Data collection and analysis of heart rate variability with the emWave2: a case study

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Abstract— **Heart rate variability is an important measure of basic cardiovascular functions, and extensively used in stress research. A portable system was introduced into the market for biofeedback applications, detecting interbeat intervals and coherence in various situations and training conditions. The aim of the present study was to describe first-order preliminary data in a case study with the help of the emWave2 system, and to test the possibility for applications in real-life situations with natural context. Additional to the first-order analysis, an advanced analysis with the help of Kubios software was also introduced, and future possible applications are also outlined.**

Keywords: Cardiovascular, Heart Rate Variability, Natural Context, Stress.

I. INTRODUCTION

A. Heart rate variability (HRV)

Heart rate is a nonstationary signal, dynamically changes during different physical or psychological stress situations. Original measures of basic cardiovascular parameters like heart rate and blood pressure have been supported with HRV analysis (variations in the interbeat intervals) [1-3]. HRV is a complex measure of cardiac functions and the state of the autonomic nervous system responsible for regulating cardiac activity. HRV has a major impact assessing sympathetic and parasympathetic elements, with a major effect of different emotional states, cognitive load or cardiovascular diseases [3]. E.g., based on the Framingham Study, repeated analyses of cardiovascular mortality were associated with decreased heart rate variability [4], and multiple associations were also described with other diseases as well [5].

Major neurophysiological laboratories use advanced systems to analyze heart rate variability during different laboratory conditions; but “more natural” portable systems (with less precision) have also major advantages in modeling real life situations. Technological development in the last 5 years created an unparalleled increase in the number of commercially available systems [6] that can be used in everyday situations. E.g., some systems provide the heart rate information during jogging or different physical activities, some containing an additional activity tracker [also calculating calorimetric changes], that might be used for monitoring diurnal activity. Another direction is the application of different biofeedback systems, like HeartMath applications [7], where targeting stress and maintaining resilience is the main question [8]. The emWave2 system has been used in recent studies, improved coherence measures were associated with better physical and emotional parameters after regular emWave2 usage in populations with marked emotional burden, major depression and hypertension [9-14].

B. Aims

The aims of the present experiments were twofold. *First*, the emWave2 system was used for detecting heart rate measures in a case study during different resting conditions (control condition, slow and fast music) and during moderate physical activity. Our hypotheses were the followings: compared to baseline resting conditions, slow and fast music might increase baseline heart rate in resting conditions, and physical activity would decrease interbeat intervals.

Second, our aim was to model first-level and advanced analysis of the heart rate on the present set of data.

These data served as preliminary data for a study in adolescents with externalization problems, the applicability of the system in different natural settings was tested. The detailed description of the above study was beyond the scope of the present paper [for background, see 15], the research entitled “Dimensional approach in externalization disorders” was approved by the Scientific and Research Ethical Committee of the Hungarian Medical Research Council (ETT-TUKEB).

II. METHODS

The HeartMath emWave2 Portable Stress Relief system has a size of 85mm x 55mm x 14mm, handy and easy to use. The setup has two types of sensors, both the ear-clip and the touch sensor (thumb or index) can be used in natural settings [7]. The system can be connected with a USB plug-in to a notebook, with a user friendly interface. Data collection can also be performed without the computer, and later data acquisition can be performed. The setup has two types of sensors. In the present set of experiments, a large number of situations were repeatedly tested, what can occur during regular daily activities (more than 20 conditions, e.g. breakfast, learning, reading, cooking etc.). Data collection lasted approximately for two days. Ear-clip and touch sensor data was also used, only the data for the touch sensor were shown. The test subject was a university student, female, 21 years old, one of the authors (I. Ny.). Her data are shown in the results section, in selected scenes.

The duration of the measurements was 180 seconds for different resting conditions. Slow (Titanic – My heart will go on, Celine Dion) and fast (Danza Kuduro, Don Omar) music condition was defined as resting condition and additional listening to the given music. In another setting, the effect of mild physical activity was tested (90 seconds). The system was able to provide sec by sec heart rate data and interbeat intervals, all the further steps were performed by the authors with the help of Statistica 7.0 and Kubios softwares.

Table 1. Heart rate data (per min) in different conditions in 30 sec packages

Heart rate		fast music	slow music	rest
first 30sec	average	69,7	75,9	70,5
	min	59,1	66,9	56,3
	max	82,2	93,6	86,7
second 30sec	average	75,0	81,7	69,1
	min	68,3	71,3	61,3
	max	92,7	97,7	86,8
third 30sec	average	74,4	72,8	68,8
	min	67,7	61,6	61,1
	max	83,2	79,6	79,8
fourth 30sec	average	72,5	73,5	70,8
	min	63,4	61,5	55,8
	max	84,7	80,8	85,2
fifth 30sec	average	75,7	75,0	68,7
	min	69,6	60,2	61,5
	max	82,4	90,6	78,9
sixth 30sec	average	74,2	66,6	68,1
	min	69,7	56,6	63,8
	max	80,3	71,7	73,3

Statistical analysis. As a case study was performed, only non-conventional measures could be used, with self-control. Statistica 7.0 was used for a GLM-based testing in the comparison of different resting states (resting vs. slow music vs. fast music), and the calculated (by emWave) 500 msec fluent heart rate data were compared in 30 sec packages. Neumann-Keuls post hoc comparisons were also run, $p<0.05$ was considered as significant. In the comparison of interbeat intervals between resting state vs. moderate physical activity, the interbeat intervals were analyzed for 120 intervals in each condition. In the latter context, frequency spectrum analysis and nonlinear analysis (Poincare plot) was applied with the help of the Kubios HRV 2.1 software (Department of Applied Physics, University of Eastern Finland).

III. Results

In the first set of data, descriptive statistics of different resting conditions (rest [without music] vs. rest with slow music vs. rest with fast music) in 30 sec packages were presented (Table 1). The average, minimal and maximal heart rate data were outlined. In the first 30 sec, a significant difference occurred between groups ($F_{(2,180)}=23.45$, $p<0.0001$), slow music was accompanied by significantly higher heart rate data compared to the resting condition (Fig. 1.). In the next four 30 sec packages, a significant increase was present in both slow and fast music conditions compared to heart rate values in resting condition (Fig. 1.; 2nd: $F_{(2,180)}=78.31$, $p<0.0001$; 3rd: $F_{(2,180)}=26.75$, $p<0.0001$; 4th: $F_{(2,180)}=5.94$, $p<0.005$; 5th: $F_{(2,180)}=34.92$, $p<0.0001$). In the last, 6th package, a significant ($F_{(2,180)}=135.40$, $p<0.0001$) but differential effect was observed: while fast music was associated with a significant increase of the heart rate, slow music was associated with lower values than in the control resting condition (Fig. 1.).

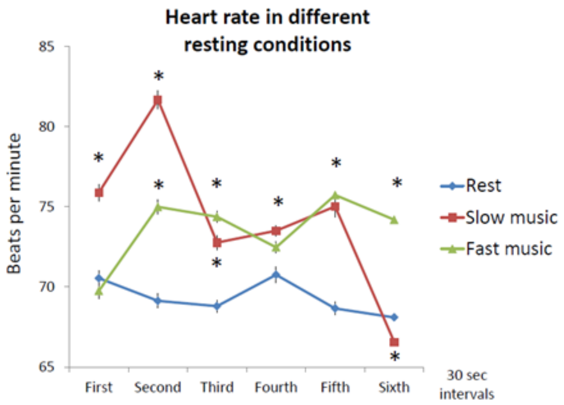


Figure 1. Heart rate data acquired with the emWave2 setup in three different conditions (averages for 30 sec, from 0.5 sec transformed data based on individual interbeat intervals). *, $p<0.05$ from the corresponding resting condition.

In the second set of data, a different type of analysis was applied. A detailed histogram shows a marked difference between resting condition and moderate physical activity (Fig. 2.). The average heart rate data for resting condition was 69.1/min, while 89.4/min for moderate physical activity. The average interbeat interval was 876.9 ms and 688.0 ms for the corresponding groups. There was a significant decrease in the interbeat interval values ($F_{(1,238)}=210.05$, $p<0.0001$) during physical activity compared to resting conditions.

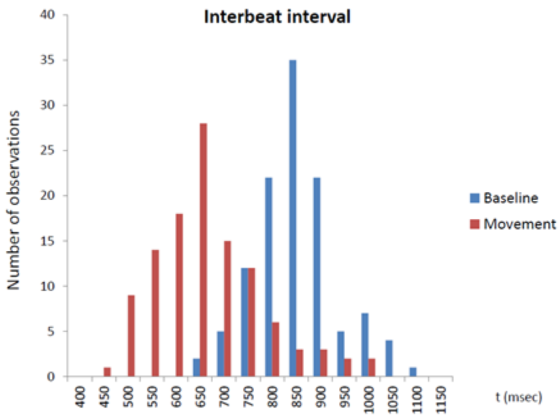


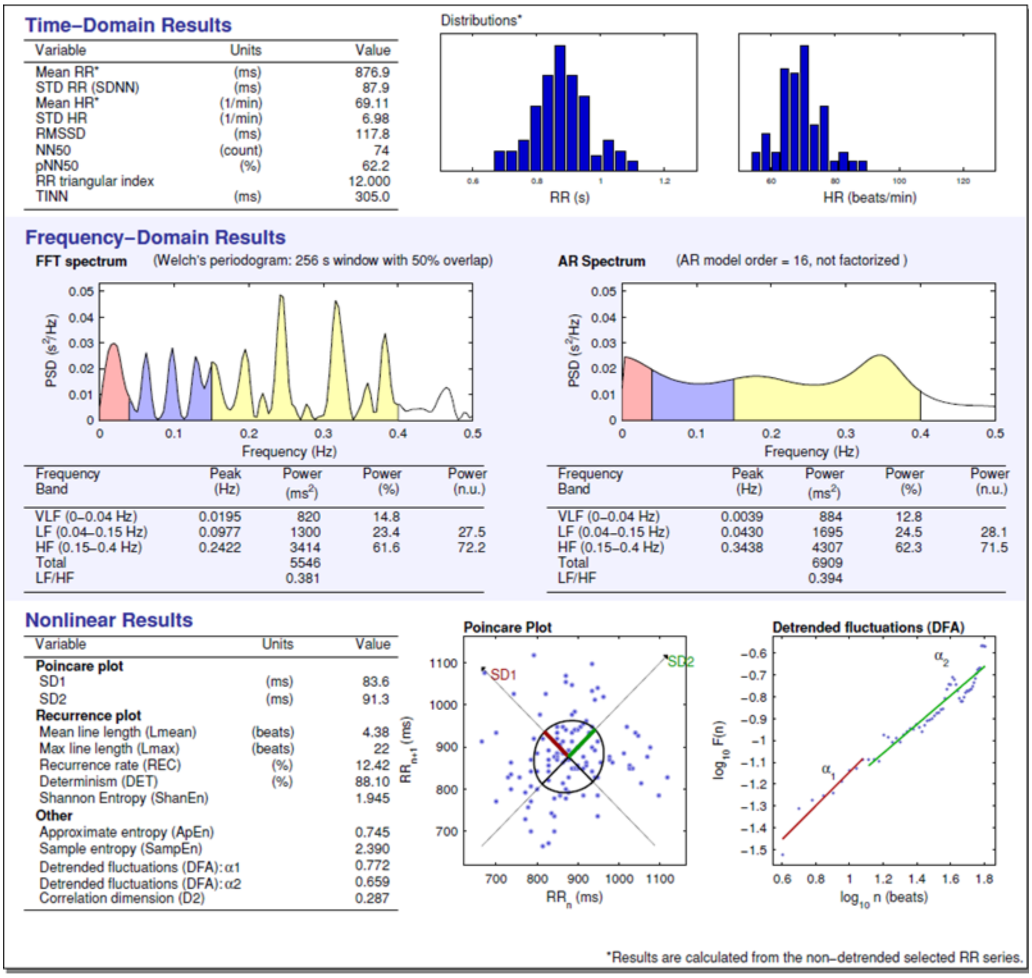
Figure 2. Interbeat interval data acquired with the emWave2 setup in two different conditions (Baseline – resting condition; Movement – mild physical activity). Interbeat interval categories were set in steps of 50 msec.

Additional to the first level analysis, an advanced analysis was also performed with the second set of data with the help of the Kubios software. Sample report pages for resting baseline conditions (Fig. 3.) and moderate physical activity (Fig. 4.) were outlined. Major differences were described between the frequency-domain spectra and in the Poincare plot.

IV. Discussion

The main results of the present case study were the followings. First, in our preliminary study, with the help of the emWave2 setup, heart rate variability measures could be reliably assessed. Second, subtle differences could be outlined in the above conditions, and these data could be used for orientation in our planned experiments in adolescents with externalization problems.

As it was mentioned in the Introduction, emWave2 is a user-friendly biofeedback instrument, what can be used in various natural conditions [7,8,12-14]. Recently, the measured improvement in coherence was not only associated with better cardiovascular parameters but also with significant increase in self-control, lower anxiety, and improved quality of life [9-14]. So far, we do not have information about the usage of the setup in



Variable	Units	Value
Mean RR*	(ms)	876.9
STD RR (SDNN)	(ms)	87.9
Mean HR*	(1/min)	69.11
STD HR	(1/min)	6.98
RMSSD	(ms)	117.8
NN50	(count)	74
pNN50	(%)	62.2
RR triangular index		12.000
TINN	(ms)	305.0

FFT spectrum:

Frequency Band	Peak (Hz)	Power (ms²)	Power (%)	Power (n.u.)
VLF (0–0.04 Hz)	0.0195	820	14.8	
LF (0.04–0.15 Hz)	0.0977	1300	23.4	27.5
HF (0.15–0.4 Hz)	0.2422	3414	61.6	72.2
Total		5546		
LF/HF		0.381		

AR Spectrum:

Frequency Band	Peak (Hz)	Power (ms²)	Power (%)	Power (n.u.)
VLF (0–0.04 Hz)	0.0039	884	12.8	
LF (0.04–0.15 Hz)	0.0430	1695	24.5	28.1
HF (0.15–0.4 Hz)	0.3438	4307	62.3	71.5
Total		6909		
LF/HF		0.394		

Variable	Units	Value
Poincare plot		
SD1	(ms)	83.6
SD2	(ms)	91.3
Recurrence plot		
Mean line length (Lmean)	(beats)	4.38
Max line length (Lmax)	(beats)	22
Recurrence rate (REC)	(%)	12.42
Determinism (DET)	(%)	88.10
Shannon Entropy (ShanEn)		1.945
Other		
Approximate entropy (ApEn)		0.745
Sample entropy (SampEn)		2.390
Detrended fluctuations (DFA): α1		0.772
Detrended fluctuations (DFA): α2		0.659
Correlation dimension (D2)		0.287

Figure 3. Time domain, frequency domain and nonlinear advanced analysis data from the Kubios software of 120 interbeat intervals in baseline resting condition (emWave2).

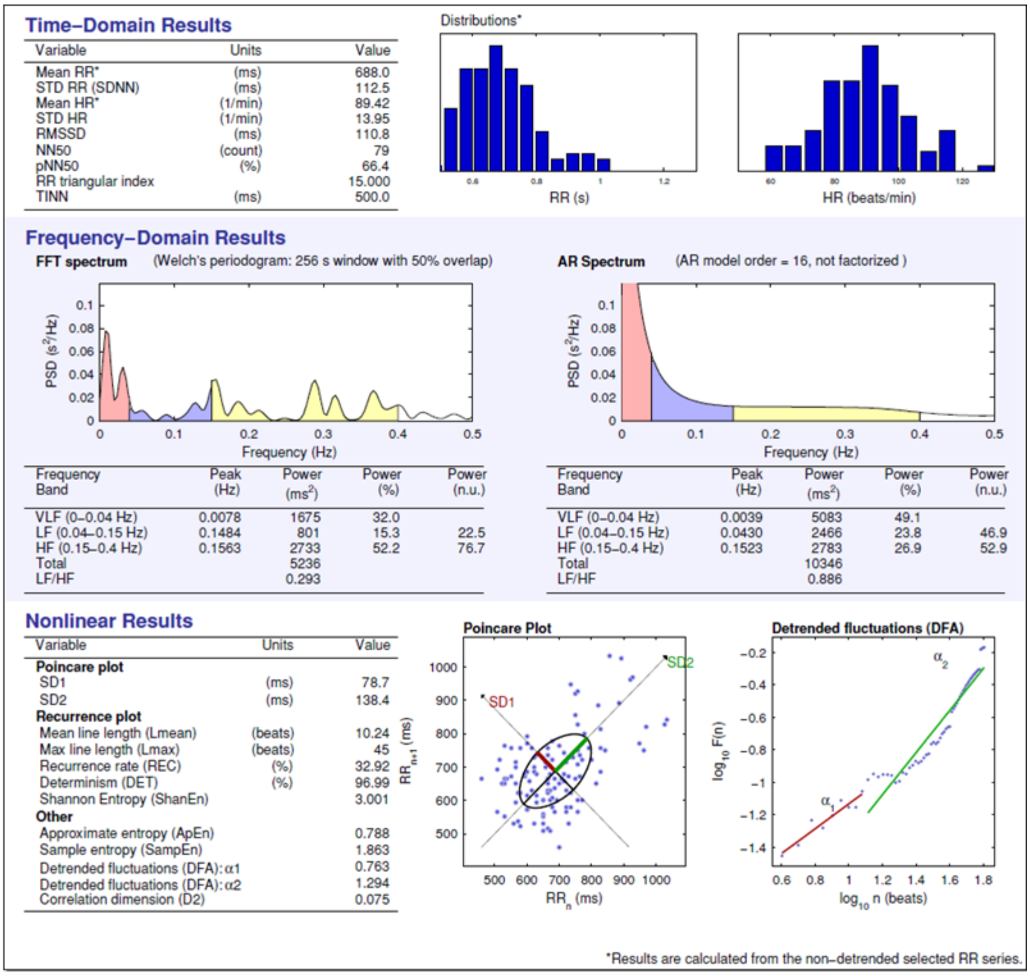


Figure 4. Time domain, frequency domain and nonlinear advanced analysis data from the Kubios software of 120 interbeat intervals during mild physical activity (emWave2).

adolescents in general or adolescent with externalization problems in particular. Nevertheless, in our preliminary case study the biofeedback effect was not used, the setup was only used for advanced data collection. As no "A" evidence exist for the successful treatment of adolescents with externalization problems [16], the future therapeutic application of a biofeedback system in anger control and improved self-management might be addressed in affected adolescents.

Heart rate related data in adolescents deliver way more message than vegetative control or stress related parameters. E.g., externalization problems might be characterized by alterations in the working of limbic brain areas, particularly the prefrontal cortex and the amygdala [17-20]. Damasio's famous intention on the relationship between the somato-vegetative and cognitive functioning based on the working of the prefrontal cortex [21] might also be taken into account. According to the somatic marker hypothesis, emotion regulation and control is highly associated with monitoring of somato-vegetative signals, thus biofeedback training in developing individuals might be especially important. As the development of the prefrontal cortex is not finished during adolescence, biofeedback setups might also be important in the "somato-vegetative training" of the prefrontal cortex in conditions where altered prefrontal functioning is associated with behavioral vulnerability [17].

In the present setting, only different levels in the analysis of heart rate and interbeat interval data were addressed. With the user-friendly emWave2 setup dynamic changes of the heart rate and oscillating spectral features easily could be assessed. Unfortunately, so far we do not have any information of child psychiatric studies targeting externalization problems in adolescents in a frame where advanced spectral and nonlinear analysis was performed in heart rate variability. Our preliminary data raise the possibility for analyzing emWave2 data with the advanced Kubios software. Detailed description of the parameters calculated within the software can be found e.g. in [5], and hopefully, behavior oriented procedures would also apply the methodology (and not just cardiology oriented research). Nevertheless, our hypotheses were fulfilled, and statistical differences could be obtained. In the first set of data, within the resting condition, rather low fluctuation in 30sec heart rate averages could be observed, while listening to slow or fast music qualitatively changed the pattern. Also, marked difference between resting and physical activity was prominent, and advanced data analysis revealed significant differences, what might be associated with cardiovascular adaptive functions.

The limitations of the study were the followings. This was a case study for preliminary data collection, thus the application of the methodology was the main question, and the design could not be compared to the size of a controlled study. Another weakness of the study that additional to the internal control of the system, external control (e.g. application of a parallel system with strict ECG record) was not applied. In future studies, these issues also have to be addressed.

V. Summary

In the present paper, a case study with preliminary data collection of heart rate variability with emWave2 portable setup was described. Numerous settings were tested, and among them, two were described in details, and corresponding data analysis with the advanced Kubios software was outlined. The present data were necessary to arrange further steps in our main research in adolescents with externalization problems, where the usage of the setup during different neuropsychological tests would create a so far unique combination in our specific area.

VI. Acknowledgment

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