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Original Article

Validation of a Non-Transmitting Memory Belt for Measuring Heart Rate Variability

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Abstract

Purpose

Validation of a non-transmitting memory belt (NTMB) for recording RR intervals and heart rate variability (HRV) under high exercise conditions.

Methods

22 participants were tested on a bicycle ergometer (BE) and 14 on a treadmill ergometer (TE). The participants carried an NTMB (Suunto Memory Belt) as well as a mobile ECG system with wire-lead transmission (Schiller Holter MT-101). The rate of artefacts, the RR intervals and the HRV parameters were analysed.

Results

The NTMB showed no artefact at all, the Holter ECG had a low artefact rate of only 0.9%-1.6%. The mean difference of the RR intervals was 1.53±25.64 ms (BE) and 3.32±32.71 ms (TE) with a high degree of correlation (r=0.903-0.959) and a limit of agreement of -48.72 to 51.78 ms respective -60.79 to 67.43 ms. Comparison of both systems' results showed differences in the HRV parameters.

Conclusions

This study confirms that an NTMB is suitable for recording RR intervals and the heart rate but not for HRV under high exercise conditions. A high degree of conformity with the Holter ECG system was revealed. Therefore, the NTMB is an acceptable alternative for use in scientific field trials if the Holter ECG or other heart rate monitors cannot be used.

Keywords: Heart rate determination; laboratory study; physical activity; ergometer; RR intervals

Abbreviations:

BE: Bicycle Ergometer

BMI: Body Mass Index

HF: High Frequency

HRM: Heart Rate Monitor

HRV: Heart Rate Variability

ICC: Intraclass Correlations

LF: Low Frequency

NTMB: Non-Transmitting Memory Belt

RMSSD: Root Mean Square of Successive Differences of NN Intervals

SDNN: Standard deviation of NN intervals

TE: Treadmill Ergometer

VLF: Very Low Frequency

Introduction

Measuring physical activity is an established method for assessing physical strain. A correlation between cardiac output per minute and respiratory minute volume and the heart rate is known [1]. Therefore, the latter measurement is also suitable to determine the individual load of physical activity [2,3], f.e. during work.

The Holter ECG system with its wire-lead data transmission has been established as the gold standard for measuring the heart rate [4]. In the last decade, an increasing number of heart rate monitors (HRM) have come into use which measure the heart rate via a chest belt and after wireless transmission store the data in a separate device, most commonly a wristwatch [1]. Modern memory chip systems have made smaller both systems and enable more detailed measurements [5]. Like the Holter monitor, modern HRMs record the time between two heartbeats (the beat-to-beat interval or RR interval) in a high sampling rate (e.g. 1000 Hz). So both measuring systems are also suitable to analyse the heart rate variability (HRV) by feeding the RR intervals into separate HRV analysis software [6]. Several validation studies have demonstrated a high degree of correlation of heart rate measurements by the HRM and Holter ECG systems; in most of the studies HRMs from Polar® (Finland) were in the focus of validation [7-17].

A disadvantage of most HRMs is the artefact rate due to electronic interference when close to electric cables [18] and inside vehicles [19]. Under such conditions, a non-transmitting memory belt without a separate watch to record the data constitutes an alternative. Such a system (Suunto Memory Belt, Suunto, Finland) was already validated under resting conditions and showed lower artefact rates in vehicles compared to other HRMs [19,20]. In fact, the recording methods of the Suunto Memory Belt and the chest belt of the Suunto T6c (an HRM with chest belt and wristwatch) are similar, and the Suunto T6c was already validated also for HRV analysis under resting and moderate dynamic exercise conditions [17]. It is not known to which extent the good results can also be transferred to high exercise conditions.

The aim of this study is to compare the chest belt system of the Suunto Memory Belt with a Holter ECG system with regard to measuring the RR interval (and therefore the heart rate) and to analysing HRV under laboratory and high exercise conditions (bicycle and treadmill ergometer).

Material and Methods

In an experimental laboratory examination volunteers carried simultaneously a wire-lead transmission system (Holter ECG, Schiller MT-101, Schiller Medizintechnik GmbH, Germany [ECG]) and a non-transmitting memory belt (Suunto Memory Belt, Suunto, Finland [NTMB]) under exercise conditions in the Sport Medicine Institute of the German Armed Forces, Warendorf, Germany. The volunteers took part in a sport medicine examination at the Sport Medicine Institute and carried on volunteer basis the two devices in additional to the normal examination instruments during the test. So, the persons took part in an ergometer test or a treadmill test in dependence if there are planned for a treadmill examination or a bicycle examination.

Exclusion parameters were the use of medication regulating the heart rate (e.g. beta blockers), known arrhythmia, status after myocardial infarction, coronary heart disease, manifest hypo- or hyperthyroidism, diabetes mellitus or pregnancy. Prior to the test, a 12-channel ECG was taken to diagnose an unknown arrhythmia.

The volunteers performed under one of the following conditions:

(i) Testing on a bicycle ergometer (Ergoline Ergometrics 900, Bitz, Germany), beginning at 50, 80 or 100 watt, increasing by 30 or 50 watt every 3 minutes depending on individual physical capabilities up to one of the termination criteria;

(ii) Testing on a treadmill ergometer (Woodway® ELG 70, Weil am Rhein, Germany), beginning individually at 6 or 8 km/hour, increasing by 2 km/hour every 3 minutes up to one of the termination criteria. After each step, measurement of vital parameters was taken during a 30 seconds interval rest.

Termination criteria were: (a) muscular exhaustion, (b) pathological ECG (e.g. ST-elevation or new arrhythmia), (c) systolic blood pressure over 250 mm Hg or (d) circulatory trouble or dizziness.

The data of the ECG and the NTMB were transferred via USB-cable to a personal computer and analysed using the Schiller MT 200 Software (Version 2.54, monec 1.78r, 1996 - 2007, Schiller, Germany) and the Suunto Training Manager (Version 2.3.0.15, Suunto Oy, Finland), respectively. The RR intervals from both systems were manually synchronized: the data used for analyses started with the beginning of the exercise and finished after a maximum of 3 min under resting conditions after completion of the test. RR intervals with a deviation of more than 30% compared with the average of the previous five RR intervals were marked as artefacts and replaced by the average of the previous five RR intervals [7,21]. The ratio of artefacts and the difference between ECG and NTMB in the RR intervals and in the HRV parameters in terms of time and frequency (SDNN, rmSSD, VLF, LF, HF and LF/HF-Ratio) were analysed (with Kubios HRV, Version 2.0, University of Kuopio, Finland [6].

All parameters are listed with mean and standard deviations (mean ± SD). Correlations were calculated by means of the Spearman formula and the limit of agreement were calculated [22]. The significance level was set to $p < 0.05$. Statistical calculations were made using IBM SPSS Statistic 21.

The ethic committee of the University of Magdeburg, Germany and of the medical association of Westfalen-Lippe, Münster, Germany, approved the study. All volunteers signed an informed consent before starting the test.

Results

Altogether 36 volunteers participated in this study. 22 were examined on the bicycle ergometer (20 men, 2 women, average age 39.0 ± 12.5 years [range 20.8 - 73.0 years], average Body Mass Index (BMI) 25.7 ± 3.9 kg/m^2 [range 21.6 - 38.4 kg/m^2], total power 294.6 ± 62.4 watt on average [range 150 - 400 watt]). 14 were examined on the treadmill ergometer (13 men, 1 woman, average age 36.6 ± 6.8 years [range 27.8 - 49.6 years], average BMI 24.6 ± 2.5 kg/m^2 [range 21.6 - 30.7 kg/m^2], maximum running speed 15.9 ± 1,2 km/hour on average [range 13.7 - 17.3 km/hour]). All persons finished the ergometer because of muscular exhaustion. The ECG showed little artefacts (0.9 - 1.6 % of all RR intervals), the NTMB showed no artefacts at all (table 1).

Table 1: Numbers of identified artefacts for the Holter ECG (ECG) and for the Suunto Memory Belt (NTMB) for cycling and treadmill ergometry for the phase of load (ergometry), for the time in recovery and in total in percent.

	Cycling ergometer			Treadmill ergometer		
	N of RR intervals	ECG	NTMB	N of RR intervals	ECG	NTMB
Ergometry	64 447	0.9%	0.0%	37 408	1.7%	0.0%
Recovery	8 006	1.1%	0.0%	3 883	0.7%	0.0%
Total	74 453	0.9%	0.0%	41 291	1.6%	0.0%

During cycling ergometry, the RR intervals of NTMB and ECG were highly correlated ($r = 0.959$, $p < 0.001$) and showed small limit of agreement (-48.72 to 51.78 ms, Figure 1). There was no correlation between the NTMB- and ECG-measured HRV parameters SDNN, rmSSD, HF and LF/HF-Ratio. VLF and LF were correlated, but the most HRV parameters showed high limit of agreement (Table 2).

Table 2: Average (Mean) and standard deviations (SD) between measurement with EKG and NTBM of RR intervals and HRV parameters with correlation after Spearman (r), level of significance (p) and limit of agreement after Bland and Altman (LoA) during cycling ergometry.

Cycling	n	mean ± SD	r (p)	LoA
RR	74 453	1.53 ± 25.64	0.959 (p < 0.001)	-48.72 to 51.78
SDNN	22	11.32 ± 10.88	0.163 (p = 0.468)	-10.00 to 32.64
rmSSD	22	17.51 ± 11.51	0.073 (p = 0.747)	-5,05 to 40.07
VLF	22	47.57 ± 143.72	0.526 **(p = 0.012)**	-234.12 to 329.26
LF	22	177.36 ± 432.57	0.561 **(p = 0.007)**	-670.48 to 1025.20
HF	22	78.28 ± 156.08	0.155 (p = 0.490)	-227.64 to 384.20
LF/HF-Ratio	22	-3.17 ± 3.10	0.315 (p = 0.154)	-2.91 to 9.25

During treadmill ergometry, only the RR intervals were highly correlated ($r = 0.903$, $p < 0.001$, -60.79 to 67.43 ms, Figure 2), the HRV parameter were not significantly correlated but showed also high limit of agreement (Table 3).

Table 3: Average (Mean) and standard deviations (SD) between measurement with EKG and NTBM of RR intervals and HRV parameters with correlation after Spearman (r), level of significance (p) and limit of agreement after Bland and Altman (LoA) during treadmill ergometry.

Running	n	mean ± SD	r (p)	LoA
RR	41 291	3.32 ± 32.71	0.903 ($p < 0.001$)	-60.79 to 67.43
SDNN	14	15.82 ± 8.25	0.046 ($p = 0.876$)	0.35 to 31.99
rmSSD	14	24.61 ± 9.14	-0.112 ($p = 0.703$)	-6.70 to 42.52
VLF	14	23.80 ± 38.15	0.174 ($p = 0.553$)	-50.97 to 98.57
LF	14	177.21 ± 258.47	0.218 ($p = 0.455$)	-329.39 to 683.81
HF	14	118.51 ± 143.57	-0.033 ($p= 0.911$)	-162.89 to 399.91
LF/HF-Ratio	14	-3.20 ± 2.59	0.042 ($p = 0.887$)	-1.88 to 8.28

Both measurements showed great differences between the RR intervals of ECG and NTMB, when high heart rate and low RR intervals was shown (Figure 1 and 2). An example for the comparison of the RR intervals during resting conditions and during high exercise load is given in Figure 3.

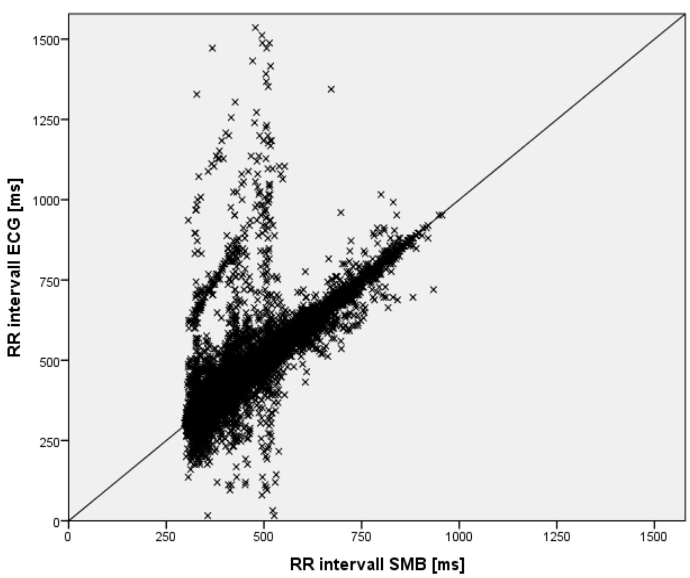

Figure 1. Scatterplot of the RR intervals in comparison of the ECG and the NTMB for cycling ergometry, 22 persons with in total n = 74 081 RR intervals.

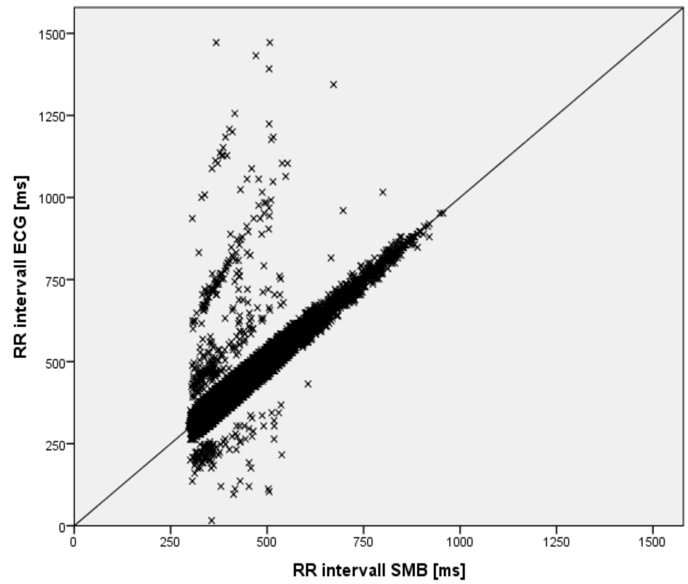

Figure 2. Scatterplot of the RR intervals in comparison of the ECG and the NTMB for treadmill ergometry, 14 persons with in total n = 41 291 RR intervals

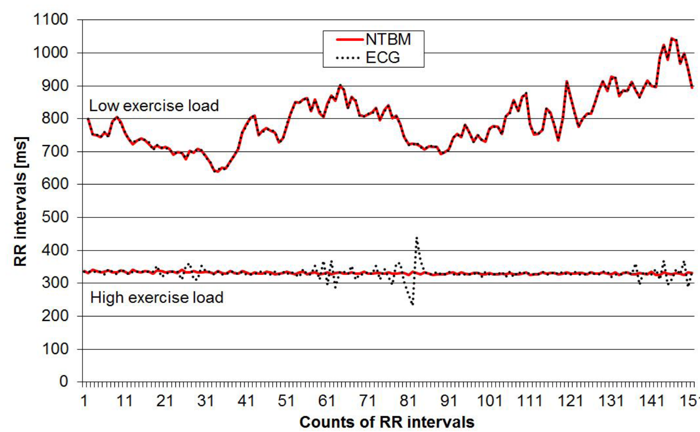

Figure 3. Example of 150 RR intervals during low and high exercise conditions, red line describes the RR intervals measured with the NTMB and the black points the RR intervals measured with the ECG

Discussion

A non-transmitting, wireless chest-belt system like the Suunto Memory Belt is suitable for measuring the heart rate and not useable for calculating heart rate variability during high-intensity exercise. Comparison of RR intervals measured by means of the NTMB and the Holter ECG as the gold standard showed a high degree of correlation.

The number of artefacts in both systems (NTMB and ECG) was low (0.0 - 1.6%). Particularly the NTMB showed no artefacts in the manual artefact correction (30% deviation compared with the moving average [7,21]. This may possibly be due to the automatic artefact correction of the Suunto Software (Suunto Training Manager, Version 2.3.0.15) which cannot be disabled. The ECG showed more artefacts during treadmill ergometer as during cycling ergometer. Especially artefacts caused by muscular activity and by the effects of the electrical conduit may be the reasons for the artefact rate of the ECG. This induces short RR intervals, which can be seen in Figures 1 and 2, and directly affects HRV analysis. This may also be the reason for non-correlation of the HRV parameters between the ECG and the NTMB.

The NTMB showed lower RR intervals with a high correlation (r = 0.903 - 0.959) and only a small limit of agreement (-48.72 to 51.78 ms). Similar validation studies with HRM showed correlations in the measurement of RR intervals of 0.927 - 0.998 [7-13,16] and intraclass correlations (ICC) of 0.996 – 0.996 [11,17] for the HRM Polar® S810. Also for older and newer HRMs (Polar Advantage, Polar RS800 and Suunto T6) high correlation and ICC were shown in comparison to ECG as a gold standard for measuring the heart rate and RR intervals [14,17,23,24]. All of these studies examined the comparison under resting or moderate dynamic exercise conditions. The high correlation of RR intervals between measuring methods was similar compared to previous studies of HRM. This could be shown for this special device (a wireless memory belt) and under high exercise conditions.

We can only speculate on the reason for the weak correlation of the HRV parameters obtained by the different measurement systems. Studies with HRM systems described good correlations under resting conditions (SDNN: r=0.886 - 0.999, ICC 0.87 - 0.97; rmSSD: r=0.822 - 0.999, ICC 0.88 - 0.94) [8,9,11,12,13,24,25] or light physical load [15]. Studies are rare with conditions with sub-maximum load [16] or exertion until total muscular exhaustion [10,14]. It could be shown that the correlation between the measurements of the Holter ECG and an HRM (Polar® S810) depend on the load: the higher the individual load the poorer the correlation of the measurements [10,14]. The physical activity could lead to an impairment in detection quality and thus to the low correlation of HRV parameters in this study. Also the different positions of electrodes and different detection algorithms of the ECG and NTMB may be a potential reason for the stronger bias under high load. The artefact rate of the ECG with the result that more than 1% of the RR intervals become shorter or longer may be another reason for the low correlation of the HRV parameters between the ECG and the NTMB.

Conclusions

Altogether, the high degree of correlation for RR intervals measured with the NTMB as compared to the gold standard Holter ECG underline the possibility of using the NTMB for measuring RR intervals and also the heart rate. The results of this study correspond well with published validation studies under resting conditions [19,20]. The analysis of the heart rate variability parameters showed insufficient correlation between the NTMB and the Holter ECG.

Especially in settings where the cable of a Holter ECG could disturb the experimentee, or where it is impossible to use a Holter ECG (e.g. under water) or an HRM (e.g. inside vehicles or near electric cables), using a chest belt system like the NTMB is a good alternative for measuring the heart rate.

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