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Validity of a Heart Rate Monitor for Heart Rate Variability Analysis During an Orthostatic Challenge

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ABSTRACT

International Journal of Exercise Science 17(2): 810-818, 2024. Heart rate variability (HRV) is used as a measure of autonomic nervous system (ANS) function and is based on heart rate (HR) beat-to-beat time interval variance analysis. Various techniques are used for recording HR, however, few studies have compared Holter-type recordings vs HR monitors (HRM) during an orthostatic challenge. OBJECTIVES: Compare HRV measures from an electrocardiogram (ECG) Holter and a HRM as a tool for investigating ANS response for post-concussion rehabilitation follow-up. METHODS: Twenty-seven participants (n = 27; 15 females, 12 males), 18 to 35 years old, non-smoking, no history of cardiac illness and physically active (3 times per week, 60 mins, moderate intensity exercise) participated in the study. ECG signals and HRM were recorded beat-to-beat (R-R) simultaneously. A motorized tilt table was set at 0 degree for supine and 85 degrees for standing position. Participants were instructed to remain for 7 minutes in each position. R-R signals from both Holter and Polar HRM recording starting points were matched before further analysis. Bland-Altman plots were used to compare recordings from the Holter (gold standard) and the Polar HRM in both positions. Unpaired t-test was used to compare measurements obtained with both systems. Significance was set at $p < 0.05$. RESULTS: No significant differences were observed between R-R measurements taken with both systems under equal conditions (supine and standing). Same variables under similar conditions were significantly correlated ($p = 0.0001$). CONCLUSION: Both recording and analysis systems (Holter vs HRM) yielded comparable results. Thus, both systems appear valid and interchangeable for HRV analysis for measuring orthostatic challenge HRV responses.

KEY WORDS: HRV, Polar, Holter, ECG, RR comparison, tilt test

INTRODUCTION

In 1995 came to market the first watch-chest strap based wearable device for beat-to-beat measurement for Heart Rate Variability analysis (HRV) (15). Since then, the robustness of heart rate monitor (HRM) technology has been compared to many other different technologies and conditions in numerous studies (6, 10, 17, 19-21). The beat-to-beat measurement, also called R-R recording in reference to the time between normal successive R waves has grown in interest especially in the autonomic nervous system (ANS) field of research.

In 1996, R-R measurement evaluation and analysis have been standardized by the The European Society of Cardiology and The North American Society of Pacing and Electrophysiology giving guidelines to physiological interpretation and clinical use of HRV data (8). Under standardized conditions, HRV analysis is used to assess the state of the ANS and its subdivisions of the parasympathetic (PNS) and sympathetic (SNS) branches (5, 7, 22). As well, long-term recordings (> 18 hours) of heart rate (HR) appear more suitable for analysis of time domain HRV parameters, while short-term recordings (5minutes) appear more suitable for frequency domain HRV parameters (8). Nonetheless, within-subject designs have now been strongly recommended to limit differences versus between-subject study and thus, decrease external factors influencing HRV parameters (14). The interest in understanding PNS and SNS regulation using HRV analysis, since its inception, has raised over the years where short-term recordings have been used in different situations, such as cardiac morbidity, work stress, diabetes, and many other areas too numerous to mention here.

The use of the orthostatic tilt test, also called the head-up tilt test, has been one of the gold standard method used in many studies to measure ANS response sensitivity (1, 9, 16, 27). Nonetheless, the establishment of a gold standard tool for HRV analysis and orthostatic response in a specific controlled environment on the ANS has brought considerable challenges (12, 27). Furthermore, in physically active individuals the ANS response to an orthostatic challenge using specific controlled parameters have not been tested to the best of our knowledge. Moreover, it is worth noting that physically active individuals also benefit from attenuating autonomic impairments, highlighting the importance of cardiovascular system health to investigate the ANS (23). As well, it has been recently reported that ECG recordings may not be the best suitable recorder for monitoring physical activity, thus limiting the role of Holter-type devices as a gold standard (10). Thus, the purpose of this study was to compare ECG Holter-type signals to a HRM for HRV analysis. The specific objective was to compare R-R intervals recorded with a Holter-type device (ECG) and a HRM using short term recordings whilst undergoing an orthostatic challenge.

METHODS

Participants
In this study, twenty-seven participants (n = 27) including 15 females and 12 males volunteered. Approval (No. 2204_e_2021) for this study was granted by Université du Québec à Montréal ethics CIEREH (Comité Institutionnel d'Éthique de Recherche avec des Êtres Humains) committee as well as aligning ethical policies of the International Journal of Exercise Science (18). Participants had to be between 18 to 35 years old non-smokers, no history of cardiac illness and physically active as per American College of Sports Medicine guidelines, i.e., 30 minutes per day, five days per week of moderate intensity exercise or 20 minutes per day, three days per week of vigorous intensity (11). Participants who had a history of cardiac illness and/or persistent concussion symptoms (PCS) were excluded from the study. Also, smokers and participants who were prescribed one of the following medications; cardio protectants, antidepressants, benzodiazepine, antihypertensors; were not admissible to this study.

Protocol

The study took place at the concussion interdisciplinary clinic at the Institute of National Sports in Quebec (INS Quebec, https://www.insquebec.org/en/), Montreal, Quebec, Canada (6). A consent form was read and explained before taking part in the study. Participants visited the CIC for approximately 45 minutes. The first 10 minutes were to explain the consent form and the test procedure with the possible implications of postural orthostatic tachycardia syndrome (POTS) and its symptoms (i.e.: light headedness, dizziness, nausea, loss of consciousness, increased heart beats, cold sweats, etc.) (4). The following 10 minutes were used to instrument the participant with cardiac monitors prior to the orthostatic challenge (explained below in detail). As for acclimation control, participants remained in a seated position for 20 minutes prior to the orthostatic challenge.

Participants were fitted with a HRM chest strap (H10, V800, Polar, Fi) and a Holter portable ECG data logger (Medilog AR12plus, Schiller, CH, and its proprietary software,) in a 12-lead standard configuration. The placement of the electrodes did not interfere with the HRM chest strap. Both HR systems sampled data continuously at a sampling rate of 1000Hz. Prior to the installation of the HR monitors, the skin of the participants was cleaned and shaved (if necessary), for proper electrodes reading. The HRM chest strap was moistened to assure reliable electrode reading for heart beats. Both recording systems were synchronized for recording simultaneously the heart beats during the entire duration of data collection (approximately 15 mins).

The heartbeat recordings gathered with the HRM were analysed with a commercially scientifically validated software (Kubios HRV Premium analysis software, Kupio, Fi) (25). The ECG signals recorded with the Holter were analysed with the proprietary software of the maker (Darwin2, Schiller, CH). Two short cycles of 5 minutes were isolated from the heartbeat recordings in each position (supine and standing) in order to obtain the beat-to-beat (R-R) intervals for subsequent HRV temporal and spectral domains analysis (5, 8).

Temporal domain variables included mean HR (average heart rate expressed as b.p.m.), mean RR (average of beat-to-beat time interval expressed in ms), SDNN (standard deviation of the average beat-to-beat intervals expressed in ms), RMSSD (root mean square of differences of successive beat-to-beat intervals expressed in ms) and pNN50 (percentage of differences between adjacent beat-to-beat intervals over 50ms) (2, 8). These variables inform on the importance of heart rate variability at rest, strongly correlated with HRV measures within short cycles of 5 minutes analysis to evaluate ANS functions (8).

The spectral domain for the purpose of this study included three variables: very low frequency (VLF, ≤ 0.04 Hz), low frequency (LF, 0.04-0.15 Hz) and high frequency (HF, 0.15-0.4 Hz) (5, 8). Briefly, these variables are calculated using Fast-Fourier Transformation (FFT) to measure ANS activity (3, 5, 8, 13). Another variable calculated is the ratio of low frequency and high frequency, also called LF/HF ratio.
A clinical room closed by a double door for noise reduction with controlled environment (humidity: 40%, temperature: 20.6 ± 1.0 °C) was used to assess the orthostatic challenge. No high frequency electronics (i.e.: microwave, neon lighting) were present in the room to avoid frequency interference with the HR measuring apparatuses. A motorized tilt table (Tri W-G inc.

TG2724) was set at 0 degree for supine and 85 degrees for standing position. Participants were instructed to remain for 7 mins in each position; supine and standing. The breathing rate was not controlled, and the participants were instructed to breath as normally as possible during the test. A time stamp was taken on the ECG system at the beginning of the recording and around the 8th minute when the table was completely tilted up. As well, a time stamp was applied when recordings of both systems (Holter and HRM) were stopped at the end of the standing segment. After minute 7 in the standing position, participants were asked how they felt in case of discomfort or intolerance to the test before stepping down and asked to sit down on a chair to remove instrumentation.

The HRM data stored in the recording device (V800, Polar, Fi) was downloaded into the manufacturer cloud system (PolarFlow web service, Fi). A space delimited text file was then opened in the commercially available software (Kubios Premium, version 3.4, Fi., department of physics, Kuopio University) for HRV analysis (24, 26). The RR interval data recorded in the Holter ECG apparatus (Schiller's, CH) was extracted using the proprietary software provided by the ECG manufacturer (Darwin2, Schiller Medilog) for HRV analysis.

HRV parameters were derived from a 300 sec segment (5 minutes) for each condition (supine and standing) and in accordance to the standard analysis Task Force for ANS functions. To synchronize recording of both apparatuses, the last 5 minutes segment was taken for the standing position spaced by 4 minutes before taking another 5 minutes segment from supine position.

Statistical Analysis

RR signals from both Holter and HRM from intrasubject recordings starting point were matched before further analysis. Analysis was performed for obtaining beat-to-beat RR intervals (ms) measurements in both positions (supine and standing). Bland-Altman plots for both supine and standing positions were used to illustrate the differences in recording interval between the Holter and HRM as a function of the mean measurement of the devices. Unpaired *t*-tests were used to compare measurements of time and spectral domain variables obtained from both software systems (Kubios vs Darwin2). Statistical analysis was performed with IBM-SPSS (Ver 24, Montreal, Qc, Canada). Statistical significant difference was set at $P < 0.05$ for analysis.

RESULTS

The comparison between Holter RR and HRM RR did not indicate a significant difference for both supine and standing (Table 1). As well, no significant differences were observed for HR (supine and standing).

Table 1. HRV variables compared to Holter and HRM means and percentage of difference.

Variables	Holter mean (n = 27)	HRM mean (n = 27)	% difference	Sig.
Heart rate supine (bpm)	62.8 (8.01)	62.7 (8.11)	0.16	.601
Heart rate standing (bpm)	82.9 (9.71)	83.0 (9.79)	0.12	.625
RR supine (ms)	971.0 (126.56)	972.6 (129.4)	0.16	.524

RR standing (ms)	732.8 (82.22)	732.5 (83.58)	0.04	.785
SDNN supine (ms)	57.6 (26.88)	61.9 (25.54)	6.95	.007
SDNN standing (ms)	44.9 (19.21)	48.9 (19.65)	8.18	.003
RMSSD supine (ms)	51.8 (28.11)	53.0 (30.88)	2.26	.197
RMSSD standing (ms)	24.1 (13.18)	24.3 (13.2)	0.82	.462
pNN50 supine (%)	29.0 (22.07)	28.5 (21.91)	1.75	.137
pNN50 standing (%)	6.3 (8.7)	6.0 (8.41)	5.00	.063
LF power supine (ms^2)	558.8 (574.48)	1323.0 (1315.13)	57.76	.000
LF power standing (ms^2)	559.5 (694.95)	1177.5 (920.9)	52.48	.000
HF power supine (ms^2)	537.2 (582.4)	1395.7 (1402.85)	61.51	.000
HF power standing (ms^2)	151.8 (224.98)	323.6 (365.71)	53.09	.001
Total power supine (ms^2)	1510.5 (1506.14)	4153.0 (2969)	63.63	.000
Total power standing (ms^2)	1078.9 (1329.37)	2711.8 (2664.17)	60.21	.000
LF % supine (%)	37.6 (13.86)	32.3 (17.35)	16.41	.005
LF % standing (%)	53.3 (12.39)	45.9 (12.44)	16.12	.000
HF % supine (%)	36.1 (18.23)	31.5 (19.13)	14.60	.003
HF % standing (%)	15.4 (8.58)	11.7 (8.62)	31.62	.033
Ratio LF/HF supine	1.9 (1.93)	2.0 (2.28)	5.00	.261
Ratio LF/HF standing	6.2 (4.83)	6.2 (4.54)	0.00	.902

Values are means (SD); % difference: relative difference between Holter and Polar; Sig.: *p* values.

The Bland-Altman plots are presented in Fig. 1.A and 1.C for supine and standing measurements illustrating the difference between Holter and HRM RR intervals (ms). As shown, the LoA is of -1.60 ms in the supine position (95% CI: LL: -6.67; UL: 3.48) and of 0.32 ms in the standing position (95% CI: LL: -2.10; UL: 2.75). As indicated, previously, this difference was not statistically significant (Table 1). As well, the regression for Mean RR intervals between the Holter and HRM (Fig. 1.B and 1.D) was significant for the supine condition indicating a slope equal to one ($r = 0.995$, $p = 0.0001$, Slope = 1.018, SSE = 12.89 ms) and similarly for the standing position with a slope equal to one ($r = 0.997$, $p = 0.0001$, Slope = 1.014, SSE = 6.15 ms).

The percentage difference between mean results from Holter and HRM are shown in Table 1. The percent difference for HR and RR mean measures were, respectively, for supine similar, 0.16% and 0.16%, while for the standing position it was 0.12% and 0.04%. The other variables having a 5% difference and lower for both conditions are RMSSD (2.26%; 0.82%), pNN50 (1.75%; 5.00%) and LF/HF ratio (5.00%; 0.00%). However, SDNN between Holter and HRM was significantly different as well as frequency domain variables except LF/HF ratio.

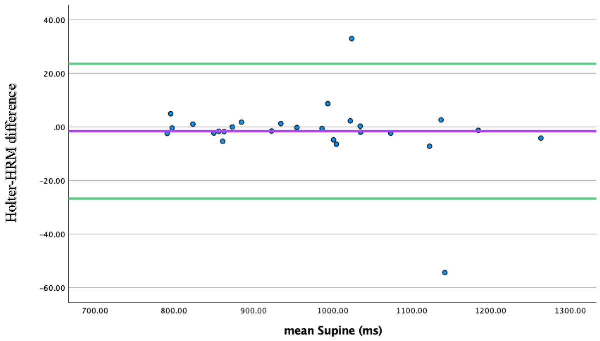

Figure 1.A. Bland-Altman plots for Supine position differences and means between Holter ECG and Polar HRM. Green lines represent confidence interval (CI 95%) and purple middle line represent level of agreement (LOA).

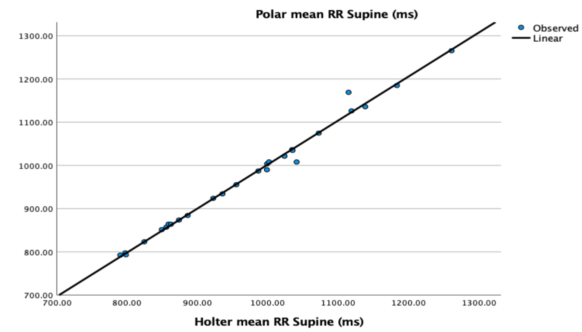

Figure 1.B. Mean RR intervals correlation (r^2 = 0.995, p = 0.0001, Slope = 1.018, SSE = 12.89 ms) from Supine position with both ECG and HRM.

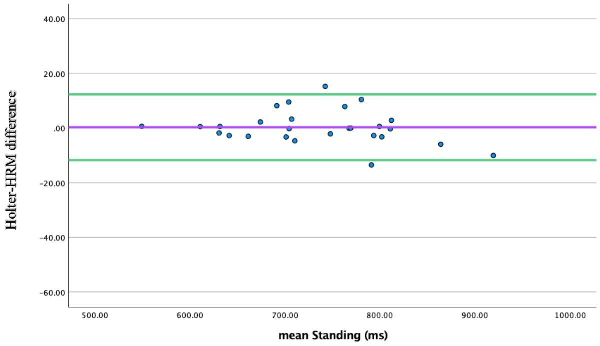

Figure 1.C. Bland-Altman plots for Standing position differences and means between Holter ECG and Polar HRM. Green lines represent confidence interval (CI 95%) and purple middle line represent level of agreement (LOA).

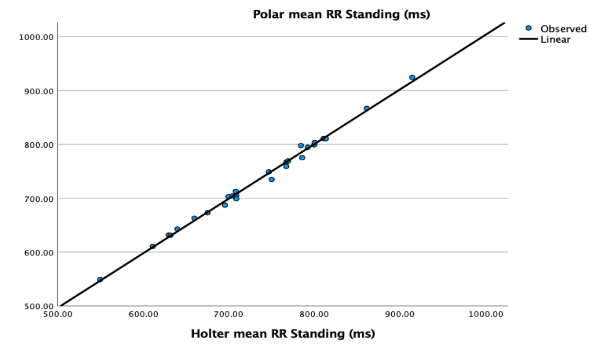

Figure 1.D. Mean RR intervals correlation (r^2 = 0.997, p = 0.0001, Slope = 1.014, SSE = 6.15 ms) from Standing position with both ECG and HRM.

Figure 1. Bland-Altman plots and correlations of mean RR data in supine and standing conditions.

DISCUSSION

The novel aspect of the current study is using an orthostatic challenge to compare two devices for HRV analysis. In this study, data from HRM (H10, Polar, Fi) and Holter-type ECG (Schiller, Medilog) were compared through two different software (Kubios Premium, Darwin2 Medilog) for HRV analysis. The main finding is that RR interval (ms) recordings using the orthostatic challenge yielded comparable results with both systems of heart rate recording and software analysis (Kubios vs Darwin2) similar to Gilgen-Ammann and Giles et al. (9, 10). These authors, however, did not perform an orthostatic challenge with a tilt table as in the current study. The validity of a HRM recording, as the one used in this study for recording RR intervals is an easier and more accessible way to measure HRV functions in physically active population and sports settings when compared to Holter-type ECG devices using multiple lead configurations (3 to 12-lead configuration), also supported by Gilgen-Ammann (10). Furthermore, methodological setups for proper data collection have been followed and supported by Zygmunt, Cygankiewicz and Task Force (5, 8, 27).

In the present study, it is shown that most time domain variables (HR, RR, RMSSD, pNN50) are not significantly different between both software systems, suggesting that the algorithms for analysis yield similar results as found in Giles et al., work (9). In the spectral domain, however, significant differences were observed (LF, HF, TP). In absolute values, the spectral variables reported using one software were considerably larger (Darwin2, Medilog) when compared to the other software (Kubios Premium). However, for the LF/HF ratio variable, the percentage of difference as shown in Table 1 was similar for both conditions (supine and standing) and showed no significant differences. Nonetheless, the lack of difference for the LF/HF ratio obtained with both software's is interesting since spectral domain calculation algorithms expressed in absolute units appears to be different for both proprietary software's (Darwin2 Medilog and Kubios Premium, respectively). Thus, most of the time domain variables and the LF/HF ratio are interchangeable between both systems and should not mislead users for clinical interpretation.

The main limitation encountered was comparing both RR interval recordings using the same software. The Holter's product (Schiller, Medilog) inaccessibility to export raw data has limited the comparison between both systems. Nevertheless, RR interval recordings from Holter and HRM are the primary data and have not been transformed or filtered besides small artefact corrections. In fact, the RR intervals is the most important component for doing ANS analysis. Although sex differences were observed in HRV measures, it is important to note that this research did not confine itself to this aspect, as all data were measured within-subject.

Conclusion: In light of the present results, equally similar data measured with the Holter ECG and a HRM (Polar H10), suggests that the latter system is found to be a valid tool for detecting RR intervals during an orthostatic test. Respecting the CI of 95% and narrow LoA for RR intervals (ms) for both positions of the orthostatic test, the Polar H10 HRM has shown a robust validity when compared with the gold standard measure Holter ECG 12-lead.

In addition, Holter's proprietary software (Schiller mediLog, Darwin2) inaccessibility to raw data (for clinical use it's fine, but not for the type of research herein) makes further HRV parameter comparisons difficult as it cannot import data from other devices (ex., Polar H10) or export its own unfiltered data. This limits further comparisons and bounds this study to only RR interval detection data.

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