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Comparison of heart rate measured by Polar RS400 and ECG, validity and repeatability

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Running headline:

Heart rate monitor validity and repeatability

Abstract

Aims: The purpose of this study was to investigate criterion-related validity and test-retest repeatability of the heart rate monitor Polar RS400 versus ECG.

Methodology: Ten healthy subjects, 19-34 years, performed a cycle ergometer test five minutes on each load (50W, 100W and 150W). Heart rate (HR) was measured with ECG and Polar RS400 and recorded digitally. After at least one hour resting the test was repeated.

Major findings: The results showed a significant correlation between HR measured by ECG and by Polar RS400 with correlation coefficients ranging from 0.97 to 1.00. In test 1 the mean difference ± 2SD between HR Polar and HR ECG was 0.7 ± 4.3 bpm and in test 2, 0.2 ± 3.2 bpm. In the repeated tests, the mean difference of HR between test 2 and test 1 ± 2SD was 3.2± 11.9 bpm with ECG and 2.6 ± 14.3 bpm with Polar RS400 and these differences were not statistically significant.

Conclusion: This study indicates good criterion-related validity and test-retest repeatability of Polar RS400. Differences observed at individual levels should be noticed, but are not considered to be clinically important. Polar RS400 is thus well suited for recording HR during physical activity and exercise training.

Keywords

ergometer test, heart rate monitoring, submaximal activity, exercise, physiotherapy

Introduction

Heart rate monitoring, allowing heart rate data to be collected, displayed and transferred to a computer, is useful to determine, assess and evaluate exercise intensity (1, 2). Commonly, heart rate (HR) is detected by a chest belt and recorded by a wrist worn unit. HR monitors are widely utilized by people performing ordinary daily exercise or elite exercise. The equipment is an excellent tool for physiotherapists to assess individual capacity and prescriptions and can also be a valuable tool in order to motivate patients for exercise at an intensity that is high enough to maintain or increase capacity. It is essential that the HR monitor devices actually deliver correct measurements and therefore comparison of HR monitors with criterion measurements (ECG) are of importance.

In order to prescribe correct exercise intensity, a percentage of measured maximal oxygen uptake (VO_2max) can be applied to specify the recommended intensity. Since there is a linear relationship between VO_2 and HR, a percentage of maximal HR (%HRmax) is more often applied to prescribe the intensity of exercise (1). Maximal HR can either be measured at a maximal exercise test or be estimated by using the formula 220-age, however the variability of this estimate is high (2SD = ±20 bpm).

ECG is the gold standard for measuring HR. Standard ECG measurements are performed by 10 electrodes collecting the electrical signals from the heart, which are recorded as ECG curves characterized by the components P-wave, QRS-complex and T-wave. HR is commonly derived from the R-R interval (evaluated from the ECG recording by determining the length of the interval between QRS complexes) or by counting number of beats during a certain time period. The calculation of heart rate in beats per minute is based on either of these measurements.

Polar RS400 (Polar Electro Oy, Kempele, Finland) has an electrode unit (a chest belt), with a transmitter, that detect the QRS-complexes with 1 ms resolution and send an electromagnetic signal to a wrist worn unit (heart rate monitor or watch). The wrist unit measures the time elapsed between consecutive heart beats, i. e. inter-beat interval (or R-R interval). The inter-beat intervals form the basis for the calculation of heart rate in beats per minute (bpm), and averages of the instantaneous heart rate data are calculated so that a relatively stable heart rate will be presented. Data can be stored, based on 5, 15 or 60 s intervals, for subsequent downloading to a personal computer(see Polar RS400 Manual). According to the manufacturer, the measurements fulfill the technical requirements of analyzed ECG signal and timing of the QRS complex as set by the ESC/NASPE Task Force 1996 (3).

This system is mainly developed for regularly monitoring of HR when performing running exercise. Usually HR or % of HRmax is shown. The monitor has several functions such as

calculation of mean, maximal and minimum HR, a program for guiding exercise in 5 pulse zones, and calculation of calorie-consumption. The monitor can save up to 99 exercise bouts, over a time of 99h 59 min 59 s. The information can be transferred to a computer and an exercise diary can be created. According to the technical information from Polar Company (RS400 Manual) the accuracy of the heart rate monitor is ±1bpm or 1%. The range of recording is between 15-240 bpm.

Previous studies have been presented on Polar Vantage XL and Polar S810/810i (4-9), but as far as we know, not on Polar RS400. However, the Polar RS400 and the Polar S810i uses the same 5 kHz technology, while the RS800 use another technology (W.I.N.D.) (4).

In order to perform a study of Polar RS400, with well-defined exercise intensities, an ergometer cycle has been utilized. The power (W) is work per unit time (Nm/s) and is regulated by the brake force (N) in combination with the pedaling rate (revolutions per minute, rpm) driving the flywheel. Commonly, ECG measurements during exercise testing are performed by cycle, since exercise testing on treadmill more often disturbs the ECG recording due to more movements of the upper body. Submaximal power outputs are often used in comparison of HR monitors and ECG. It should be noted that submaximal HR can be influenced by factors such as temperature, body water balance, food intake, caffeine, tobacco, stress and medical treatment.

Aims

The purpose of this study was to investigate the criterion-related validity and the test-retest repeatability of HR measured by Polar RS400 compared with the criterion measure ECG on three different submaximal power levels during ergometer cycle tests. The overall aim was to determine whether Polar RS400 is suitable for measuring HR during physical activity and exercise training.

Method

Subjects

Ten healthy volunteers were recruited to participate in the study. According to the inclusion criteria the subjects should be between 19-34 years, be healthy and able to cycle, have no medical treatments that affect HR and be non-smokers. The subjects were asked to abstain from food intake or and intake of coffee, or beverages that contain caffeine, for 2 hours immediately preceding the test. They were also asked not to drink alcohol or exercise on high intensity for the 24 hour period prior the test. The study was approved by the Advisory Committee for Research Ethics in Health Education at Lund University. Informed consent was given by all subjects.

Exercise test

Prior to the exercise test the participants answered a questionnaire regarding general health, physical activities and exercise habits as well as if the pre-instructions had been followed. Length and weight were measured.

ECG (CS-200 Ergospirometry, Schiller AG, Altgassse 68, CH-6341 Baar Switzerland) using standard 12 lead, was measured with 6 electrodes placed at the chest, 1 at each arm proximal, lateral and 1 at each lateral, distal part of lower body (10) .

The Polar chest-belt was wetted and placed around the thorax. The wrist unit was placed at the left side wrist of the test subject, see Picture. The same monitor and wrist unit were utilized by all test subjects.

The exercise test was performed on a cycle ergometer (Monark 839E). The initial power and stepwise increase in power were pre-programmed in the computerized Ergospirometry unit (CS-200, Schiller). Prior to the test measurements, each subject was instructed to cycle with a pedal rate of 50 rpm at a load of 25 W.

The Polar RS-400 recording, the ECG recording, and load increase were manually started by two test leaders using a count-down procedure (3, 2, 1, go). Thus criterion measures (HR via ECG) were obtained simultaneously with HR from Polar RS-400.

The test subjects then cycled for 5 minutes at each of three power levels, 50 W, 100 W and 150 W, with no rest in between. The test ended when the computer switched the load to 200 W and the ECG and Polar RS-400 recordings were then stopped. The subject continued to cycle at 25 W for cooling down.

The ECG electrodes and the chest belt were left in place during the 1 hour rest in between the repeated tests. During the rest the test subjects were offered water to drink but no food.

The HR data from Polar RS400 were stored in a personal computer as bpm averaged over 5 s intervals. For comparative analyses of HR the mean value of the last two recordings (i.e. over a 10 s interval) was calculated for the 5th, 10th and 15th min. The HR from ECG was recorded in 10 s intervals and the averaged HR data from the last 10 s-interval at the 5th, 10th and 15th min were chosen for the HR analyses.

Statistical analysis

The correlations between the recorded HR data from Polar RS400 and ECG were obtained by linear regression and by using Pearson product moment correlation. Student's paired t-test was used to statistically test the differences between the methods. A significance cut-off level of $p=0.05$ was chosen. To further explore the agreement between the methods in absolute values (bpm), the recorded HR data were analyzed by plotting the differences between the methods against the ECG-derived HR, according to Altman and Bland with modification of the x-axis (usually the mean of the two measurements) (11, 12). The upper and lower limits of agreement were calculated as mean difference ±2SD.

The repeatability of the recorded HR was tested in a similar manner according to Altman and Bland, by making a plot of the differences against the mean of HR recorded from Polar RS400 and from ECG respectively. The repeatability coefficients, defined as 2SD, were calculated.

Results

Subject characteristics

The mean age of the ten subjects was 23 (range 19-34) years. All subjects were physically active between 80-510 min each week, the distribution between low, middle and high intensity is shown in Table 1. Eight of the subjects had sitting work. The mean BMI in the group was 26 kg/m^2; three subjects had a BMI>30 kg/m^2. At the day of the testing, two of the subjects had a slight cold and two subjects were on medication, (with no known effects on HR). One subject had diabetes type I, which was well controlled.

All subjects followed the pre-test instructions regarding restricted food and beverage -intake and exercise, as documented in the questionnaires.

Validity

Scatterplots including all observations show statistically significant linear relationships between HR measurements derived from Polar RS400 and ECG at the three different power levels at each of the repeated ergometer tests (Fig 1 a,b). Positive correlations (see regression lines), with correlation coefficients between 0.97-1.0 were obtained, with the highest correlation coefficient at the highest power (150W).

The paired comparison did not detect any statistically significant differences between HR measured by Polar RS400 or by ECG.

The agreements between the methods were analyzed. The difference in absolute values between HR measurements derived from Polar RS400 and ECG at the three different power levels (y-axis) versus HR from ECG (x-axis), are shown in Figure 2 a and b. Each individual is represented by three markers, one for each power level. The horizontal zero-line indicates no difference between the methods. As can be seen in the figure the mean difference (dotted line) ±2SD (dashed lines) between the methods was 0.7±4.3 bpm in test 1 and 0.2±3.2 bpm in test 2.

The variation was slightly lower in test 2 compared with test 1. The variations seem random and have an even distribution above and below the mean. It can be observed that the variation was less at the highest load (150W). At an individual level the highest variation observed was 7 bpm.

Repeatability

In order to study the repeatability of the methods, two repeated measurements on the same subject, with one hour in between, were made.

The paired comparison showed no statistically significant difference in test-retest between any of the compared measurements.

The differences, in absolute values of HR derived from ECG, between the repeated test are plotted versus the mean of HR for each subject in Figure 3 a. Each individual are represented by three markers, one for each power level. It can be seen that the mean and 2SD of the differences was 3.2±11.9 bpm.

The differences, in absolute values of HR derived from Polar RS400, between the repeated tests are plotted versus the mean of HR for each subject, in Figure 3 b. Each individual are represented by three markers, one for each power level. It can be seen that the mean and 2SD of the differences was 2.6±14.3 bpm.

The variation between the repeated tests was lower with ECG compared with the variation observed with Polar RS400. The variation seems randomly distributed above and below the mean values in both Figure 3 a and b, however the variation was lower at the highest power level (150 W). The highest individual variation between the repeated tests by ECG was -13 bpm and by Polar RS400 -21 bpm.

The coefficient of repeatability (2SD) was as described above 11.9 bpm for the ECG measurements and 14.3 for the Polar measurements. The coefficient of repeatability expressed in percent of the mean HR was 9 % for the ECG measurements and 11 % for the Polar measurements.

Discussion

This study indicates good criterion-related validity and test-retest repeatability of Polar RS400 compared with ECG in ergometer cycle tests. However, the differences that have been observed at individual levels should be considered.

Clinical implications

Our results indicate that the Polar RS400 equipment can be a valuable tool for physiotherapists in order to monitor and record HR during physical activity and exercise training in young healthy subjects. The equipment might also be useful in clinical practice for handling young patients, without heart rhythm disturbances or other heart related problems.

The Polar RS400 can preferably be used during maximal exercise tests to measure HR, unless ECG is required to monitor arrhythmias or other heart-related problems. Thus, the issue of not being able to see if the recording is abnormal either directly or later on, when the recording is off-line in the computer is a limitation, which influences the applicability for these conditions.

With the good validity and repeatability the Polar RS400 is well suited in order to specify the recommended exercise intensity, and monitor this exercise intensity either as %HRmax or as %THR (1). The latter is more closely related to VO_2max which might give an advantage, however in the Swedish physical activity recommendations %HR is chosen as an intensity measurement (2).

During all sorts of physical activities or exercise HR can easily be monitored, however when exercising in groups where each participant's HR are monitored by Polar equipment, the transmitters can disturb the HR recording within other monitors. This is observations that have been made during group activities in clinical practice by the authors (it can be noted that other Polar equipment is available that solves this group problem by using "coded transmission").

However, a difference of 3-4 bpm (2SD seen in the validation between Polar RS400 and ECG) may be regarded as clinically important if for instance submaximal HR is measured in order to estimate maximal oxygen consumption (VO_2max) by the Åstrand test (13). According to the nomogram or tables a difference of 5 bpm at submaximal load gives a variation of estimated VO_2max of 100-300 ml/min. However, this is probably not of a major importance since the Åstrand submaximal exercise test is commonly based on the estimated maximal HR (220-age) which has a substantially larger variation (2 SD are ±20 bpm).

Notable is the greater individual variation seen at the repeated tests both with ECG and Polar RS400 (11.9 and 14.3 bpm, respectively, for more discussion see Repeatability below), which

emphasizes one of the risks of relying on submaximal HR-based exercise tests regardless of HR recording method.

The purchase of a fairly basic heart rate monitor, like PolarRS400, can increase the efficiency of the Physiotherapist. The patients can be taught to apply their equipment on their own during exercise, which may increase motivation to exercise and also increase the feeling of control and safety. The possibility to transfer data to a computer, and together with the patient analyze training frequency, duration and intensity, increases the ability to document and easily present effects of exercise both to patients and to colleagues and co-workers in the clinic.

Subjects and methods

The current study is focused on the validity and repeatability of Polar 400 in a small sample of young healthy subjects. Previously, a study of possibilities and limitations with Polar RS800 included a greater sample with a wider range of age and showed gender differences as well as differences between ECG and Polar RS800 recordings in women above 60 years (14).

One of the test subjects had diabetes type I and three subjects had a BMI>30 kg/m^2 as previously stated in the result section. However, these factors were not considered to influence the test results, since the subject with diabetes was well controlled and all subjects were physically active and thus adapted to exercise.

The subjects were asked not to eat later than 2 h before the test and not in between the tests. Some of the subjects performed their tests and re-test a long time (more than 2 hours) after their meal, which possibly could affect the carbohydrate energy-store negatively, especially at the re-test. As a result adrenaline then may be increased in order to release glucose from the liver. Also, a slightly higher room temperature was observed during test 2. This might explain the higher heart rate observed at test 2, (see Fig 3) both at individual level (more of the subjects are above the zero line than below) and as a positive mean difference of 3.2 and 2.6 bpm.

The lower variation observed at higher power levels could be due to the fact that a higher heart rate means that more beats are included in each 10 s recording which will lead to a smaller variation in the average assessment. The lower individual variations at higher power level could be due to less contribution of psychological initial stress.

During the exercise test the recordings from the ECG occasionally were disturbed by muscular movements. Generally small disturbances were seen during low power levels, with an increase at higher power levels. However, the muscle disturbances were judged not to influence the HR recording negatively. Also, during the tests ECG electrodes were occasionally coming loose,

which could be due to hairy chest or that the lower extremity electrodes were close to the trouser lining. Correction of the loose electrode or switch to new electrode was quickly performed and none of the recordings at the end of each 5 min session were disturbed. The chest belt was tightly fit and no disturbances of the recording from the Polar RS400 sensor were detected. However, in a previous study of Polar RS 800 was stated that artifacts and bad connection with the belt resulting in loss of beats (or arrhythmic beats) are possible limitations which cannot be detected on-line, or not possible to separate from each other later on, when the recording is off-line in the computer (14). These limitations might give the patient and / or the physiotherapist a false sense of safety and control and are necessary to consider also when using Polar 400.

An advantage of ECG-measurements is the online and printable ECG-curves where rhythm disturbances can be detected as well as normal variation in heart rate due to respiration (respiratory sinus-arrhythmia) (10). In the ECG curves no other arrhythmia than the normal sinus-elicited arrhythmia was observed in our study. Nor were there any detectable disturbances from background electrical devices.

As described in the Methods section the heart rate (HR) recordings from ECG were made over an interval of 10 s and from Polar RS400 over a 5 s interval. In order to compare the HR recordings we used the mean of the last two 5 s recordings from the Polar RS400. A shorter recording (averaging) interval could influence negatively on the result since just a few heart beats (R-R recordings) would then be included, especially at low work rate, however at higher work rate and higher HR more heart beats will be included, which is likely to increase the validity. Previously it has been shown that the HR recorded every 5 s by Polar Vantage XL might give an overestimation of HR (5).

The recording of HR from ECG and Polar RS400 were manually started by two test leaders, after a count down. There is a minor possibility that some delay occasionally occurred between the startup of the two devices. However, since the last 10 s from each 5 min recording were chosen in the comparison between the methods, the subjects were expected to have reached their steady state, and thus the start of the equipment was not judged to greatly influence the measurement. The same conclusion was drawn in a previous study, i.e. that the result at the end-recording is not extensively influenced by the fact that two recording devices were started manually (6).

Validity

In our study the Polar RS400 had a good criterion-related validity, which is in agreement with previous studies of Polar S810, Polar S810i and Polar Vantage XL and ECG (4-9). The correlation-

coefficient is very high at both 50 and 100W and is 1.0 at 150 W. This indicates that the measurement of HR with Polar RS400 is as reliable as with ECG.

The mean difference between the methods are 0.2 and 0.7 bpm (at test 1 and 2 respectively), which also indicates a good validity on group level. However, the differences between the methods on the individual level (seen in fig. 2 a,b) varies between 3.2-4.3 bpm. The variation of the differences are slightly less in test 2 compared with test 1. The differences are evenly distributed and are smaller at higher power levels.

Possible physiological reasons for the differences in HR detected on an individual level have been discussed above (Discussion subjects and methods), but these differences may also be due to different approaches within the two recording devices regarding signal processing of the ECG signal, QRS-detection, calculation and averaging of HR over time.

Repeatability

The rational for the repeatability test is to investigate whether the Polar 400 detect the variations between tests as accurate as the ECG measurements ("the degree of closeness between the instruments"). Thus, not to explore the physiological individual differences between the tests, per se.

The repeatability of HR measurements from Polar RS400 and ECG, respectively, is very good and similar values are found. The mean difference between the repeated measurements from Polar RS400 and ECG are very similar (3.2 bpm and 2.6 bpm respectively) and the difference between the devices is thus 0.6 bpm. This difference of HR between the devices indicates no clinical importance. In a previous study the reliability of Polar S810 was found to be "not high" (when comparing r-r interval raw measures in ms) and the authors suggested more reliability studies with comparison of Polar and ECG (4).

The coefficient of repeatability (2SD) indicates a similar but relatively high individual variation both at the repeated test with ECG (11.9 bpm, 9 %) and with Polar RS400 (14.3 bpm, 11 %). Also, the largest test-retest variation observed was 13 bpm with ECG measurement and 21 bpm with PolarRS400 measurement. However, comparable HR variations have been observed at repeated submaximal day-to-day ECG measurements (±16 bpm (2SD) in women) and between measurements 4-6 weeks apart (±16bpm for women while the corresponding values for men ±20 bpm) (15, 16).

Possible reasons for differences between the methods with regard to the repeatability in this study are the same as described above e.g. different approaches within the two recording devices regarding signal processing of the ECG signal, QRS-detection, calculation and averaging

of HR over time. But most likely the main factors behind the variation are the previously well described physiological diurnal differences, psychological stress and environmental factors (17).

Further studies

Further studies might focus on extending the comparison of Polar 400 and ECG by including a greater number of participants and by an extended age- range. Patients with arrhythmia or other heart-related problems would be interesting to study in order to further evaluate the validity and repeatability also for these patient categories.

Conclusion

This study indicates good criterion-related validity and test-retest repeatability of Polar RS400 compared with ECG in ergometer cycle tests. The differences that have been observed at individual levels should be noticed, but are not considered to be clinically important for healthy people. Thus, the Polar RS400 is an instrument well suited for measuring HR during physical activity and exercise training.

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Polar RS400 Manual

http://www.polar.fi/en/support/product_support?product=123&category=User+Manuals&documenttitle=%0AUser+manual+for+RS400+in+English&document=/gip/PKBStoGIP.nsf/web_cat/C225742500419A8AC22571BE003BD96C?openDocument

Legends of tables and figures

Table 1. Subject characteristics and activity levels (n=10).

Fig 1, a) test 1, b) test 2. HR measured by Polar RS400 (y-axis) versus HR measured by ECG (x-axis). Each individual value at 50 W (open circles), 100 W (closed circles) and 150 W (triangles) is plotted (n=10). Regression lines for each power level (black) and a line of identity (dashed) are drawn. The correlation coefficients for each power level are presented in the graphs.

Fig 2, a) test 1, b) test 2. The difference (HR measured by Polar RS400 - HR measured by ECG) (y-axis) versus HR for each individual measured by ECG (x-axis). Each individual difference at 50 W (open circles), 100 W (closed circles) and 150 W (triangles) can be seen. The zero line (black line) and the mean of the difference (dotted line) are given together with ±2SD (dashed lines).

Fig 3, Repeated tests of HR measurements by a) ECG and b) Polar RS400. The difference between the tests (HR test 2 - HR test 1) (y-axis) versus the mean of HR of the two measurements (x-axis). Each individual difference at 50 W (open circles), 100 W (closed circles) and 150 W (triangles) can be seen. The zero line (black line) and the mean of the difference (dotted line) are given together with ±2SD (dashed lines).

Table 1

Subject	Gender W =woman M=male	Age (year)	Weight (kg)	Height (m)	BMI (kg/m^2)	Work sitting=1 Middle intensity=2 Very intense=3	Low activity min/week	Middle activity min/week	High acitivity min/week
A	W	26	60.0	1.74	20	1	150	-	360
B	M	21	73.6	1.75	24	1	80	-	-
C	W	23	65.3	1.62	25	1	100	240	-
D	W	23	66.7	1.65	24	1	-	-	420
E	W	21	67.3	1.61	26	1	100	100	-
F	M	20	68.7	1.72	23	3	-	360	-
G	W	34	89.3	1.69	31	1	-	300	-
H	W	19	73.7	1.55	31	1	-	300	-
I	M	19	107.9	1.86	31	1	-	180	-
J	W	22	59.4	1,57	24	2	100	-	180
Mean		23	73	1.68	26	1,3	103	254	320
Median		22	68	1.67	25	1	100	300	360
Min		19	59	1.55	20	1	80	100	180
Max		34	108	1.86	31	3	150	360	420

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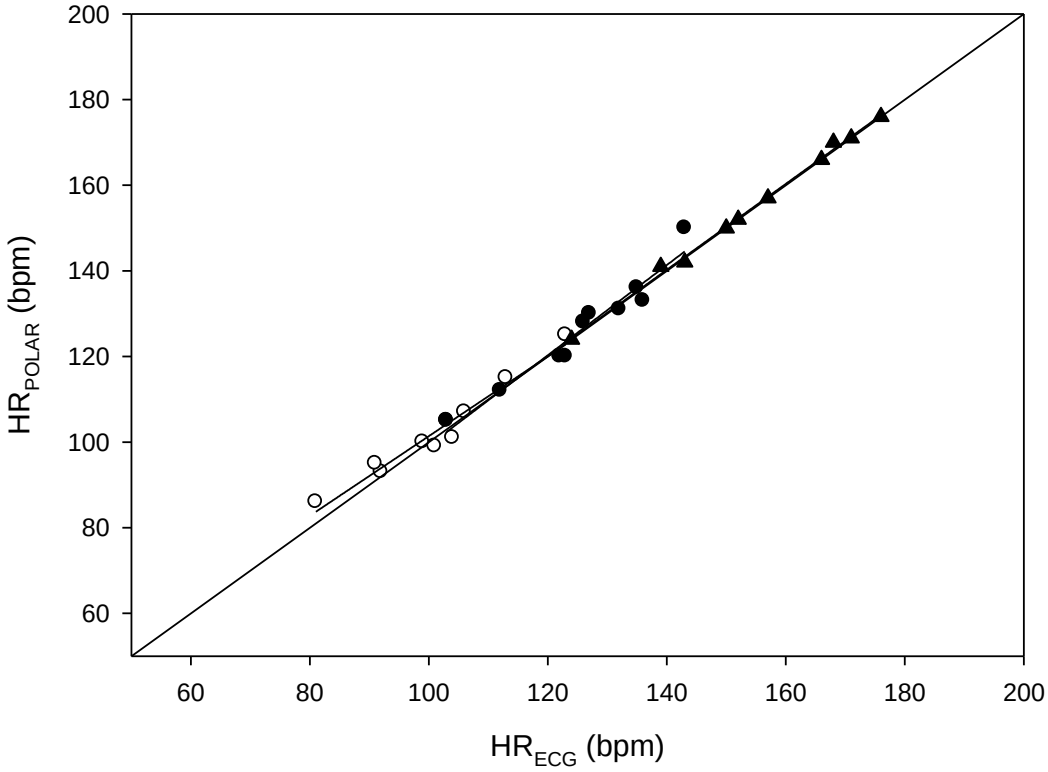
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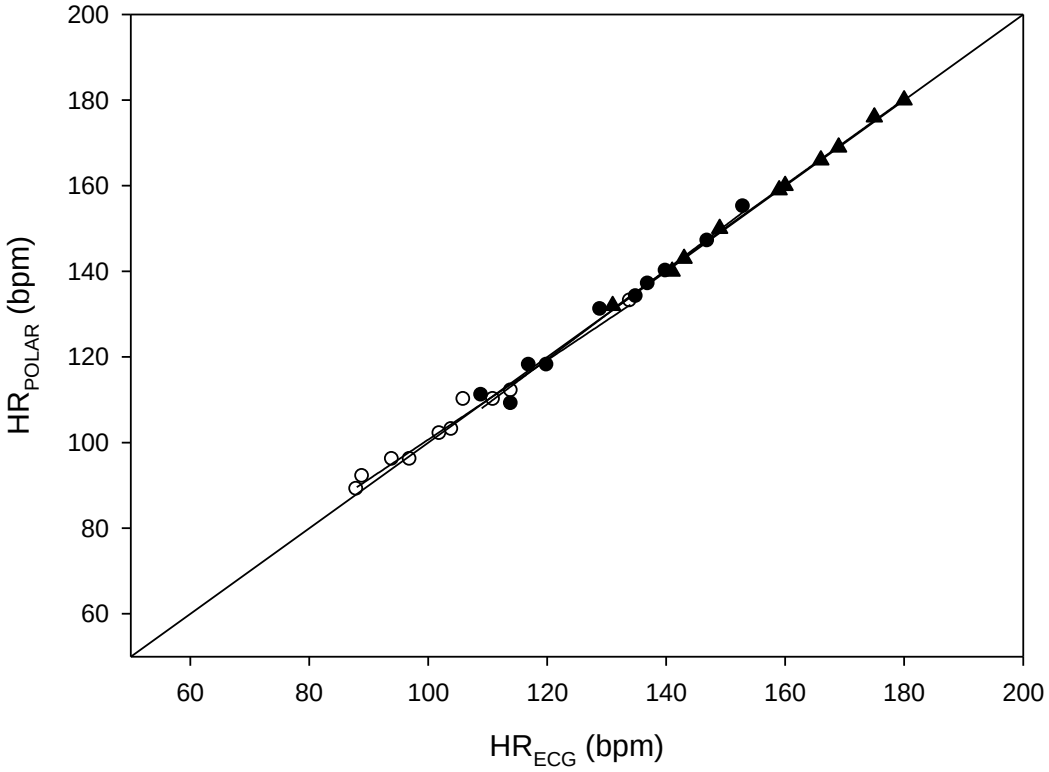
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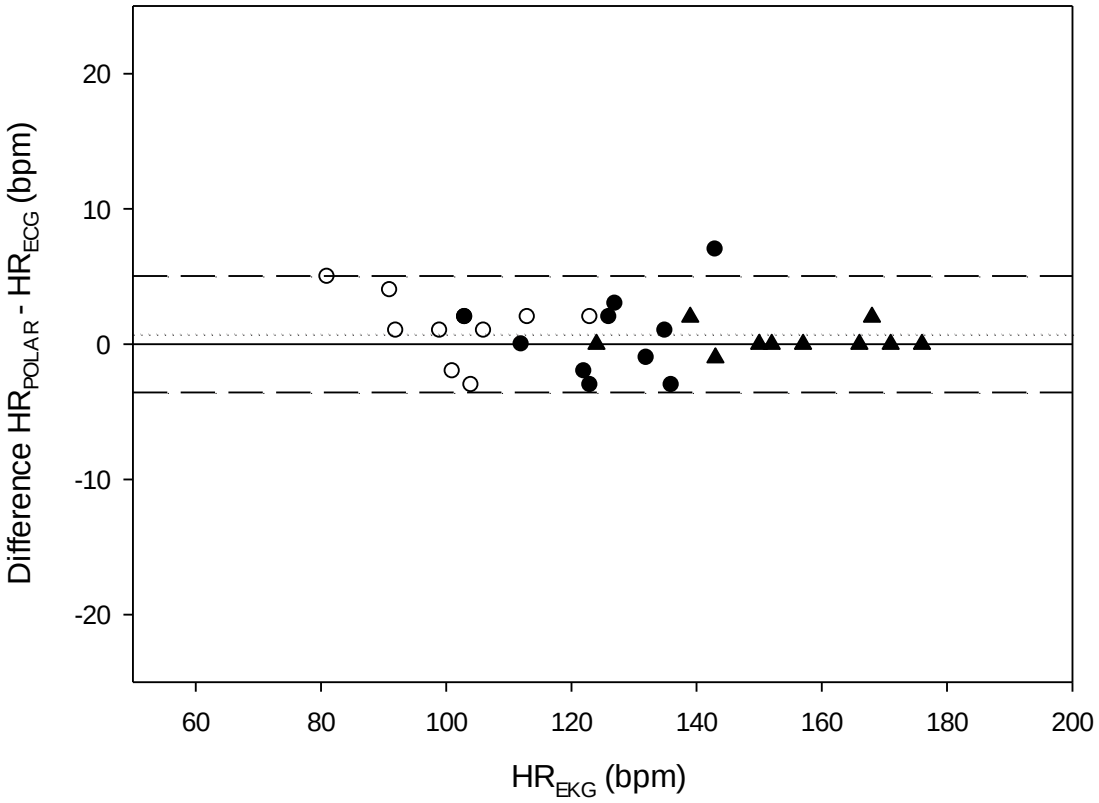
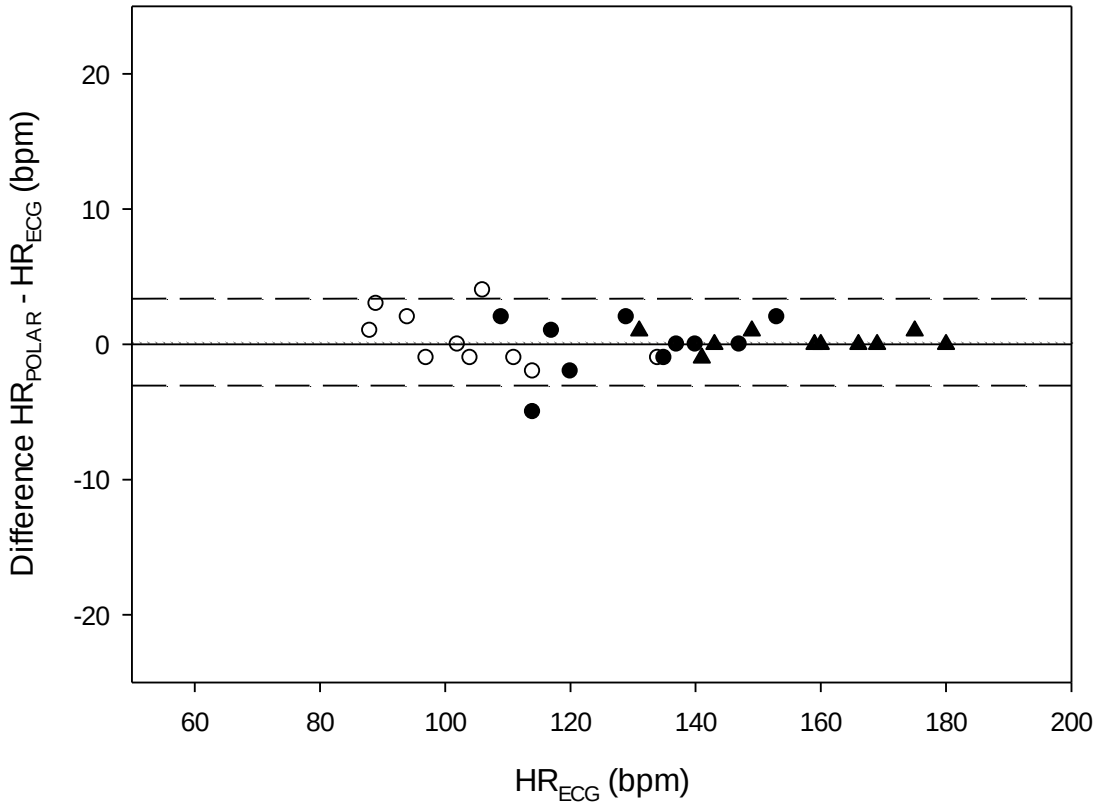
HR$_{POLAR}$ (bpm)
60
80
100
120
140
160
180
200
HR$_{ECG}$ (bpm)

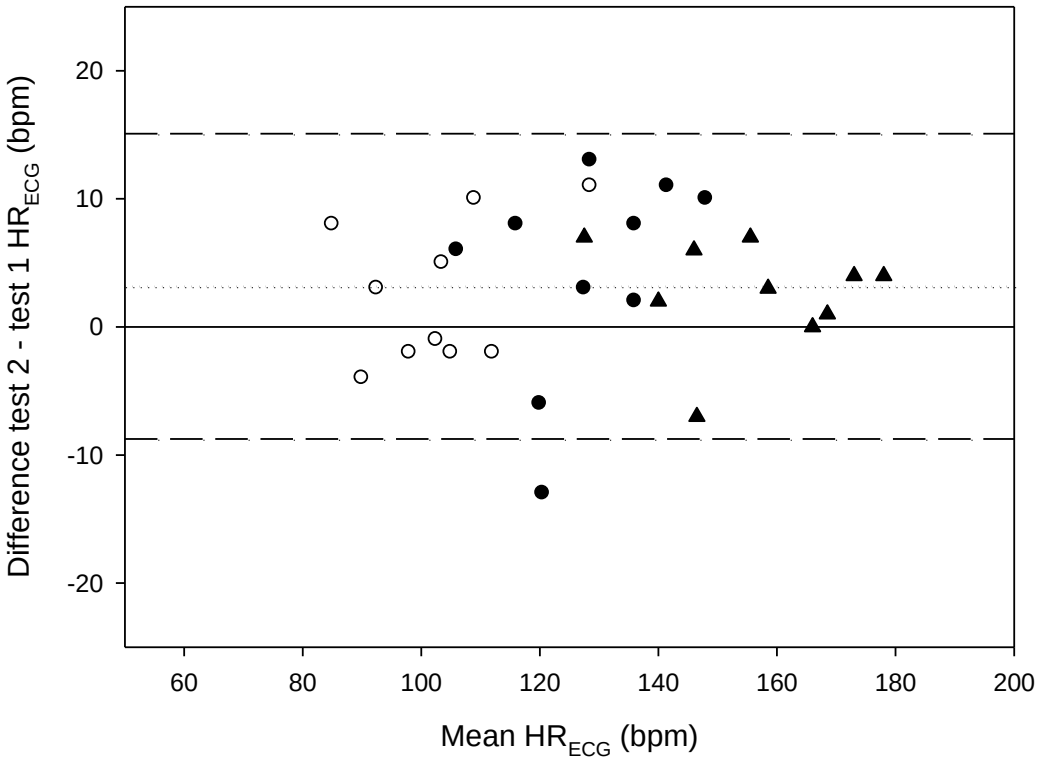
a


20
10
0
-10
-20
Difference HR$_{POLAR}$ - HR$_{ECG}$ (bpm)
60
80
100
120
140
160
180
200
HR$_{EKG}$ (bpm)

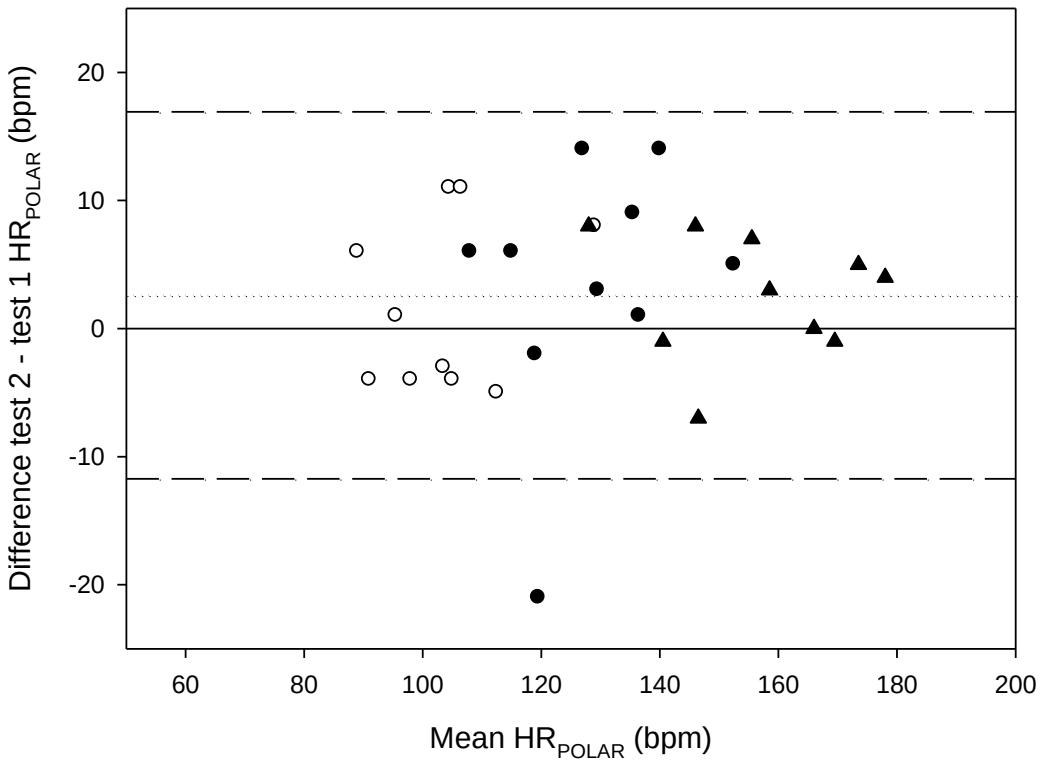
b


20
10
0
-10
-20
Difference HR$_{POLAR}$ - HR$_{ECG}$ (bpm)
60
80
100
120
140
160
180
200
HR$_{ECG}$ (bpm)

a


20
10
0
-10
-20
60
80
100
120
140
160
180
200
Difference test 2 - test 1 HR$_{ECG}$ (bpm)
Mean HR$_{ECG}$ (bpm)

b


20
10
0
-10
-20
60
80
100
120
140
160
180
200
Difference test 2 - test 1 HR$_{POLAR}$ (bpm)
Mean HR$_{POLAR}$ (bpm)

Picture