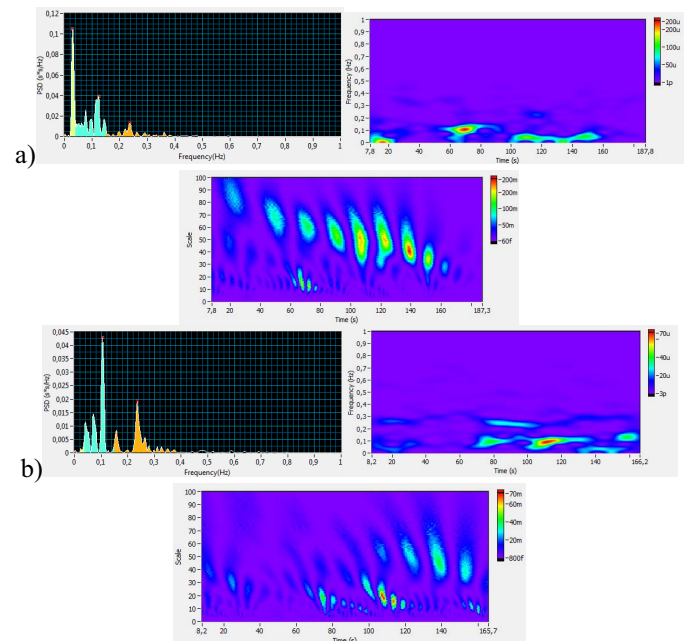


Figure 5. PSD, spectrogram, respectively scalogram of HRV
a) in normal conditions; b) exposed at 50 Hz field.

The same increasing of the HF component of Power Spectral Density (PSD) of the HRV graphs in exposure conditions can be seen in [12].

IV. STATISTICAL PROCESSING OF RESULTS

Table I is shown some extracted feature from the ECG signal: duration and amplitude of the QRS complex, of the PR and QT interval, and also from the HRV signal (PSD, pNN50). For those features extracted from the ECG signal we apply the Levene's Test for equality of variances, Student's t-test distribution for equality of the mean and Mann-Whitney U-test to determine if a difference exists between two groups (expose-unexposed).

TABLE I. PARAMETERS EXTRACTED FROM THE HRV SIGNAL

HRV parameters	Levene's Test P_L	Student's t-test P_t	Mann-Whitney U-test P_U	Average Difference D
PR interval mean	.013*	.386	.747	-13.5 (ms)
PR interval std	.626	.886	.621	-1.03 (ms)
QRS width mean	.001**	.357	.688	2.81 (ms)
QRS width std	.015*	.107	.214	2.65 (ms)
QRS amplitude mean	.418	.498	.360	-0.07 (mV)
QRS amplitude std	.001**	.007*	.004**	0.062 (mV)
QT interval mean	.863	.510	.543	-3.1 (ms)
QT interval std	.443	.268	.459	3.55 (ms)
RR Mean	.001**	.001**	.002**	-153.81 (ms)
RR Std.	.474	.447	.569	-5.111 (ms)
HR Mean	.001**	.001**	.003**	13.2 (bpm)
Heart Rate Std.	.511	.8670	.894	0.116 (bpm)
RMSSD	.784	.123	.080	-15.524 (ms)
NN50	.797	.003**	.008*	-37.794
pNN50	.010*	.001**	.001**	21.0175 (%)
RR triangular index	.018	.308	.284	1.30
TINN	.195	.103	.138	32.62
VLF Power	.003**	.71	.231	-204.92 (ms ²)
LF Power	.866	.974	.718	-11.190 (ms ²)
HF Power	.001**	.004**	.003**	-632.8 (ms ²)
VLF	.141	.424	.581	-2.206 (%)
LF	.591	.001**	.001**	16.857 (%)
HF	.010*	.003**	.003**	-14.906 (%)
LF	.131	.001*	.002**	17.73 (n.u.)
HF	.013*	.002*	.001**	-15.90 (n.u.)
LF/HF	.807	.076	.001**	1.8636
SD1	.873	.109	.074	-11.31
SD2	.973	.314	.295	-11.603

*P<0.05.

**P<0.01.

The statistical processing of results (Fig. 6) shown a reduction in variation of the QRS amplitude (Student's t-test: $P_t=0.007$; Mann-Whitney U-test $P_U=0.004$; average difference $D=0.062$) at field expose persons.

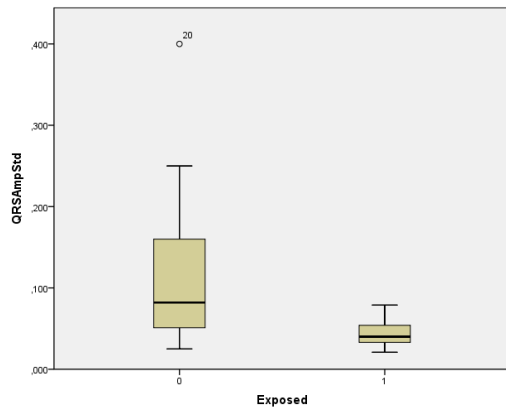


Figure 6. Boxplot of the QRS amplitude.

The most relevant effect, resulting from exposure to combined 50 Hz electric and magnetic fields, is slowing the mean HR (lengthening of the cardiac inter beat interval). This biological effect (Fig 7) was also observed in many studies performed with healthy young men [13], [14], [15] and this response appears attributable to the magnetic aspect of exposure.

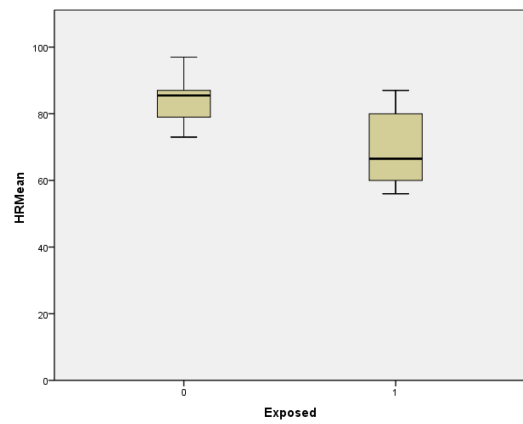


Figure 7. Boxplot of the heart rate.

In our study statistical processing of results (Fig 7), regarding the 50 Hz electromagnetic field exposure, has an decreasing effect to HR Mean (Student's t-test: $P_t=0.001$; Mann-Whitney U-test $P_U=0.003$; average difference $D=13.2$).

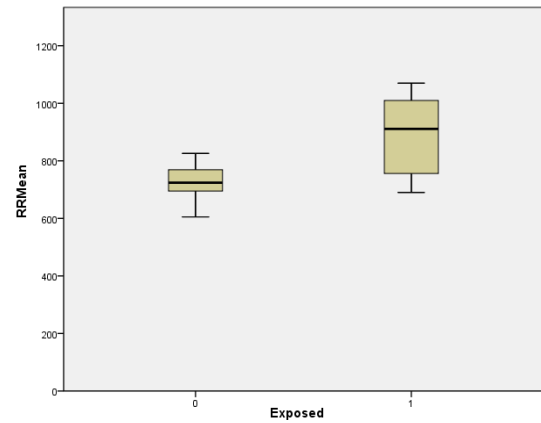


Figure 8. Boxplot of the RR interval.

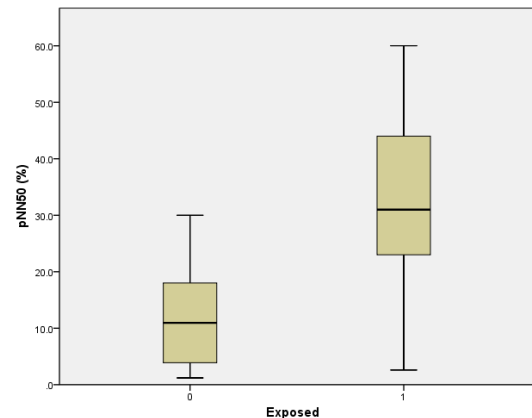


Figure 9. Boxplot of the pNN50.

Our results indicated a significant difference 17% increase for R-R mean (Fig 8), when: Student's t-test $P_t=0.001$; Mann-Whitney U-test $P_U=0.002$; average difference $D=-153.81$ and 65% increase for pNN50 (Fig 9), when: Student's t-test $P_t=0.001$; Mann-Whitney U-test $P_U=0.001$; average difference $D=21.0175$, during magnetically field exposure.

The biological magnitude of the reduction in HRV observed by [13] was approximately 17%, 0.2% in [15] and 8% in [16].

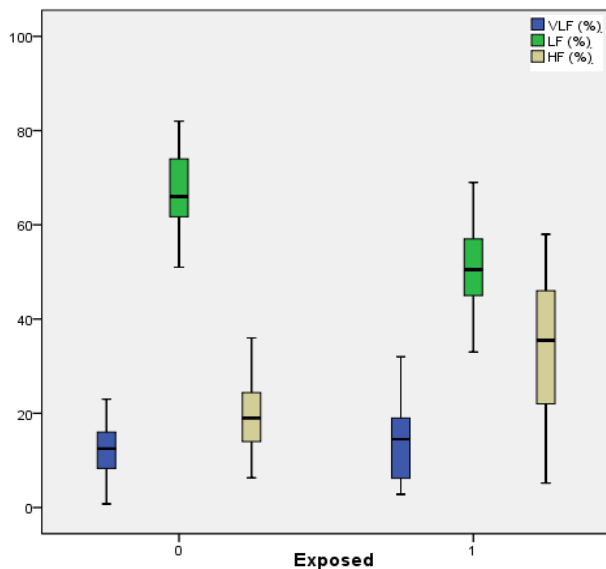


Figure 10. Comparison between PSD of HRV in considered frequency bands on the unexposed/exposed volunteers

Our analyses of the effects of exposure to 50 Hz magnetic field have revealed two significant effects (Fig 10): decrease in power spectral density of HRV in the LF band and an increase in power in the HF band. The spectral representation of the HRV revealed a significant increase (Student's t-test: $P_t=0.003$; Mann-Whitney U-test $P_U=0.003$; average difference $D=14.9$) in the power of the HF (%) and also in HF (n.u.).

The spectral analyses of heart rate time series revealed a significant reduction in the power of the low-frequency (Student's t-test: $P_t=0.001$; Mann-Whitney U-test $P_U=0.001$; average difference $D=16.857$) in case of volunteers exposed. The reductions of the low frequency (LF) band of the HRV frequency spectrum of N-N sequence were also reported in [17] and [15].

CONCLUSION

We recorded and processed the ECG signals both in normal electric/magnetic fields and in relative high levels of 50 Hz magnetic fields. Thus, heart rate variability was determined and analyzed.

These analyses of the effects of exposure to electromagnetic field below the maximum level of exposure have revealed two significant effects: decrease in power density of HRV in the low spectral band and an increase in power in the high spectral band. It is important to note that clinical studies of HRV as a predictor of cardiovascular risk report that higher risk is associated with a reduction in low band power.

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