Accuracy of Firstbeat Bodyguard 2 beat-to-beat heart rate monitor

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Abstract— **Firstbeat Bodyguard 2 (BG2) is a beat-to-beat heart rate monitoring device which is targeted for long-term monitoring of heart rate variability (HRV) and physical activity. Device records ECG with electrodes, processes the signal with an integrated algorithm and provides beat-to-beat R-to-R interval (RRI) as an output with 1ms resolution. We tested the accuracy of the BG2 RRI extraction against standard clinical ECG derived RRI during rest and different types of physical activity (walking, running, biking) in 19 healthy volunteers. BG2 detected on average 99.95% of the heartbeats (0.05% of beats missed) and had 0.16% extra beat detection rate, with 2.96ms (0.54%) mean absolute error (MAE) in RRI as compared to the standard ECG. When Firstbeat artifact correction was applied to the data, erroneous detections were further reduced (0.04% extra detections, 0.02% missed beats). BG2 provides accurate data for HRV analysis; RMSSD difference between BG2 and clinical ECG derived HRV was -1.30ms after the artifact correction. It can be concluded that BG2 provides an accurate method for long term HRV monitoring during daily life.**

Index Terms—**Firstbeat Bodyguard 2, RR interval, heart rate variability, accuracy**

I. INTRODUCTION

Heart rate variability (HRV) provides significant clinical information about the health status of an individual [1]. Chronic stress and effort at work are related to cardiac autonomic functions and can be examined by using HRV [2]. HRV is also related to subjective well-being [3]. For any HRV analysis, accurate and error-free RRI acquisition is critical.

The aim of this study was to evaluate the accuracy of the Firstbeat BG2 device (Firstbeat Technologies Ltd, Jyväskylä, Finland) combined with an offline beat correction algorithm by Firstbeat. The accuracy of BG2 was compared to standard clinical ECG with off-line R-wave detection.

II. METHODS

A. Subjects

Twenty-one healthy volunteers (15 males and 6 females; 31.3 ± 10.7 years old) participated in the study. All participants were nonsmokers and physically moderately active performing some type of physical activity weekly. Two subjects were excluded from the final analysis because of lost electrode contact during the recording. Therefore, nineteen subjects were included in the statistical evaluation of accuracy.

TABLE I
TESTING PROTOCOL TASKS AND DURATION

Activity	Duration [min]
Rest sitting	4:00
Lying on bed	6:00
Standing,	1:00
Walking 3km/h - 0% inclination	3:00
Walking 3km/h - 5% inclination	3:00
Walking 3km/h - 10% inclination	3:00
Walking 5km/h - 0% inclination	3:00
Walking 5km/h - 5% inclination	3:00
Walking 5km/h - 10% inclination	3:00
Running 9km/h - 0% inclination	3:00
Running 11km/h - 0% inclination	3:00
Rest sitting	6:00
Cycling 60 rpm	3:00
Cycling 90 rpm	3:00
Rest sitting	4:00

B. Testing protocol

Total testing time was 50 minutes and contained activities from rest to intensive exercise (Table 1).

C. Data acquisition

RRI were acquired with the Firstbeat BG2 wearable heart rate monitor on 1ms resolution. Two-channel reference ECG signal (256Hz) was recorded with the Embla Titanium [4]. The Embla Titanium is a multi-parameter wearable recorder designed for acquiring several biosignals including ECG. The reference device electrodes were placed according to the instructions for a 2-channel Holter measurement [5]. The BG2 and disposable electrodes were set up on a subject's body according to the instructions in the user manual. Skin was cleaned using alcohol before the placing of the electrodes. The disposable electrodes and cables were fastened with medical tape to decrease the level of possible motion artifacts.

D. Signal processing

The BG2 RRI signal was derived from the device after the recording and processed with the Firstbeat artifact correction method [6]. Both original BG2 RRI and corrected BG2 RRI were used in the analysis.

The reference ECG was analyzed with the Kubios HRV tool [7]. Visual inspection was used to select the channel with better ECG RAW signal quality for every subject. An automatic R-peak detection algorithm contained in the HRV tool was applied on the selected channel. In this procedure, QRS complexes were re-sampled at 2048 Hz with sinc-interpolation prior to R-peak detection. This approach reduces the quantization error caused by low ECG sampling rate [8].

Manual beat correction was performed to verify correct R-wave detection in the reference signal. Arrhythmias (ectopic beats) were identified by using algorithm for heart timing signals [9] and excluded from the final statistical evaluation and comparison. Before statistical evaluation the BG2 RRI and reference RRI signals were synchronized in time with 1 ms precision by applying cross-correlation function on the derivation of the signals.

RRI detection accuracy was evaluated by the number of missed beats (%), extra detections (%), mean error, and mean absolute error (MAE) between the BG2 RRI and reference RRI. Error in HRV was evaluated by calculating the difference between RMSSD derived from both signals. Calculations were done both prior and after the artifact correction.

III. RESULTS

Figures 1 and 2 show an example of the BG2 2 RRI and the reference RRI prior (Fig 1) and after (Fig 2) the artifact correction.
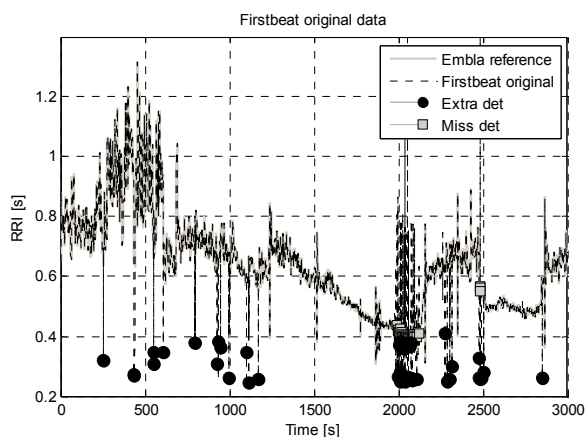

Fig. 1. Extra and missing beats detection in original recorded data.
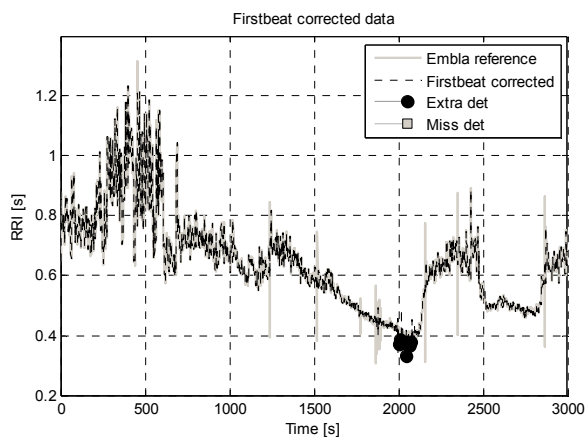

Fig. 2. Extra and missing beats detections in offline algorithm corrected data.

Table 1 contains statistical evaluation of the accuracy of the original real-time beat detected data without the artifact correction. Table 2 shows results of the detections corrected by applying the offline artifact correction algorithm.

The BG2 device correctly detected 99.95% of all heartbeats. When the artifact correction was applied, 99.98% of all heartbeats were correctly detected. MAE was 2.27% after the artifact correction, and the mean difference in RMSSD was -1.30ms. This difference may be partly related to lower sampling rate of the reference ECG signal.

IV. CONCLUSION

This study explored the accuracy of the Bodyguard 2 beat-to-beat heart rate monitor. The heart rate monitor was tested in various conditions during several tasks according to the testing scenario protocol. The results showed that BG2 is an accurate device for monitoring HRV. When applied with an artifact correction, the beat detection rate is very high and allows accurate HRV analysis in various conditions.

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TABLE II
STATISTICAL EVALUATION OF THE ORIGINAL RECORDED DATA (REAL-TIME BEAT DETECTIONS IN BODYGUARD DEVICE)

Activity	Extra beats [%]	Missing beats [%]	Mean error [ms]	Mean absolute error [ms]	Mean absolute error [%]	RMSSD error [ms]
rest	0.45	0.26	-0.70	4.31	0.67	7.99
walking	0.19	0.08	-0.30	2.81	0.47	4.44
running	0.96	1.12	1.50	10.42	2.34	20.54
cycling	0.06	0.06	0.10	2.93	0.55	7.50
global	0.37	0.30	-0.06	4.45	0.83	9.87

TABLE III
STATISTICAL EVALUATION OF THE OFFLINE CORRECTED DATA (OFFLINE ARTIFACT CORRECTION ALGORITHM IN FIRSTBEAT SPORTS SW)

Activity	Extra beats [%]	Missing beats [%]	Mean error [ms]	Mean absolute error [ms]	Mean absolute error [%]	RMSSD error [ms]
rest	0.07	0.03	-0.21	2.43	0.32	-3.18
walking	0.00	0.00	-0.02	1.79	0.26	1.38
running	0.12	0.09	-0.46	2.97	0.72	-2.48
cycling	0.00	0.00	-0.02	2.30	0.40	1.92
global	0.04	0.02	-0.16	2.27	0.38	-1.30