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original article

Accuracy of the Suunto system for heart rate variability analysis during a tilt-test

Acurácia do sistema Suunto para a análise da variabilidade da frequência cardíaca durante um teste de inclinação

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Abstract – The aim of this study was to assess the accuracy of the Suunto Memory Belt (SMB) heart rate (HR) recorder compared with that of a standard electrocardiogram system (ECG) and compared the heart rate variability (HRV) analyses conducted with each dataset. Heart rate was simultaneously recorded using ECG and SMB in fifteen participants [mean (SD) age 27.3 (13.9) years, height 177.4 (10.2) cm and body mass 66.8 (15.3) kg] during an orthostatic tilt test. The two datasets were analysed to compare the number and type of R-R interval artefacts and indices from HRV (RMSSD, pNN50, HF, LF, SD1, and SD2). For artefact detection, 16,742 R-R intervals were analysed during all recordings. Only 18 artefacts, 9 type 1 (long R-R interval) and 9 type 2 (short R-R interval), were identified with the SMB. Bland-Altman analysis indicated excellent accuracy for the SMB, with limits of agreement of -2.00 and +1.94 ms. Further, the reference and SMB systems were strongly correlated. The similarity between each device indicated that the SMB could reliably record R-R intervals.

Key words: Heart rate; Physiology; Validation studies.

Resumo – *Este estudo foi realizado com o objetivo de avaliar a precisão das medidas de Frequencia cardíaca (FC) e da variabilidade da FC (VFC) obtidas através de um cardiofrequencímetro Suunto Memory Belt, em comparação com um sistema de eletrocardiograma (ECG) de referência. Quinze participantes [média (desvio padrão), idade de 27,3 (13,9) anos, estatura de 177,4 (10,2) cm e massa corporal de 66,8 (15,3) kg] foram equipados para o registro simultâneo da FC através do ECG de referência e do cardiofrequencímetro Suunto Memory Belt durante um teste de inclinação ortostático. Os dados obtidos pelos dois sistemas foram analisados para comparar o número e tipo de artefatos dos interavalos R-R e também comparar diversos indices de VFC (RMSSD, pNN50, HF, LF, SD1 e SD2). Para todos os participantes, foram analisados 16.742 intervalos R-R e comparados entre os dois sistemas. Somente 18 artefatos foram encontrados para o Suunto Memory Belt em relação o ECG de referência: 9 foram do tipo 1 (intervalos RR longos) e 9 do tipo 2 (intervalos RR curtos). A análise de Bland-Altman mostrou excelente precisão do sistema Suunto Memory Belt com limites de concordância entre -2.00 e +1.94 ms. O sistema Suunto Memory Belt também mostrou uma forte correlação com o sistema ECG de referência. De acordo com os testes realizados, e a similaridade com o ECG de referência conclui-se que o Suunto Memory Belt é capaz de registrar de forma precisa os intervalos R-R.*

Palavras-chave: *Fisiologia; Frequência cardíaca; Estudos de validação.*

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INTRODUCTION

The variability of R-R intervals, the period between 2 successive R-peaks of the QRS complex, is the basis for calculating heart rate variability (HRV). HRV analysis is a non-invasive tool used to assess the impact of the parasympathetic and sympathetic systems on the heart. Since the studies of Sayers[1], 40 years ago, HRV has been used in sports science to prevent or detect overtraining[2-4]. The basic principle of HRV monitoring is to infer possible changes in cardiac autonomic nervous system (ANS) status with training with repeated HRV assessments over the time. ANS status can be explored via HRV assessments in various situations (at rest, awake, asleep, during or after exercise). The physiological determinants of resting HRV are related to genetics, plasma volume, autonomic activity and body position[5-8]. Moving from the supine to standing posture results in the translocation of 300-800 ml of blood from the central intravascular compartment to dependent regions in the legs, buttocks, pelvis and splanchnic circulation. This orthostatic stress evokes a sequence of compensatory cardiovascular responses to maintain homeostasis. The sympathetic nervous system, parasympathetic nervous system and baroreflex play a role in this homeostatic response[9]. Because an HRV test is very simple to perform, it can easily be used for advanced detection of an acute tiredness state or indicate an overtraining state[10].

During the last 2 decades, technological advances produced a number of portable devices that may reliably, accurately, and easily record R-R intervals. The use of HRV requires accurate measuring devices and a rigorous method of treatment and analysis as defined by the Task Force of European Society of Cardiology and the North American Society of Pacing and Electrophysiology[11]. To ensure the validity of HRV analysis, these portable devices are usually compared with traditional electrocardiogram (ECG) systems[12-13]. However, in many situations, these conditions and recommendations are not followed.

The quality of heart rate recording and subject activity during the recording may compromise the interpretation of the HRV analysis due to body motions or other external electronic or mechanical stimuli. The poor quality of the signal may in turn affect HRV parameters[14-16].

The Suunto Memory Belt (Suunto, Vantaa, Finland) is a unique simple system that enables R-R interval recording in a chest belt without transmission to a receiver. Transmission could be an element of disturbance; the distance between the emitter and transmitter and items of clothing between the two can affect the signal. Recording several people in the same area can also cause interference between nearby emitters and transmitters. The Suunto Memory Belt (SMB) does not have this limitation because the recording is made directly on the thorax with no transmission. In addition, transmission to the receiver may disturb athletes during their practice. A comparable tool has already been validated[17]. However, whether SMB can be used to accurately analyse HRV has not been confirmed. Our objective was to assess the accuracy of the SMB recorder compared with that of a standard ECG system (BioAmp, Powerlab, ADInstruments, Castell Hill, Australia) during an active orthostatic tilt-test and to verify the consistency of HRV data obtained with the SMB system during a standard test.

METHODOLOGICAL PROCEDURES

Subjects

To assess the accuracy of the SMB system, a total of 15 subjects, 13 men and 2 women [mean (SD) age 27.3 (13.9) years, height 177.4 (10.2) cm and body mass 66.8 (15.3) kg], with no known cardiovascular disease volunteered for this study. All participants took part in regular recreational sports, were in good health and were not taking any medication. We intentionally selected subjects with several anthropometrical and physical conditions to compose a heterogeneous sample to evaluate measures from the SMB and ECG in a potentially wide range of heart interval variability. Prior to testing and after receiving a full explanation concerning the nature and purpose of this study, the subjects provided written informed consent. This study was conducted in accordance with the Declaration of Helsinki[18] and approved by the Human Research Ethics Committee 'CPP EST II' (Protocol reference: 12/667).

Experimental Design

The subjects underwent an active tilt test in the laboratory. First, the subjects were equipped with two devices. Three self-adhesive ECG electrodes were placed on both clavicles and the lower left ribcage. To register R-R intervals using the SMB, an elastic belt was fixated to the chest of the volunteer at the lower end of the sternum. Then, the subjects maintained a supine position for 8 minutes on a common bed, followed by a standing position for 8 minutes. Respiratory rate was not controlled because the HRV assessment was performed simultaneously with both systems.

Data Acquisition

R-R intervals were recorded simultaneously with the following two devices.

- PowerLab: ADInstruments products are designed, manufactured and serviced under the internationally recognized ISO9001: 2008 quality management system. Powerlab is a stationary ECG system equipped by an analog-digital converter (ADC) used to digitalize all signals. The digital signals were then transferred to a PC and analysed using LabChart software (version 7) with the peak analysis module.
- Suunto Memory Belt: This belt is a sophisticated heart rate recorder. It records data on an integrated memory chip for downloading and

analysing at a later time with Kubios HRV analysis software, 2.0, for Windows (Biomedical Signal and Medical Imaging Analysis Group, Department of Applied Physics, University of Kuopio, Finland). This software is distributed free of charge upon request (http://venda.uku.fi/research/biosignal).

Data Analysis

The ECG signal was collected using LabChart 7. R-peaks were detected with a cyclic measurement using a human ECG model, and R-R intervals were exported to a Microsoft Excel spreadsheet for comparison. Recordings from the SMB were transferred to a computer and analysed with the Kubios HRV analysis software. R-R intervals were exported in the same manner as the ECG signal. Data synchronization from both devices was performed with a temporal event marker (30 sec of apnoea) prior to the supine position period, using the shorter recorded R-R interval. After synchronization, the R-R intervals recorded via the SMB were visually examined for artefacts. Artefacts were detected throughout the measurement session and differentiated according to type. The first type of artefact (A1) occurs when a beat is ~30% longer than the previous qualified interval value[19]. The second type of artefact (A2) occurs when noise is considered as a beat, resulting in 2 or more short R-R intervals (30% shorter than the previous qualified interval value).

For HRV analysis, the same recording periods of 256 beats collected with each device during supine and standing conditions were analysed.

In the time domain, we compared RMSSD (square root of the mean squared differences of successive R-R intervals) and pNN50 (proportion derived by dividing NN50 by the total number of R-R intervals, where NN50 is the number of interval differences of successive R-R intervals greater than 50 ms). In the frequency domain, low frequency (LF) was considered 0.04-0.15 Hz, and high frequency (HF) was considered 0.15-0.5 Hz. The absolute power in each of these frequencies was compared. In the nonlinear domain, we compared the SD1 and SD2 parameters.

Statistical Analysis

Each entire recording was compared with the Bland-Altman method[20], which involves plotting the discrepancy between the 2 different measurement techniques of the same signal on the y-axis against the value of the reference method (ECG R-R interval) on the x-axis. The Bland-Altman method enables calculation of the limits of agreement, including 95% of all discrepancies, according to the following formula:

$$\text{Lower limit} = M - 1.96 * SD$$
$$\text{Upper limit} = M + 1.96 * SD$$

where M is the mean and SD is the standard deviation of all differences.

Regarding HRV assessments, we used Bland-Altman plots to evaluate agreement between the results from both instruments. Additionally, we used a paired t-test to identify systematic differences in R-R intervals or HRV indices between systems. Effect size (ES), which represents the ratio of the mean difference over the pooled variance[21], was used to estimate the magnitude of the difference. As proposed by Cohen (1998), the difference was considered small when ES ≤ 0.2, moderate when ES ≤ 0.5 and large when ES > 0.8. All calculations were performed with Sigmaplot 12.0 (Systat Software Inc., Chicago, USA). Statistical significance was set at P = 0.05 for all analyses.

RESULTS

Fifteen subjects completed the entire testing procedure. For artefacts detection, 16,742 R-R intervals were analysed during all recordings. No artefacts were produced with ECG during either position. With SMB, 18 errors were identified, 9 A1 and 9 A2 errors.

The Bland-Altman comparison (Figure 1) between the R-R intervals from each device in the supine and standing positions indicated strong agreement for all individual data. During the entire recording free from artefacts (mean R-R, 842.4 ± 193.0 ms), the accuracy analysis had limits of agreement of -2.00 and 1.94 ms.

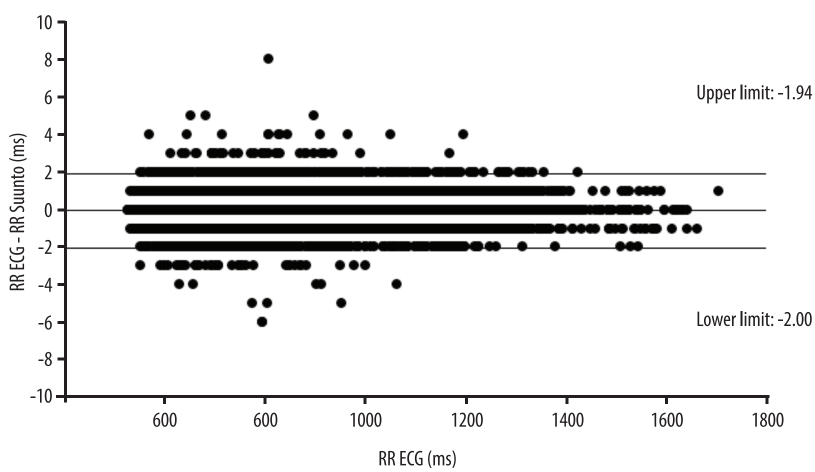

Figure 1. Bland-Altman plot to compare the means R-R intervals with SMB and ECG.

The comparisons of HRV analysis on the 256-second segments recorded in supine and standing positions with SMB and ECG are shown in Table 1. Strong correlations were observed between devices, and all Cohen coefficients were insignificant between the two datasets.

Table 1. HRV parameters obtained from the ECG and SMB signals (mean ± SD), correlation between ECG and SMB parameters, bias, magnitude of bias, and limits of agreement (LoA) in supine and standing positions.

	Parameter	ECG	SMB	Correlation	Bias	LoA	Magnitude of bias	
							Effect size	Interpretation
Supine	Mean HR SU	61.3 ± 9.4	61.3 ± 9.4	1.00	-0.0031	-0.009 to 0.003	0	Small
	RMSSD SU	86.7 ± 60.6	86.7 ± 60.6	1.00	0.0064	-0.21 to 0.22	0.00005	Small
	pNN50 SU	36.9 ± 21.9	37.1 ± 22.0	1.00	0.12	-1.14 to 1.39	0.003	Small
	LF (nu) SU	43.4 ± 26.7	43.4 ± 26.7	1.00	-0.012	-0.31 to 0.28	0.0002	Small
	HF (nu) SU	56.6 ± 26.7	56.6 ± 26.7	1.00	0.012	-0.28 to 0.31	0.0002	Small
	SD1 SU	61.5 ± 42.9	61.5 ± 42.9	1.00	0.0045	-0.15 to 0.16	0.00005	Small
	SD2 SU	119.2 ± 49.8	119.1 ± 49.7	1.00	-0.011	-0.19 to 0.16	0.0001	Small
Standing	Mean HR ST	85.0 ± 9.6	85.0 ± 9.6	1.00	-0.003	-0.009 to 0.002	0	Small
	RMSSD ST	24.6 ± 19.5	24.5 ± 19.4	1.00	-0.087	-0.35 to 0.19	0.002	Small
	pNN50 ST	6.4 ± 11.6	6.2 ± 11.6	1.00	-0.19	-0.70 to 0.33	0.008	Small
	LF (nu) ST	81.6 ± 14.0	81.8 ± 14.1	1.00	0.20	-0.43 to 0.85	0.007	Small
	HF (nu) ST	18.4 ± 14.0	18.2 ± 14.1	1.00	-0.021	-0.85 to 0.43	0.007	Small
	SD1 ST	17.4 ± 13.8	17.4 ± 13.8	1.00	-0.061	-0.25 to 0.13	0.002	Small
	SD2 ST	68.9 ± 34.5	68.9 ± 34.4	1.00	-0.070	-0.35 to 0.21	0.001	Small

Figure 2 depicts an example of the synchronised R-R interval data during the entire recording.

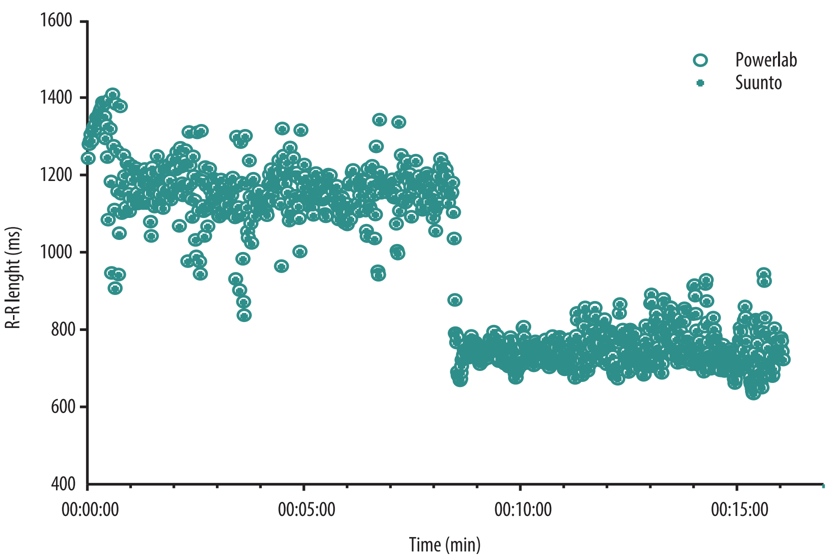

Figure 2. The graph shows synchronised R-R data measured by SMB and ECG systems for a typical subject.

DISCUSSION

This study analysed the accuracy of the SMB for measuring R-R intervals compared with an ECG signal using a stationary standard system and investigated the validity of the heart rate variability analysis using data collected with the SMB.

The SMB is technologically similar to other devices with R-R interval tachograms obtained using an R-peak detection algorithm; however, the SMB does not transmit because the data are recorded and stored in an integrated memory chip, which appears to be essential for HRV analysis because wireless transmission can increase artefact production and reduce tachogram accuracy. The error rate in detecting the R-peak for SMB compared with ECG was 0.11%, which makes it more reliable than other systems analysed in previous studies, which have reported error rates of 0.32-2.8%[22,23]. Among the eighteen total errors using SMB, 50% were A1, and 50% were A2; no artefacts were observed with ECG. Artefacts can contaminate the bio-signals related to heart rate while measuring these signals, and the R-R interval data can be missed[14-16]. The importance of R-R series editing prior to analysis is often overlooked[11]. Moreover, the presence of a single ectopic beat over a 5-min recording can modify common HRV indices up to 50%[24]. Because these differences might not reflect real changes in ANS status, proper editing of the R-R series prior to analysis is crucial.

Concerning the validity of the SMB, our results showed a strong relationship between the R-R intervals extracted from ECG signal collected with Powerlab system and the R-R intervals extracted from the SMB device. Furthermore, these results are in agreement with the literature[10, 17]. A small effect size was reported between the R-R intervals measured with both systems. Considering all R-R measured (16,742), low and high limits of agreement were -2.00 ms and +1.94 ms, respectively. The narrow confidence interval suggests that the SMB is a valid tool for measuring R-R intervals.

All parameters estimated using the SMB and ECG signals were strongly correlated ($r > 0.99$, $P < 0.05$) in each position. The magnitude of the bias was lower than 0.2 for all parameters, confirming this very slight difference[17]. We found that the SMB was a very reliable portable device able to provide many data necessary to optimize analyses. Although non-linear analyses provide quantitative information on the regularity and complexity of autonomic cardiovascular control, linear analyses are most commonly reported in the literature. Time-domain approaches are based on calculations derived from the direct measurement of R-R intervals or differences between successive R-R intervals[11]. Frequency-domain variables are based on spectral analysis of R-R intervals. Power spectral density decomposes R-R intervals into their fundamental frequency components and provides information on the distribution of power as a function of frequency. LF ranges from 0.04-0.15 Hz and reflects the aggregate influences of both sympathetic and parasympathetic branches of the ANS[25, 26]. HF ranges from 0.15-0.40 Hz and represents parasympathetic activity[26, 27]. Very low frequency (0.0033-0.04 Hz) and ultra low frequency (<0.003 Hz) are less studied and are believed to be influenced by the renin-angiotensin system, thermoregulatory processes and circadian rhythms. Methodological study designs partly guide how data are partitioned for cleaning and aggregating. Partitioning data into meaningful conditions, categories, or smaller segments due to signal quality interrupts the contiguous nature of the

ECG signal. Further, reduction of the duration of analytical epochs used to compute aggregated HRV indices across the epochs might yield different values. These decisions have important implications and must be carefully considered, especially for time-domain variables[28].

To use SMB during exercise or sport competitions, field testing sessions should be performed to ensure that laboratory results are transferable to detect thresholds and assess the impact of training load.

CONCLUSIONS

This study assessed the accuracy of the SMB HR recorder, a simple system that enables R-R interval recording without transmission to a receiver. We conclude that this tool is very accurate for assessing changes in ANS, similar to a standard ECG system. Indeed, the low percentage of artefacts, narrow LoA, very good correlation and small effect size support the use of the SMB to measure HRV in supine and standing positions. Although this study was focused on sport applications, HRV can be used in a very large population and under different conditions. Further studies are required to compare systems with no receiver and systems with a receiver in more ecological situations. Because HRV analyses depend on tachogram accuracy, using the most accurate system is necessary. Thus, comparisons between systems and under environmental conditions can provide information to improve the quality of analyses.

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