

# Development and Validation of an Ambulatory HRV Measurement System

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**Introduction:** Validation of measurement accuracy and precision of an electrocardiography (ECG) based ambulatory heart rate variability (HRV) measurement system (eMotion HRV<sup>1</sup>) by Mega Electronics) were assessed in laboratory and field conditions. Also, data acquisition software for the system was developed in this work in C# for Windows. HRV can be used to assess the control of the autonomic nervous system on the heart in e.g. cardiology [1], diabetes care [2] and sports science[3].

**Methods:** The system was validated by simultaneous measurements with an MDD and FDA approved clinical ECG device. Orthostatic, bicycle ergometer and 24 h daily activity experiments were conducted on five healthy, young persons. The accuracy of QRS detection of the system was assessed with sensitivity and positive predictivity measures. Precision of measured ECG RR intervals in the laboratory experiments was assessed with histogram of RR differences and Bland-Altman analysis. The effect of the differences in RR intervals between systems was assessed by calculating a set of time domain and frequency domain HRV measures for both systems from the orthostatic experiment data. Spectrum estimation methods Welch's periodogram and stationary AR(16) model were used. Smoothness priors was implemented to detrend the data before spectrum analysis. Reliability of the system in long-term measurements was assessed with artefact ratio analysis. All analysis methods, a QRS detection algorithm and an artefact detection algorithm were implemented in Matlab.

**Results:** The sensitivity and positive predictivity in the laboratory measurements were  $s_{qrs} = 99.989\%$  and  $p_{qrs} = 99.989\%$ . The 95 % limits of agreement from Bland-Altman analysis were  $(0.591 \pm 0.962)$  ms during rest and  $(0.820 \pm 1.308)$  ms during exercise. The smallest difference between systems in HRV measures was 0.001 % and the highest 0.718 %. The artefact ratios in the 24 h daily activity measurements were 0.009 % at the lowest and 0.266 % at the highest.

**Conclusions:** The eMotion HRV system was accurate in QRS detection and the differences in measured RR intervals and calculated HRV measures were small. Thus, the performance of the system was comparable to the clinical ECG device in laboratory measurements and the precision was better than chest strap heart rate monitors [4]. The quality of data was good also in long-term measurements in field conditions.

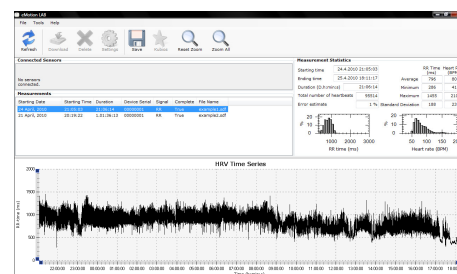


Figure 1: The graphical user interface of the developed data acquisition software.

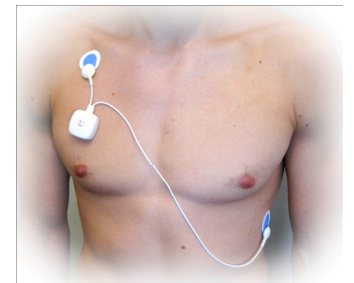


Figure 2: The HRV sensor weighs 16 g, is 35x35x15 mm in size and attaches with two disposable Ag-AgCl electrodes.

Table: Relative differences in HRV measures between systems in the orthostatic experiment.

HRV Measure	Unscaled data		Scaled data	
	Supine (%)	Standing (%)	Supine (%)	Standing (%)
RR	0.079	0.075	0.002	-0.001
HR	-0.079	-0.075	-0.002	0.001
SDNN	0.211	0.105	0.140	0.044
RMSSD	0.275	0.217	0.204	0.146
Welch $P_{LF}$	0.342	0.143	0.165	0.004
Welch $P_{HF}$	0.093	0.431	0.031	0.515
Welch $P_{LF}/P_{HF}$	0.255	-0.256	0.141	-0.485
Welch $P_{total}$	0.254	0.177	0.124	0.062
AR(16) $P_{LF}$	0.760	0.416	0.339	0.245
AR(16) $P_{HF}$	0.763	0.992	0.377	0.718
AR(16) $P_{LF}/P_{HF}$	0.008	-0.538	-0.026	-0.434
AR(16) $P_{total}$	0.720	0.408	0.322	0.168

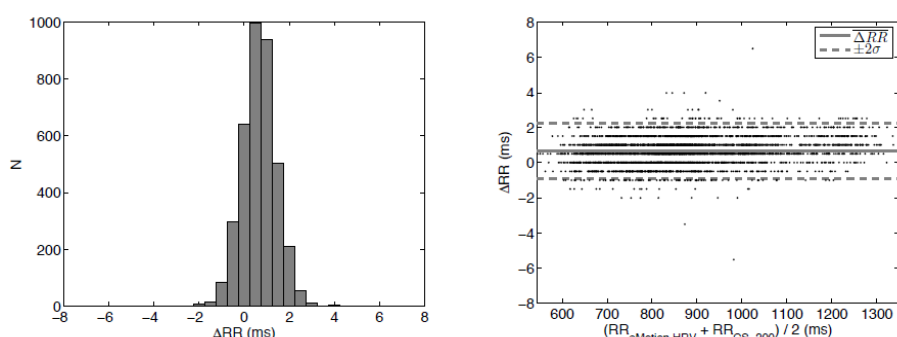


Figure 3: Histogram of differences and Bland-Altman plot for unscaled data during rest. Sampling frequency was 1 kHz for eMotion HRV and 500 Hz upsampled to 2 kHz for the comparison system.

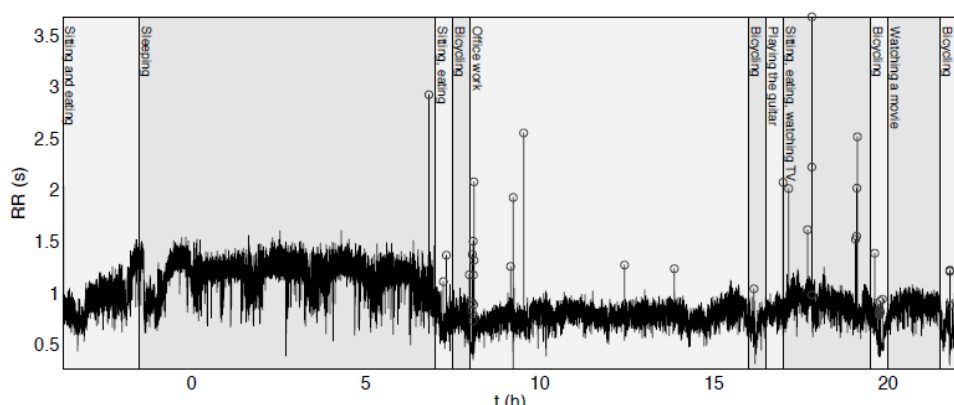


Figure 4: 24 h measurement of one subject with reported activities and detected artefacts (o) labeled.

## References:

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- [4] Weippert M, Kumar M, Kreuzfeld S, Arndt D, Rieger A & Stoll R. Comparison of three mobile devices for measuring R-R intervals and heart rate variability: Polar S810i, Suunto t6 and an ambulatory ECG system. *European Journal of Applied Physiology*, 109:779–786, 2010.

1) Also sold under the trade name Firstbeat Bodyguard.



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