RESEARCH ARTICLE

Validation of the Polar RS800CX for assessing heart rate variability during rest, moderate cycling and post-exercise recovery [version 1; peer review: 2 approved with reservations]

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Abstract

Background: Heart rate variability (HRV) is an autonomic nervous system marker that provides reliable information for both disease prevention and diagnosis; it is also used in sport settings. We examined the validity of the Polar RS800CX heart rate monitor during rest, moderate cycling, and recovery in considering the total of 24 HRV indices.

Method: A total of 32 healthy males (age=24.78±6.87 years, body mass index=24.48±3.13 kg/m²) completed a session comprised by three 20-minute time periods of resting, cycling at 60% of maximal heart rate, and recovery using a Polar RS800CX and an electrocardiogram (ECG) monitors. The HRV indices included time-domain, frequency-domain, Poincaré plot and recurrence plot. Bland-Altman plot analysis was used to estimate agreement between Polar RS800CX and ECG.

Results: We detected significant associations ($r > 0.75$, $p < 0.05$) in all HRV indices, while five out of 24 HRV indices displayed significant mean differences ($p < 0.05$) between Polar RS800CX and ECG during the resting period. However, for the exercise and recovery periods, we found significant mean differences ($p < 0.05$) in 16/24 and 22/24 HRV indices between the two monitors, respectively.

Conclusion: It is concluded that Polar RS800CX is a valid tool for monitoring HRV in individuals at resting conditions, but it displays inconsistency when used during exercise at 60% of maximal heart rate and recovery periods.

Keywords

Heart Rate, HR, HRV, Polar RS800CX, Electrocardiogram, ECG

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Introduction

Variations in successive heart rate (HR) and RR intervals [the peak of the Q, R, and S waves of the electrocardiogram (ECG)] simultaneously are described as heart rate variability (HRV), which is the conventionally accepted term to portray variations of RR intervals¹. HRV is an autonomous nervous system (ANS) marker that may provide reliable information for both disease prevention and diagnosis^{2,3}, while it is frequently applied to sport settings^{4,5}. Furthermore, HRV can be used as a tool to identify physiological^{6,7} and psychological^{8,9} disorders, while it has been utilised for diagnosis in both clinical¹⁰ and non-clinical studies¹¹.

Regarding sport settings, HRV is primarily utilized to determine training loads^{12–14} and endurance training adaptation^{15,16}. The wide use of HRV in both clinical and basic research as a diagnostic criterion has resulted in increased production of HRV-related equipment and software. Reference gold standard such as Power Lab (AD Instruments, Australia) and Reynolds Pathfinder program (Reynolds Medical Limited, United Kingdom) were developed and used extensively when compared with other HR monitors (i.e. Polar)¹⁷. However, most of these innovations present disadvantages, such as difficulty of access and high cost¹⁸. To address these issues, more practical and cost-effective HRV tools were developed. The Polar RS800CX HR monitor (Polar Electro, Finland) was presented^{19–21} as a valid HR monitor for HRV analysis during rest and stress conditions (e.g. exercise). To date, however, the wide spectrum of HRV indices (i.e. time and frequency domain, Poincaré and recurrence plot) has not been tested for validation in the Polar RS800CX. Also, the performance of Polar RS800CX in post-stress conditions has not been extensively investigated to date. Therefore, the purpose of this study was to assess the validity of Polar RS800CX in a large spectrum of HRV indices by comparing it with results gained using an ECG monitor during rest, exercise (cycling) and recovery.

Methods

Volunteers and experimental protocol

An informed written consent form was signed by and obtained from 32 apparently healthy males [age: 24.78±6.87, body mass index (BMI): 24.48±3.13 kg/m²] with no history of respiratory, metabolic, or cardiovascular conditions. Participants were recruited via flyers from the university population and the local community in Trikala, Thessaly, Greece between June and November 2012. Participants who responded to our flyer advertisement were then interviewed to determine eligibility and they were informed of all experimental procedures, associated risks, and discomforts, before providing written informed consent. The sample size was a sample of convenience. We included only male participants to avoid discomfort for females due to potential menstrual cycle. Ethical approval was obtained from the Ethics Review Board of the University of Thessaly (Protocol no. 469).

All participants visited the Environmental Physiology Laboratory in the Department of Exercise Science only once; they were instructed to refrain from food, caffeine and strenuous exercise 12 hours prior to the visit. Participants arrived at the physiology

laboratory between 7–8 am and they were subject to height (cm) and weight (kg) measurements via a Seca 220 (Hamburg, Germany) device. Subsequently, both a Polar RS800CX (Polar Electro Oy, Kempele, Finland) and a 12-lead ECG (Welch Allyn, CardioPerfect, New York, USA) monitors were adjusted to participants who then remained in a supine position on a comfortable bed and rested for 20 minutes in a quiet room at thermo-neutral conditions (22–24°C and 40–60% relative humidity). Immediately after the 20 minutes of resting, participants performed an aerobic exercise session on a cycle-ergometer (Monark, Ergonomic) at 60% of their maximum HR for 20 minutes. The maximum HR was calculated using Karvonen's formula²²: $[(220 - \text{age}) - \text{resting HR}] \times 0.60 + \text{resting HR}$. At the end of the exercise period, the participants rested in a supine position for another 20 minutes for the post-exercise recovery period. To avoid any displacement, an investigator continuously checked the position of both the chest belt of the Polar RS800CX and the electrodes of the ECG, throughout the experiment. Data were collected throughout the experimental trial using both a Polar RS800CX and an ECG, as previously described^{23,24}. For the Polar RS800CX the data downloaded and saved in a text format via **Polar ProTrainer 5** software, while the ECG data were collected via the Welch Allyn, **CardioPerfect Workstation 1.6.6** software.

Analysis of heart rate variability indices

The raw data of the RR intervals of both the Polar RS800CX and the ECG were analysed using Premium Kubios HRV Analysis Software v1.1 (Biomedical Signal Analysis Group, University of Kuopio, Finland 2002). The retrieved HRV indices covered the time domain, frequency domain, Poincaré plot and recurrence plot indices (**Table 1–Table 3**).

Statistical analyses

Normal distribution was checked via Shapiro-Wilk test. Due to non-normal distribution, a two-step transformation was used to normalise all HRV variables, given that the Bland–Altman method requires normally distributed data²⁵. Pearson's correlation coefficient was employed to assess the associations and paired-sample t-tests to calculate the mean differences of HRV indices between the Polar RS800CX and the ECG during rest, exercise and recovery. The Bland–Altman plots and the 95% limits of agreement (95%LoA) were used to calculate agreement for all HRV indices during rest, exercise and recovery. We also calculated effect sizes between the Polar RS800CX and the ECG via the Cohen's *D* pooled effect size analysis for each HRV index during rest, exercise and recovery. We estimated the error rate of Mean RR intervals during rest, cycling and recovery, with the following equation: $[(\text{Mean RR ECG} - \text{Mean RR RS800CX}) / \text{Mean RR ECG}] \times 100$. Missing data were removed from the analysis, given that they were missing at random. The statistical analysis was completed using IBM SPSS v24 and the level of significance was set at $p < 0.05$.

Results

The results of the Pearson correlation coefficient, paired-sample t-tests, 95%LoA and Cohen's *D* pooled effect size analyses appear in **Table 1** for the resting period, **Table 2** for the

Table 1. Heart rate variability indices during the resting period. Values for ECG and RS800CX presented as mean $\pm$ standard deviation.

Variable	ECG [‡]	RS800CX [‡]	Correlation	Bias	LoA	Effect size
Time domain						
Mean RR (ms)	947.2 $\pm$ 151.6	944.9 $\pm$ 140.4	0.91*	2.2	-118.08–122.6	0.02
STDRR (ms)	85.2 $\pm$ 24.2	81.2 $\pm$ 28.04	0.92*	4.02	-18.06–26.1	0.15
Mean HR [1/min]	63.9 $\pm$ 19.5	66.7 $\pm$ 17.5	0.89*	-2.7	-20.4–14.8	0.15
STDHR [1/min]	6.1 $\pm$ 4.3	6.3 $\pm$ 2.9	0.89*	-0.3	-4.7–4.01	0.04
RMSSD (ms)	76.5 $\pm$ 32.2	67.5 $\pm$ 27.4	0.86*	7.1#	-24.4–38.7	0.29 (small)
NN50 [beats]	210.9 $\pm$ 88.6	200.9 $\pm$ 89.4	0.95*	4.9	-49.5–59.4	0.11
pNN50 (%)	35.1 $\pm$ 14.4	33.6 $\pm$ 15.3	0.92*	0.6	-11.07–12.4	0.10
HRV triangular	17.1 $\pm$ 4.2	17 $\pm$ 5.08	0.92*	0.2	-3.7–4.2	0.02
TINN [ms]	228.9 $\pm$ 244.4	238.2 $\pm$ 187.8	0.79*	-9.2	-304.7–286.1	0.04
Frequency domain						
LF (ms ²)	55.3 $\pm$ 14.9	55.7 $\pm$ 15.3	0.86*	-0.4	-16.2–15.3	0.03
HF (ms ²)	44.5 $\pm$ 14.5	43 $\pm$ 14.2	0.82*	0.5	-16.2–17.3	0.10
LF/HF [-]	1.7 $\pm$ 2.3	0.07 $\pm$ 4.8	0.85*	1.8#	-4.2–7.8	0.45 (small)
Poincaré plot						
SD1 [ms]	54.7 $\pm$ 21.3	48.9 $\pm$ 20.05	0.93*	4.5#	-10.7–19.9	0.28 (small)
SD2 [ms]	106.2 $\pm$ 26.9	100.8 $\pm$ 30.9	0.92*	5.4#	-18.9–29.8	0.19
SamplEn [-]	1.4 $\pm$ 0.3	1.4 $\pm$ 0.3	0.92*	0.03	-0.2–0.2	0.11
ApEn [-]	1.2 $\pm$ 0.2	1.2 $\pm$ 0.2	0.94*	0.03#	-0.1–0.2	0.13
DFA_a1 [-]	1.0 $\pm$ 0.2	1.0 $\pm$ 0.2	0.86*	0.01	-0.2–0.2	0.06
DFA_a2 [-]	0.9 $\pm$ 0.1	0.9 $\pm$ 0.1	0.80*	0.0004	-0.2–0.2	0.00
Recurrence plot						
Lmin [beats]	14.3 $\pm$ 34.3	16.1 $\pm$ 40.02	0.88*	-1.8	-38.7–35.1	0.05
Lmax [beats]	279.2 $\pm$ 201.3	297.8 $\pm$ 205.7	0.93*	-18.6	-172.7–135.5	0.09
REC [%]	34.7 $\pm$ 9.0	34.3 $\pm$ 9.2	0.75*	0.4	-12.3–13.1	0.05
DET [%]	97.7 $\pm$ 0.8	97.8 $\pm$ 0.7	0.86*	-0.09	-0.9–0.7	0.12
ShanEn [-]	3.3 $\pm$ 0.4	3.3 $\pm$ 0.5	0.87*	-0.04	-0.5–0.4	0.09
D2 [-]	2.8 $\pm$ 1.0	2.6 $\pm$ 1.1	0.78*	0.1	-1.2–1.6	0.14

*Significant association between ECG and Polar RS800 CX. #Significant mean differences between ECG and Polar RS800 CX. ‡n=32. ECG, electrocardiogram; MeanRR [ms], standard deviation of all RR intervals; STDRR [ms], standard deviation of normal to normal R-R intervals; MeanHR [1/min], The mean heart rate; STDHR [1/min], Standard deviation of instantaneous heart rate values; RMSSD [ms], root mean square of differences; pNN50, proportion of differences between adjacent NN intervals of more than 50ms; NN50 [beats], number of NN intervals that differ more than 50 ms; HRV triangular index [-], The integral of the RR interval histogram divided by the height of the histogram; TINN [ms], Baseline width of the RR interval histogram; LF (ms²), low frequency; HF (ms²), high frequency; LF/HF [-], Ratio LF [ms²]/HF [ms²]; SD1 [ms], represents the dispersion of the points along the line of identity and is thought to be an index of the instantaneous beat-to-beat variability of the data; SD2 [ms], represents the dispersion of the points along the line of identity and is thought to represent the slow variability of heart rate; SamplEn [-], complexity of NN series; ApEn, approximate entropy of the complexity or irregularity of the signal; DFA, Detrended fluctuation analysis of the correlation within the HRV signal divided into short-term and long-term fluctuations; Lmin (beats), mean line length; Lmax (beats), maximum line length; REC [%], recurrence rate; DET [%], determinism; ShanEn [-], shannon entropy consider the lengths of the diagonal lines; D2 [-], correlation dimension.

exercise period and **Table 3** for the recovery period. **Dataset 1** contains all raw data obtained using both measurement methods²⁶. The Bland–Altman plots for the resting, exercise and recovery periods, can be found in **Supplementary File 1**. Missing values were removed from the analysis and the final number of participants for each HRV index appears in **Table 1**

for the resting period, **Table 2** for the exercise period and **Table 3** for the recovery period.

During the resting period, Polar RS800CX showed significant correlations ($r>0.75$, $p<0.05$) with the ECG in all studied HRV indices. We found one time domain (RMSSD), one frequency

Table 2. Heart rate variability parameters during the exercise period. Values for ECG and Polar RS 800CX presented as mean $\pm$ standard deviation.

Variable	ECG [‡]	RS800CX [‡]	Correlation	Bias	LoA	Effect size
Time domain						
Mean RR (ms)	552.2 $\pm$ 15.8	749.5 $\pm$ 88.2	0.05	-197.2 [#]	-547.4–153	1.51 (large)
STDRR(ms)	41.9 $\pm$ 27.4, n=31	107.6 $\pm$ 25.8	-0.42 [*]	-65.6 [#]	-153.8–22.4	2.48 (large)
Mean HR [1/min]	117.3 $\pm$ 14.6, n=31	92.5 $\pm$ 10.8	0.24	24.7 [#]	-6.6–56.1	1.91 (large)
STDHR [1/min]	11.2 $\pm$ 2.9, n=31	12.2 $\pm$ 2.7	0.27	-0.9	-7.7–5.7	0.34 (small)
RMSSD (ms)	12.2 $\pm$ 27.3, n=31	48.2 $\pm$ 23.6	0.32	-35.9 [#]	-94.2–22.2	1.39 (large)
NN50 [beats]	19.4 $\pm$ 78.1, n=31	132.3 $\pm$ 75.8	0.22	-112.9 [#]	-301.37to 75.5	1.40 (large)
pNN50 (%)	-0.08 $\pm$ 12.2, n=31	20.6 $\pm$ 12.7	0.24	-20.7 [#]	-50.7–9.3	1.64 (large)
HRV triangular	7.3 $\pm$ 3.9, n=31	14.8 $\pm$ 3.8	0.30	-7.4 [#]	-16.5–1.5	1.92 (large)
TINN[ms]	356.1 $\pm$ 311.9, n=31	455.2 $\pm$ 130.2	0.23	-99.1	-703.8–505.5	0.40 (small)
Frequency domain						
LF(ms ²)	64.2 $\pm$ 12.8, n=31	64.4 $\pm$ 10.4	-0.07	-0.1	-33.7–33.3	0.07
HF (ms ²)	35.2 $\pm$ 13.9, n=31	34.9 $\pm$ 10.6	0.09	0.2	-32.5–32.9	0.01
LF/HF[-]	3.2 $\pm$ 1.7, n=31	3.7 $\pm$ 3.5	0.24	-0.4	-7.5–6.5	0.24 (small)
Poincaré plot						
SD1[ms]	8.3 $\pm$ 18.8, n=31	34.4 $\pm$ 17.1	0.34	-26.06 [#]	-66.7–14.6	1.42 (large)
SD2[ms]	57.6 $\pm$ 36.3, n=31	149 $\pm$ 34.2	-0.31	-91.3 [#]	-203.4–20.7	2.61 (large)
SamplEn [-]	0.8 $\pm$ 0.2, n=31	0.7 $\pm$ 0.3	0.56 [*]	0.02	-0.5–0.6	0.11
ApEn[-]	0.8 $\pm$ 0.1, n=31	0.7 $\pm$ 0.2	0.65 [*]	0.09 [#]	-0.2–0.4	0.48 (small)
DFA_a1[-]	0.9 $\pm$ 0.2, n=31	1.1 $\pm$ 0.1	0.08	-0.2 [#]	-0.8–0.3	1.18 (large)
DFA_a2[-]	0.9 $\pm$ 0.1, n=31	1.0 $\pm$ 0.1	0.55 [*]	-0.1 [#]	-0.4–0.2	0.64 (moderate)
Recurrence plot						
Lmin [beats]	61.7 $\pm$ 19.9, n=31	66.8 $\pm$ 25.7	0.51 [*]	-5.02	-50.5–40.4	0.23 (small)
Lmax [beats]	691.2 $\pm$ 254.4, n=31	614.5 $\pm$ 147.6	0.30	76.7	-418.3–571.8	0.35 (small)
REC [%]	49.9 $\pm$ 7.5, n=31	47.6 $\pm$ 8.5	-0.12	2.2	-21.3–25.8	0.23 (small)
DET [%]	99.6 $\pm$ 0.8, n=31	99.1 $\pm$ 0.9	0.47 [*]	0.4 [#]	-1.3–2.3	0.53 (moderate)
ShanEn[-]	4.2 $\pm$ 0.3, n=31	4.1 $\pm$ 0.4	0.31	0.08	-0.8–1.06	0.06
D2[-]	0.7 $\pm$ 0.6, n=31	1.8 $\pm$ 0.5	-0.06	-1.1 [#]	-2.9–0.7	1.73 (large)

*Significant association between ECG and Polar RS800 CX. # Significant mean differences between ECG and Polar RS800 CX. ‡n=32 unless indicated. ECG, electrocardiogram; MeanRR [ms], standard deviation of all RR intervals; STDRR [ms], standard deviation of normal to normal R-R intervals; MeanHR [1/min], The mean heart rate; STDHR [1/min], Standard deviation of instantaneous heart rate values; RMSSD [ms], root mean square of differences; pNN50, proportion of differences between adjacent NN intervals of more than 50ms; NN50 [beats], number of NN intervals that differ more than 50 ms; HRV triangular index [-], The integral of the RR interval histogram divided by the height of the histogram; TINN [ms], Baseline width of the RR interval histogram; LF (ms²), low frequency; HF (ms²), high frequency; LF/HF [-], Ratio LF [ms²]/HF [ms²]; SD1 [ms], represents the dispersion of the points along the line of identity and is thought to be an index of the instantaneous beat-to-beat variability of the data; SD2 [ms], represents the dispersion of the points along the line of identity and is thought to represent the slow variability of heart rate; SamplEn [-], complexity of NN series; ApEn, approximate entropy of the complexity or irregularity of the signal; DFA, Detrended fluctuation analysis of the correlation within the HRV signal divided into short-term and long-term fluctuations; Lmin (beats), mean line length; Lmax (beats), maximum line length; REC [%], recurrence rate; DET [%], determinism; ShanEn [-], shannon entropy consider the lengths of the diagonal lines; D2 [-], correlation dimension.

domain (LF/HF) and three Poincaré plot (SD1, SD2, ApEn) HRV indices, to show significant mean differences ($p<0.05$) between Polar RS800CX and the ECG. Also, one time domain (RMSSD), one frequency domain (LF/HF) and one Poincaré plot (SD1) HRV indices showed small effect sizes (0.28–0.45) between the Polar RS800CX and the ECG (Table 1). Finally,

during rest, the error rate of Mean RR intervals obtained from Polar RS800CX and the ECG, was 0.3%.

In the exercise period, one time domain (STDRR) ($r=0.42$, $p<0.05$), three Poincaré plot [SamplEn ($r=0.56$, $p<0.05$), ApEn ($r=0.65$, $p<0.05$), DFAa2 ($r=0.55$, $p<0.05$)] and two recurrence

Table 3. Heart rate variability indices during the recovery period. Values for ECG and Polar RS 800CX presented as mean $\pm$ standard deviation, n=number of cases.

Variable	ECG*	RS800CX	Correlation	Bias	LoA	Effect size
Time domain						
Mean RR (ms)	807 $\pm$ 87.08	512 $\pm$ 112.2, n=27	0.36	294.6#	70.7–518.5	2.41 (large)
STDRR (ms)	72.7 $\pm$ 21.5	56.8 $\pm$ 28.5, n=27	0.02	15.9#	-53.2–85.1	0.57 (moderate)
Mean HR [1/min]	81.5 $\pm$ 10.4	121.8 $\pm$ 13.9, n=27	0.29	-40.2#	-69.3–11.1	2.99 (large)
STDHR [1/min]	6.7 $\pm$ 3.9	11.1 $\pm$ 4.7, n=27	-0.20	-4.4#	-17.6–8.8	0.68 (moderate)
RMSSD (ms)	53.2 $\pm$ 30.6	2 $\pm$ 20.1, n=27	0.39*	51.1#	-6.06–108.4	1.31 (large)
NN50 [beats]	136.6 $\pm$ 100.4	-1.9 $\pm$ 61.5, n=27	0.38	138.6#	-48.8–326.1	1.20 (large)
pNN50 (%)	23.4 $\pm$ 18.3	-0.5 $\pm$ 12.3, n=27	0.59*	23.9#	-4.9–52.9	1.19 (large)
HRV triangular	14.1 $\pm$ 4.2	6.2 $\pm$ 3.6, n=27	0.31	7.9#	-1.1–17	1.63 (large)
TINN [ms]	380.6 $\pm$ 180.2	285.5 $\pm$ 283.7, n=27	0.36	95.04	-444.4–634.5	0.44 (small)
Frequency domain						
LF (ms ²)	65.7 $\pm$ 16.2	78.9 $\pm$ 12.9, n=27	0.20	-13.2#	-49.7–23.3	0.80 (large)
HF (ms ²)	34.7 $\pm$ 15.7	21.3 $\pm$ 12.2, n=27	0.22	13.4#	-21.1–47.9	0.87 (large)
LF/HF [-]	2.8 $\pm$ 2	8.3 $\pm$ 4.4, n=27	0.13	-5.4#	-14.4–3.6	1.57 (large)
Poincaré plot						
SD1 [ms]	37.6 $\pm$ 22.8	2.4 $\pm$ 15.4, n=28	0.17	35.1#	-14.3–84.7	1.30 (large)
SD2 [ms]	94.4 $\pm$ 26.3	80 $\pm$ 40.03, n=27	0.01	14.4	-78.6–107.6	0.42 (small)
SamplEn [-]	1.2 $\pm$ 0.3	0.6 $\pm$ 0.3, n=27	0.21	0.6#	-0.1–1.4	1.40 (large)
ApEn [-]	1.1 $\pm$ 0.2	0.6 $\pm$ 0.2, n=27	0.15	0.4#	-0.1–1.03	1.42 (large)
DFA_a1 [-]	1.1 $\pm$ 0.2	1.3 $\pm$ 0.2, n=27	0.22	-0.1#	-0.7–0.3	0.56 (moderate)
DFA_a2 [-]	0.8 $\pm$ 0.1	1.1 $\pm$ 0.1, n=27	0.29	-0.2#	-0.6–0.1	1.31 (large)
Recurrence plot						
Lmin [beats]	19.8 $\pm$ 25.05	70.8 $\pm$ 29.8, n=27	0.41*	-50.9#	-109.8–7.9	1.35 (large)
Lmax [beats]	380.4 $\pm$ 243.1	904.9 $\pm$ 171.5, n=27	0.29	-524.5#	-1019.5–29.5	1.92 (large)
REC [%]	38.2 $\pm$ 9.5	53.6 $\pm$ 8.07, n=27	0.43*	-15.3#	-33.9–3.1	1.34 (large)
DET [%]	98.4 $\pm$ 1.04	99.9 $\pm$ 0.7, n=27	0.40*	-1.4#	-3.4–0.4	1.08 (large)
ShanEn [-]	3.5 $\pm$ 0.5	4.4 $\pm$ 0.4, n=27	0.35	-0.9#	-2.01–0.1	1.47 (large)
D2 [-]	2.3 $\pm$ 1.3	0.4 $\pm$ 0.7, n=27	-0.09	1.8#	-1.1–4.9	1.74 (large)

*Significant association between ECG and Polar RS800 CX. #Significant mean differences between ECG and Polar RS800 CX. n=32. MeanRR [ms], standard deviation of all RR intervals; STDRR [ms], standard deviation of normal to normal R-R intervals; MeanHR [1/min], The mean heart rate; STDHR [1/min], Standard deviation of instantaneous heart rate values; RMSSD [ms], root mean square of differences; pNN50, proportion of differences between adjacent NN intervals of more than 50ms; NN50 [beats], number of NN intervals that differ more than 50 ms; HRV triangular index [-], The integral of the RR interval histogram divided by the height of the histogram; TINN [ms], Baseline width of the RR interval histogram; LF (ms²), low frequency; HF (ms²), high frequency; LF/HF [-], Ratio LF [ms²]/HF [ms²]; SD1 [ms], represents the dispersion of the points along the line of identity and is thought to be an index of the instantaneous beat-to-beat variability of the data; SD2 [ms], represents the dispersion of the points along the line of identity and is thought to represent the slow variability of heart rate; SamplEn [-], complexity of NN series; ApEn, approximate entropy of the complexity or irregularity of the signal; DFA, Detrended fluctuation analysis of the correlation within the HRV signal divided into short-term and long-term fluctuations; Lmin (beats), mean line length; Lmax (beats), maximum line length; REC [%], recurrence rate; DET [%], determinism; ShanEn [-], shannon entropy consider the lengths of the diagonal lines; D2 [-], correlation dimension.

plot [Lmin (r=0.51, p<0.05), DET (r=0.47, p<0.05)] HRV indices showed significant correlations between Polar RS800CX and the ECG. However, we detected seven out of nine time domain, five out of six Poincaré plot and two out of six recurrence plot HRV indices to display significant mean differences (p<0.05) between Polar RS800CX and the ECG. Small to large effect sizes (0.23–2.61) found in 20 out of the

24 examined HRV indices between Polar RS800CX and the ECG (Table 2). Finally, during exercise, the error rate of Mean RR intervals obtained from the Polar RS800CX and the ECG, was 28.1%.

During the recovery period, two time domain (RMSSD, pNN50) and three recurrence plot (Lmin, REC, DET) HRV

indices showed significant correlations ($r=0.39-0.59$, $p<0.05$) between Polar RS800CX and the ECG. In total, eight out of nine time domain, all the frequency domain, five out of six Poincaré plot and all the recurrence plot HRV indices showed significant mean differences ($p<0.05$) between Polar RS800CX and the ECG. All the HRV indices showed small to large effect sizes (0.42–2.99) between Polar RS800CX and the ECG (Table 3). Finally, during recovery, the error rate of Mean RR intervals obtained from Polar RS800CX and the ECG, was 68.3%.

Dataset 1. Validation of Polar RS800CX for heart rate variability measurements

<https://doi.org/10.5256/f1000research.16130.d216722>

Discussion

The aim of the current study was to assess the validity of Polar RS800CX in a large spectrum of HRV parameters by comparing it with a 12-lead ECG monitor during rest, moderate cycling and recovery. We found that all the HRV indices ($n=24$) based on Polar RS800CX are correlated, while only five HRV indices displayed mean differences with the ECG HRV indices during the resting period. This confirms recent data showing that Polar RS800CX is valid for resting HRV measurements^{19–21,27,28}. However, we confirmed for the first time that this is the case for the wide spectrum of HRV indices. Also, the majority of the previous studies showed that other Polar HR monitors (i.e. S810, 810s, S810i, V800) showed good agreement with ECG in detecting RR intervals in supine and standing positions of adult individuals^{5,18,23}, and children^{24,29}. One previous study nevertheless, showed a bias of the Polar S810 in detecting HRV indices in supine and standing positions during rest³⁰.

During the exercise period, Polar RS800CX displayed a disagreement with the ECG in HRV indices. The error rate of Mean RR intervals obtained from Polar RS800CX and the ECG in our study was 28.1%. This is significantly higher than the error rate (0.71%) of RR intervals in a previous similar study examined the validity of Polar V800 during exercise³¹. Also, a previous study showed similar bias of Polar S810 HR monitor during exercise in high frequency (HF) HRV index at intensities $>60\%$ of VO_2 max and low frequency (LF) HRV index at intensities 80–100% of VO_2 max, even though the HR monitor found relatively valid in exercise intensities $<60\%$ of VO_2 max²⁹. Subsequent studies showed the Polar S810 had no bias during exercise¹⁸ and Polar V800 during high endurance running³¹. Reasons that Polar HR monitors may display bias in measuring HRV indices during exercise include: a) the insecure

placement of the elastic band on the thorax; b) the movement of the ECG electrodes during exercise, given that our participants were healthy and they showed no arrhythmia; c) the corresponding transmission of the data from the HR monitors; and d) changes of R-wave detection and the peak detection algorithms used^{29,32–35}.

Regarding the recovery period, the existing evidence is rather scarce. In our study, we found that the Polar RS800CX displayed bias in the recovery period. For instance, the error rate of mean RR intervals obtained from the Polar RS800CX and the ECG, was 68.3%. Perhaps some of the reasons reported above for the displayed bias during stress/exercise conditions may also apply to the recovery stage.

A limitation of the current study might be the small sample size of participants. However, a post-measurement online power calculation (DSS Research), using as an index the resting RS800CX Mean RR HRV index of the current study and the resting RS800CX Mean RR HRV index from a previous similar study¹⁹, showed 100% of statistical power ($n=32$) in our study. Another limitation might be that only males participated in this study and, therefore, our outcomes should be treated with caution when apply to females. However, we used a well-established statistical approach, as previously described^{19,21,23,31}. Finally, even though an investigator continuously checked the displacement of the chest belt and the electrodes of the Polar RS800CX and the ECG respectively, there is a possibility of a displacement due to sweating during the exercise and recovery periods, as previously suggested³⁶.

We conclude that Polar RS800CX found to be a valid tool for monitoring HRV during resting periods, but not for assessments during exercise at intensity of $60\% \text{VO}_2$ max and recovery periods. Testing the validity of devices such as Polar monitors in stressful (hot/cold or extreme) conditions such as exercise, requires further scientific attention, given that these instruments could provide a cost-effective method for monitoring HRV.

Data availability

Dataset 1. Validation of Polar RS800CX for heart rate variability measurements. DOI: <https://doi.org/10.5256/f1000research.16130.d216722>³⁶.

Grant information

The author(s) declared that no grants were involved in supporting this work.

Supplementary material

Supplementary File 1. Bland–Altman plots for resting, cycling and recovery periods.

[Click here to access the data.](#)

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Rita Khadka

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The present study aimed to validate RS800CX for assessing HRV during rest, moderate cycling and post exercise recovery by comparing its data with the data obtained from a gold standard ECG device. The study has been conducted very well. The acquisition of ECG signals for HRV analysis in all three conditions has been done simultaneously from both the devices. Statistical tests used to analyze the data are appropriate. The study has found that Polar RS800CX is a valid tool for monitoring HRV in individuals at resting conditions, but it displays inconsistency when used during exercise at 60% of maximal heart rate and recovery periods.

I found the paper interesting, however, I have some comments that need to be discussed for the improvement of the work.

Introduction:

- The introduction is well, however, there is a comment for the use of HRV as a diagnostic tool written on pages (in abstract: page 1, line 3; in introduction: page 3, para 1, line 7 & last line). The HRV can be taken as a prognostic tool rather than a diagnostic tool. It is one of the independent predictors of sudden cardiac death. However, it is not a very specific test for diagnosis of a disease.
- It is better to write down "autonomic nervous system" rather than "**autonomous** nervous system" (page 3, para 1, line 5).

Methods:

The description about volunteers and the experimental protocol are well written. However, the methods applied for the acquisition of ECG signals and processing of ECG signals for HRV analysis are not written.

- What were the sampling frequency, low pass filter or band pass filter and gain for ECG

signal acquisition in both the devices? Whether all ECG signals were checked for errors and edited for errors or discarded the data are not mentioned. These major points are missing. At times, peaks are not detected by the algorithm used in the devices during exercise and recovery period, because, features of ECG are not very regular. These signals need to be properly checked manually for missing peaks or artifacts detected as peaks and if required need to be edited properly following the standard rule of editing signals for HRV. In Polar devices RR intervals need to be checked for errors, i.e. very short or very long RR intervals in comparison to the average RR intervals. These are not mentioned in the methods section in the present study. This is important for HRV analysis.

- It would be better to record baseline respiratory rate also in such a type of study.

Results:

Results written in the texts are well, however, there are comments for the tables:

- The titles of all three tables are not self-explanatory. It would be better to rewrite them.
- It would be better to write down the number of the cases in the titles of the tables rather than in the legend of the tables.
- The tables are long. It would be better to remove "Mean HR and STDHR". These parameters are not very important for HRV interpretation.
- It would be better to write down the full form of NN50 before pNN50 in the table legends.
- The level of significance has not been mentioned in all three table legends. It is must be mentioned.
- There is a comment for SD1 representation given in the legends of Tables 1, 2 and 3. The SD1 represents the dispersion of the points perpendicular to the line of identity rather than the dispersion of the points along the line of identity. Please check for it.
- In the source data set supplied, I found markedly reduced Mean RR intervals during recovery period by Polar RS800CX. Similarly, markedly reduced Mean RR intervals are found in several subjects during exercise period by ECG device. These RR intervals need to be rechecked manually for the errors.

Discussion:

- In the present study, it has been discussed well that the majority of the previous studies showed that other Polar HR monitors (i.e. S810, 810s, S810i, V800) showed good agreement with ECG in detecting RR intervals in supine and standing positions of adult individuals and children. Also, during exercise periods Polar S810 and Polar V800 showed low biases and good agreements with ECG devices.
- The present study showed disagreement of Polar RS800CX with the ECG in HRV indices. The error rate of Mean RR intervals obtained from Polar RS800CX and the ECG was 28.1%. However, the reasons have not been discussed. Also, in the methods, sampling frequency and gain for both the devices are not mentioned. ECG signal processing for HRV analysis is also not mentioned. These parts of the methods are very important and must be rechecked

before interpretation of results and drawing conclusions.

Is the work clearly and accurately presented and does it cite the current literature?

Yes

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Yes

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Assessment of heart rate variability, Blood pressure variability, Spontaneous baroreflex sensitivity, cardiovascular autonomic function test (cardiovascular autonomic reactivity test), and EEG in health and disease conditions. Cardiovascular exercise physiology, yoga, and high altitude physiology.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 19 March 2019

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Alberto Hernando

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The article provides the validation of the Polar RS800CX in rest and during an exercise test when compared with a reference Gold-Standard ECG. To do that, a full database is recorded and several

times, frequency and entropy indices are compared. Similarities between Polar and ECG measures are found in the rest stage, but not during exercise and recovery phases. Therefore, the use of Polar RS800CX is not fully recommended in exercise tests.

I found the paper interesting but I have some comments that should be discussed in order to improve the understanding of the entire work.

Introduction:

- A more detailed introduction is needed, especially in two different areas: HRV (why is it so useful, which parameters can be extracted from it and how, what is the meaning of these parameters, has the respiration got any implication in HRV analysis?) and in the conditions that HRV could be applied in sport analysis (is it easy to point out the QRS complex in a noisy ECG? What happened with the non-stationary nature of HRV during exercise? How could the frequency analysis be affected with the high values of respiratory rate? Is there any component associated with the cadence/rhythm?). These details must be mentioned to put in context all the peculiarities of HRV analysis in sport.

Methods:

- Volunteers and experimental protocol: what is the sampling frequency of the ECG? Is the cycling cadence controlled? Has the respiratory rate been registered and analysed somehow?
- Analysis of heart rate variability: does QRS detection work fine? Was any artefact detection and correction applied? An explanation of the different indices (their meaning, how they are computed) must be included, especially for frequency indices (the method used, the frequency limits, and is the respiratory rate considered in HF?). Also, a plot with HRV extracted from the Polar and HRV extracted with the ECG may help to understand the paper.
- Statistical analysis: Due to the non-normal distribution of the results, I think the Spearman correlation test for correlation and Wilcoxon test for differences between polar and ECG are more appropriate than the Pearson and paired-sample t-test. Is the error rate presented in any Table?

Results:

- For the 3 Tables, if the distribution is non-normal, median and IQR are more suitable than mean and std. Why does the correlation limit change from one Table to another? If $r > 0.75$ is the value marked, it must be maintained in all the article. By the way, why 0.75 and no other value? If the correlation appears in all the values of the Table, maybe it is better to not mark with * in all the cells and only say this in the Table explanation. The number of subjects is another parameter that maybe would be better to say at the beginning and not put in all the cells.
- The Tables are too big, so a little simplification may help to understand the final purpose of the article. For example, mean RR-STDRR and mean Hr-STDHR are not too redundant? Maybe with only one pair is enough. Also if the indices are defined in the methods section the Table caption is reduced considerably.

Discussion:

- This part is based in the comparison between ECG and Polar, but if you have analysed 24 parameters, I would explain something more about them (differences between stages, why

to trust or not to trust in one/some parameter(s)...).

- Possible explanations of the differences in ECG and Polar, reasons 'a' and 'b' are not supposed to be controlled by the investigator?
- To finish, more details about possible practical applications could be given too.

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

No source data required

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: HRV analysis

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

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