

Accuracy of Polar S410 Heart Rate Monitor to Estimate Energy Cost of Exercise

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ABSTRACT

CROUTER, S. E., C. ALBRIGHT, and D. R. BASSETT, JR. Accuracy of Polar S410 Heart Rate Monitor to Estimate Energy Cost of Exercise. *Med. Sci. Sports Exerc.*, Vol. 36, No. 8, pp. 1433–1439, 2004. **Purpose:** The purpose of this study was to examine the accuracy of the Polar S410 for estimating gross energy expenditure (EE) during exercise when using both predicted and measured $\dot{V}O_{2\max}$ and HR_{\max} versus indirect calorimetry (IC). **Methods:** Ten males and 10 females initially had their $\dot{V}O_{2\max}$ and HR_{\max} predicted by the S410, and then performed a maximal treadmill test to determine their actual values. The participants then performed three submaximal exercise tests at RPE of 3, 5, and 7 on a treadmill, cycle, and rowing ergometer for a total of nine submaximal bouts. For all submaximal testing, the participant had two S410 heart rate monitors simultaneously collecting data: one heart rate monitor (PHRM) utilized their predicted $\dot{V}O_{2\max}$ and HR_{\max} , and one heart rate monitor (AHRM) used their actual values. Simultaneously, EE was measured by IC. **Results:** In males, there were no differences in EE among the mean values for the AHRM, PHRM, and IC for any exercise mode ($P > 0.05$). In females, the PHRM significantly overestimated mean EE on the treadmill (by 2.4 kcal·min⁻¹), cycle (by 2.9 kcal·min⁻¹), and rower (by 1.9 kcal·min⁻¹) (all $P < 0.05$). The AHRM for females significantly improved the estimation of mean EE for all exercise modes, but it still overestimated mean EE on the treadmill (by 0.6 kcal·min⁻¹) and cycle (by 1.2 kcal·min⁻¹) ($P < 0.05$). **Conclusion:** When the predicted values of $\dot{V}O_{2\max}$ and HR_{\max} are used, the Polar S410 HRM provides a rough estimate of EE during running, rowing, and cycling. Using the actual values for $\dot{V}O_{2\max}$ and HR_{\max} reduced the individual error scores for both genders, but in females the mean EE was still overestimated by 12%. **Key Words:** MAXIMAL OXYGEN UPTAKE, ENERGY EXPENDITURE, PHYSICAL ACTIVITY, RATING OF PERCEIVED EXERTION

Heart rate (HR) monitors are a valuable tool for athletes and those who are interested in improving fitness. HR is often used to estimate exercise intensity or prescribe exercise either based on a percentage of an individual's HR_{\max} or HR reserve. Furthermore, because HR is linearly related to oxygen uptake for dynamic activities involving large muscle groups (6,24), it can provide a reasonable estimate of energy expenditure (EE) during exercise (5,8). This application could be useful for athletes and for individuals who exercise for weight control.

HR monitoring can also be a valuable tool for researchers seeking to quantify the intensity of exercise bouts. The use of HR does have limitations due to influence of other factors that can affect exercise HR. These include stress, hydration level, environmental factors such as temperature and humidity, mode of exercise (upper vs lower body), gender, and training status. Motion sensors such as electronic pedometers and accelerometers are

commonly used to assess PA, but they are mainly limited to ambulatory activities. Motion sensors have been shown to be ineffective at predicting the energy cost of activities such as cycling, upper-body exercise, swimming, rowing, or walking/running up an incline (9,11,13,19,20,26). In addition, uniaxial accelerometers and pedometers cannot detect increases in EE that occur at running speeds over 9 km·h⁻¹ (3,11).

Polar Electro, Inc., is a leading manufacturer of HR monitors. Their instruments have been shown to provide valid measurements of HR when compared with electrocardiograms (15,16,27). This company has developed software that allows a user to estimate EE during exercise. To accomplish this, Polar developed the "OwnIndex," which uses nonexercise prediction equations for $\dot{V}O_{2\max}$ and HR_{\max} . The estimated EE during exercise is determined from the "OwnCal" software, which is based on user data and exercise HR. The Polar S410 HR monitor is one of the Polar watches that gives users the option to either predict $\dot{V}O_{2\max}$ and HR_{\max} or to program the actual, measured values into the watch.

To our knowledge, no published studies have examined the accuracy of Polar HR monitors to predict EE during exercise. Therefore, the purpose of this study was twofold: 1) to examine the accuracy of the Polar S410 for estimating EE during exercise using one's predicted $\dot{V}O_{2\max}$ and HR_{\max} , and 2) to determine whether the use of measured $\dot{V}O_{2\max}$ and HR_{\max} improves the accuracy of the Polar S410 for estimating EE.

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METHODS

Subjects. Twenty active participants (10 male, 10 female) from the University of Tennessee volunteered to participate in the study. Inclusion criteria for the study included regular exercise (at least 3 d·wk⁻¹) and absence of contraindications to exercise testing. The procedures were reviewed and approved by the University of Tennessee Institutional Review Board before the start of the study. Each participant signed a written informed consent and completed a Physical Activity Readiness Questionnaire (PAR-Q) before participating in the study. Weight and height were measured in light clothing (without shoes) using a calibrated physician's scale and stadiometer, respectively.

Protocol. Each participant performed a maximal exercise test, nine submaximal exercise bouts, and a resting metabolic rate (RMR) test. For all testing, participants were asked to refrain from physical activity 24 h before testing and to refrain from food, alcohol, and tobacco 3 h before the tests.

Predicted $\dot{V}O_{2max}$ and HR_{max} . The predictions of $\dot{V}O_{2max}$ and HR_{max} were performed according to the manufacturer's recommendations outlined in the Polar S410 user's manual (7). The Polar S410 device uses a nonexercise prediction equation based on user information (age, height, weight, gender, physical activity level) and resting heart rate information. The participants defined their physical activity level (low, middle, high, top) based on descriptions given by the Polar S410 user's guide (7). The physical activity level along with the participant's information was then programmed into the S410 HR monitor. The participant was allowed to relax in a reclining position for 15 min before the Polar S410 predicting his/her $\dot{V}O_{2max}$ and HR_{max} .

Measurement of $\dot{V}O_{2max}$ and HR_{max} . Participants performed a maximal exercise test on a motor driven treadmill (Quinton model Q55XT, Seattle, WA) for the purpose of measuring $\dot{V}O_{2max}$ and HR_{max} . The treadmill speed was calibrated by measuring the belt length (3.190 m) and the time required to complete 25 revolutions of the treadmill belt. This was verified using a hand-held digital tachometer (Nidec-Shimpo America Corp. Model DT-107, Itasca, IL) that had been calibrated to an accuracy of within $\pm 0.1\%$. A carpenter's level was used to calibrate the treadmill grade to 0.0%, according to the manufacturer's instructions. Metabolic measurements were made by indirect calorimetry (IC) using a TrueMax 2400 computerized metabolic system (ParvoMedics, Salt Lake City, UT), which was validated against the Douglas bag method in our laboratory (1). Before each test, the O₂ and CO₂ analyzers were calibrated using gases of known concentrations, and the flow meter was calibrated using a 3-L syringe.

Before the maximal exercise test the participant warmed up on the treadmill, and a comfortable running speed was determined, which was used as the starting point of the maximal exercise test. A 5-min rest period separated the warm-up and the start of the maximal exercise test. During the first 2 min of the test the participant was brought back to the predetermined running speed and then the grade was

increased 1% per minute until volitional fatigue. After 3 min of recovery, a blood sample was taken from a fingertip and analyzed for blood lactate concentration using an automated lactate/glucose analyzer (YSI 2300 STAT Plus, Yellow Springs, OH).

Maximal oxygen uptake ($\dot{V}O_{2max}$) was determined from the highest 1-min average of oxygen uptake and was verified by the participant meeting three of the four following criteria; 1) 3-min postexercise lactate >8.0 mmol·L⁻¹, 2) maximal HR within 10 beats per minute of age-predicted maximal HR (220 - age), 3) R value > 1.15, and 4) $\dot{V}O_2$ plateau (<150 mL·min⁻¹ increase between stages) (12).

Submaximal exercise bouts. To examine the accuracy of the Polar S410 to estimate EE during exercise, participants performed three submaximal exercise tests at various intensities on a Quinton Q55XT motor driven treadmill, Lode Excalibur Sport electronically braked cycle ergometer (Groningen, NL), and a Concept II rowing ergometer (Morrisville, VT), for a total of nine submaximal exercise tests. Before the submaximal testing, one watch was programmed with the participant's predicted $\dot{V}O_{2max}$ and HR_{max} , which hereafter is referred to as the predicted HR monitor (PHRM). A second watch was programmed with the participant's actual $\dot{V}O_{2max}$ and HR_{max} , which is referred to as the actual HR monitor (AHRM). Each stage consisted of 10 min of exercise at self-selected work rates equivalent to a rating of perceived exertion (RPE) of 3 (moderate), 5 (hard), and 7 (very hard) (0–10 Borg Category-Ratio Scale) (22). The participant was instructed on interpretation of the RPE scale during the warm-up and worked at each RPE during the warm-up (21). The first 5 min of exercise at each work rate allowed for the participant to reach the correct RPE and to achieve a steady state. During the second 5 min, HR and RPE values were recorded from the PHRM and AHRM, while actual EE was measured by IC. Heart rate, RPE, and work rate were recorded at 1-min intervals, and 5-min rest was given between each stage to allow for recovery.

Both the exercise mode and RPE were assigned in random order. For all submaximal tests the participants were blinded as to their HR. For the treadmill submaximal tests the grade was set at 0%, and the participant controlled the speed of the treadmill to reach the desired RPE. To eliminate bias of previous treadmill experience, participants could not see the speed they were walking/running at, and the investigator measured speed with a Nidec-Shimpo DT-107 handheld digital tachometer. On the cycle ergometer, the participant was allowed to pedal at a comfortable cadence that was maintained for all three RPE levels. As on the treadmill, the participant was not able to see the work rate, which was increased by the investigator until the desired RPE was reached. For the rowing ergometer, the participant maintained an average power output (W) that corresponded to the desired RPE.

RMR was measured by IC using a TrueMax 2400 computerized metabolic system. The participants came in early in the morning after an overnight fast, with the exception of water. They were also asked to refrain from stimulants

(including caffeine, tobacco, and medication) and intense physical activity for the 12 h before the test. Once the subjects arrived they were allowed to relax in a reclining position while the test was explained. Gas exchange measurements were taken for 40 min. The first 20-min period allowed the individual to return to achieve a stable baseline, and the second 20-min period was used for the determination of RMR.

Statistical treatment. Statistical analyses were carried out using SPSS version 11.5.0 for windows (SPSS Inc., Chicago, IL). Initially, three-way repeated measures ANOVA (intensity \times measurement device \times gender) were carried out to compare EE values ($\text{kcal}\cdot\text{min}^{-1}$) for each exercise device. The initial results showed that there was a gender effect, so all further analyses were done for each gender separately. Subsequently, two-way repeated measures ANOVA (intensity \times measurement device) were used to compare EE values ($\text{kcal}\cdot\text{min}^{-1}$) for PHRM, AHRM, and IC at all three RPE levels for each gender. Where appropriate, *post hoc* analyses were performed using Bonferroni corrections. An alpha of 0.05 was used to denote statistical significance.

Paired *t*-tests were performed to examine differences between predicted and actual $\dot{V}O_{2\text{max}}$ and HR_{max} . Pearson product moment correlation coefficients were performed to examine the strength of the relationship between predicted and actual $\dot{V}O_{2\text{max}}$.

Bland-Altman plots were used to graphically show the variability in individual estimated EE values ($\text{kcal}\cdot\text{min}^{-1}$) around zero (2). This allows for the mean error score and the 95% prediction interval to be shown. Devices that are accurate will display a tight prediction interval around zero. Data points below zero signify an overestimation, whereas points above zero signify an underestimation.

RESULTS

Descriptive data for males and females are presented in Table 1. In males, the average gross EE values for PHRM, AHRM, and IC on the treadmill, cycle, and rowing ergometer are shown in Figure 1. There were no differences in male EE values among PHRM, AHRM, and IC for any exercise mode ($P > 0.05$). Figure 2 shows the individual errors in estimating EE across all exercise modes. For the PHRM the mean error (IC - PHRM) was $-0.1 \text{ kcal}\cdot\text{min}^{-1}$ (-4.6 to

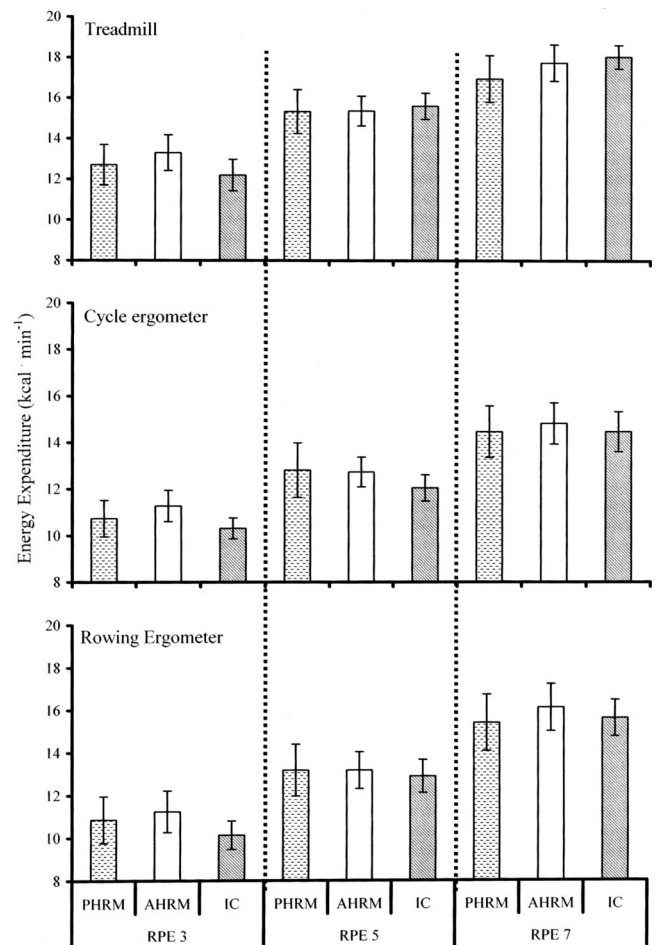


FIGURE 1—Male energy expenditure values at each RPE level (3,5,7) for the predicted heart rate monitor (PHRM), actual heart rate monitor (AHRM) and indirect calorimetry (IC) on the treadmill, cycle and rowing ergometer (mean \pm standard error).

$+4.3 \text{ kcal}\cdot\text{min}^{-1}$, 95% CI) and for the AHRM the mean error (IC - AHRM) was $-0.5 \text{ kcal}\cdot\text{min}^{-1}$ (-3.2 to $+2.1 \text{ kcal}\cdot\text{min}^{-1}$, 95% CI).

In females, average gross EE values for PHRM, AHRM, and IC on the treadmill, cycle, and rowing ergometer are shown in Figure 3. The PHRM significantly overestimated mean EE on the treadmill (by $2.4 \text{ kcal}\cdot\text{min}^{-1}$), cycle (by $2.9 \text{ kcal}\cdot\text{min}^{-1}$), and rower (by $1.9 \text{ kcal}\cdot\text{min}^{-1}$) (all $P < 0.05$). The AHRM for females significantly improved the estimation of mean EE for all exercise modes, but it still overestimated mean EE on the treadmill (by $0.6 \text{ kcal}\cdot\text{min}^{-1}$) and cycle (by $1.2 \text{ kcal}\cdot\text{min}^{-1}$) ($P < 0.05$). Figure 4 shows the individual errors in estimating EE across all exercise modes. For the PHRM, in females, the mean error (IC - PHRM) was $-2.4 \text{ kcal}\cdot\text{min}^{-1}$ (-5.2 to $+0.4 \text{ kcal}\cdot\text{min}^{-1}$, 95% CI). Although the AHRM still overestimated EE in females, the mean error (IC - AHRM) was improved to $-0.7 \text{ kcal}\cdot\text{min}^{-1}$ (-2.2 to $+0.8 \text{ kcal}\cdot\text{min}^{-1}$, 95% CI).

All participants achieved $\dot{V}O_{2\text{max}}$ based on the criteria used for the present study. For males, the mean predicted and measured $\dot{V}O_{2\text{max}}$ values were not significantly different ($P > 0.05$), but they were significantly different for females ($P = 0.001$). For males, there was a significant

TABLE 1. Physical characteristics of participants (mean \pm SD).

| | Men (N = 10) | Women (N = 10) |
|--|-----------------|-------------------|
| Age (yr) | 26 \pm 3.1 | 23 \pm 2.4 |
| Height (cm) | 179.6 \pm 4.7 | 167 \pm 4.0 |
| Weight (kg) | 83.6 \pm 21.6 | 58.5 \pm 5.7 |
| BMI ($\text{kg}\cdot\text{m}^{-2}$) | 25.9 \pm 6.1 | 21.0 \pm 1.8 |
| Measured $\dot{V}O_{2\text{max}}$ ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) | 51.0 \pm 11.4 | 42.2 \pm 4.0 |
| Predicted $\dot{V}O_{2\text{max}}$ ($\text{mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) ^a | 50.7 \pm 15.1 | 53.0 \pm 7.8 |
| Measured HR_{max} (bpm) | 190 \pm 10.3 | 191 \pm 6.7 |
| Predicted HR_{max} (bpm) ^a | 192 \pm 3.3 | 195 \pm 2.8 |
| Peak Lactate (mM) ^b | 11.7 \pm 2.3 | 9.3 \pm 1.7 |

^a Measured 3-min postmaximal treadmill exercise test.

^b Predicted using the Polar S410 HR monitor.

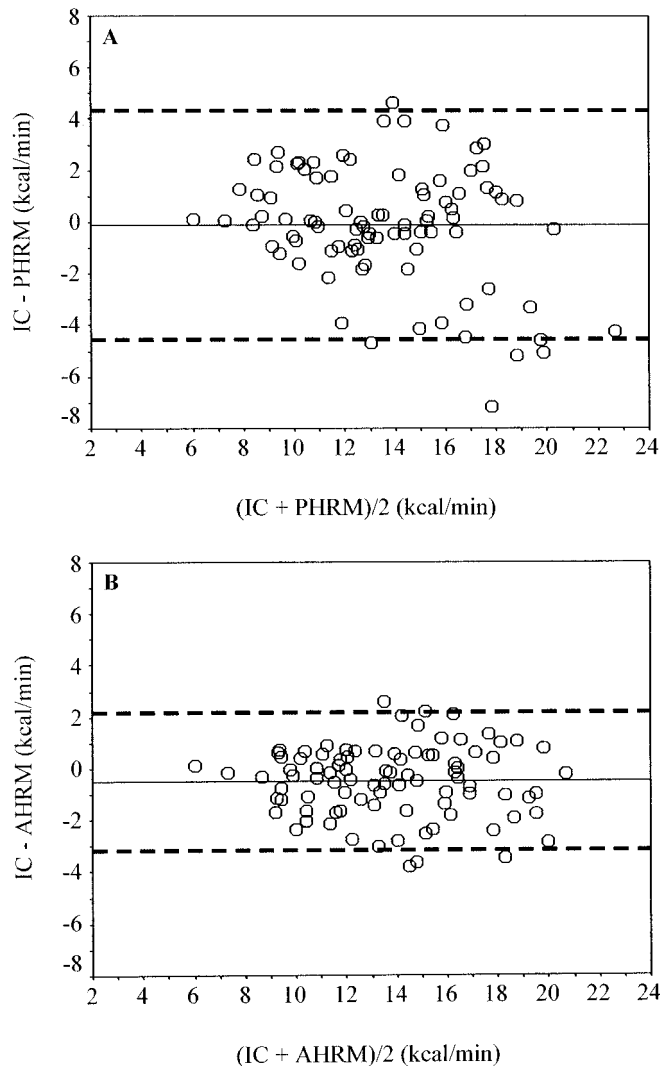


FIGURE 2—Bland-Altman plots depicting error scores (indirect calorimetry (IC) – device) for each watch in males: (A) Heart rate monitor with the predicted $\dot{V}O_{2max}$ and HR_{max} (PHRM), and (B) the heart rate monitor with the actual values (AHRM). *Solid line* represents mean difference; *dashed lines* represent 95% prediction intervals.

correlation between predicted and actual $\dot{V}O_{2max}$ ($r = 0.872$, $P = 0.001$) but not for females ($r = 0.477$, $P > 0.05$) (Fig. 5). There were no significant differences between predicted and measured HR_{max} for males or females ($P > 0.05$).

DISCUSSION

In males, there were no significant differences among the mean EE values for PHRM, AHRM, and IC for any exercise mode. Although the mean errors were close to zero, the Bland-Altman plots showed that, on an individual basis, there is considerable variation in the estimation of EE when using the PHRM. However, the AHRM tightened up the 95% prediction interval and provide a more accurate estimation of EE.

In females, the PHRM significantly overestimated EE for all exercise modes. The AHRM improved the estimates of

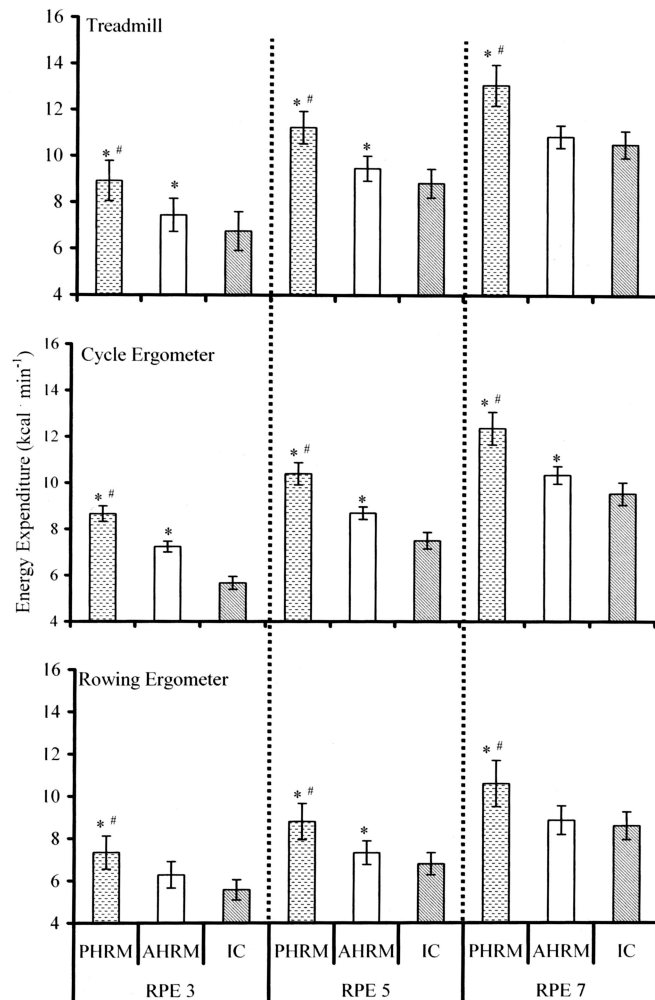


FIGURE 3—Female energy expenditure values at each RPE level (3,5,7) for the predicted heart rate monitor (PHRM), actual heart rate monitor (AHRM), and indirect calorimetry (IC) on the treadmill, cycle, and rowing ergometer (mean \pm standard error). #Significantly different from AHRM; *significantly different from IC ($P < 0.05$).

EE considerably, but there was still a small, but statistically significant, overestimation on the treadmill and cycle. In addition, the Bland-Altman plots show the same finding in females as in males with a tighter scatter of error scores around zero when using the AHRM.

A new finding of this study is that a simple, user-friendly device (the Polar HR monitor) can yield reasonable estimates of EE for exercise modes where motion sensors (i.e., pedometers and accelerometers) often fail. For example, Campbell et al. (4) showed that the Tritrac accelerometer was significantly different from IC for activities such as cycling, walking, jogging, and arm ergometer. For walking and jogging, the Tritrac overestimated EE by 30.6% ($SD \pm 23.4\%$) and 15.8% ($SD \pm 2.3\%$), respectively, whereas it underestimated cycling EE by 53% ($SD \pm 59.53\%$). Jakicic et al. (13) found a similar magnitude of error as Campbell et al. (4) during treadmill walking/running, stepping, cycling, and slideboard exercises. In the current study, when the actual $\dot{V}O_{2max}$ and HR_{max} were used, the Polar S410 had a mean error of 4% ($SD \pm 10\%$) in males, whereas in females

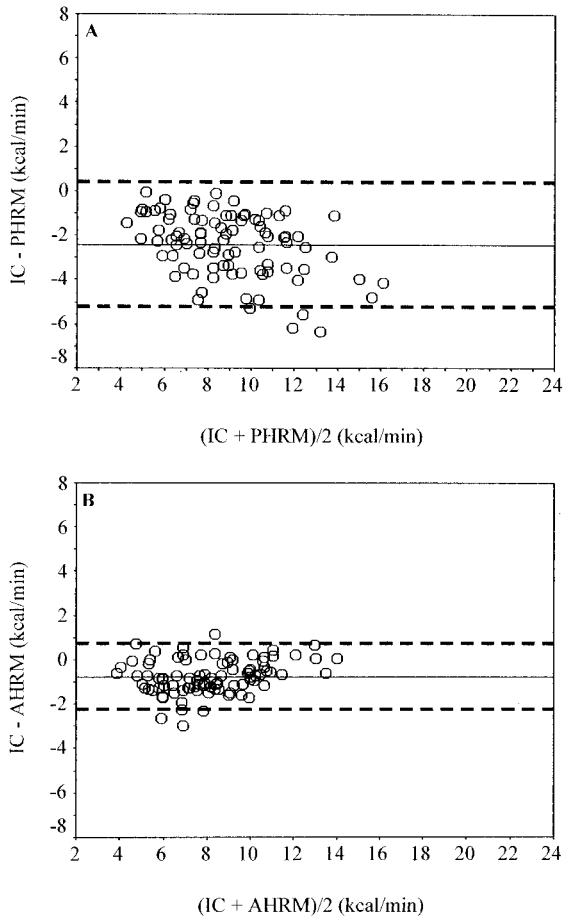


FIGURE 4—Bland-Altman plots depicting error scores (indirect calorimetry (IC) – device) for each watch in females: (A) heart rate monitor with the predicted $\dot{V}O_{2max}$ and HR_{max} (PHRM), and (B) the heart rate monitor with the actual values (AHRM). *Solid line* represents mean difference; *dashed lines* represent 95% prediction intervals.

the mean error was 12% (SD \pm 13%). The advantage of using HR is that it is a physiological parameter that can detect changes in exercise intensity even when the movement patterns differ greatly. Thus, the HR monitor is able to estimate EE in activities such as rowing and cycling, which do not elicit vertical displacement of the trunk, where pedometers and accelerometers would fail (4,13).

It is important to note the differences between the Polar method of estimating EE and the Flex HR method. The Flex HR method utilizes HR and $\dot{V}O_2$ measured at rest (lying, standing, sitting) and during exercise of various intensities to develop HR- $\dot{V}O_2$ calibration curves (10). The Flex HR is defined as the average of the highest HR during rest and the lowest HR during light exercise. In a field setting, the assumed RMR (1 MET) is used for any value below the Flex HR, whereas the HR- $\dot{V}O_2$ calibration curve is used to estimate EE for any value above the Flex HR. A drawback to this method is that it is time consuming to develop individual calibration curves for individuals (10). The present study examined planned bouts of structured exercise whereas Flex HR studies have used much longer time periods, ranging from 6 h (23,25) to 3–4 d (18). It should be noted that the

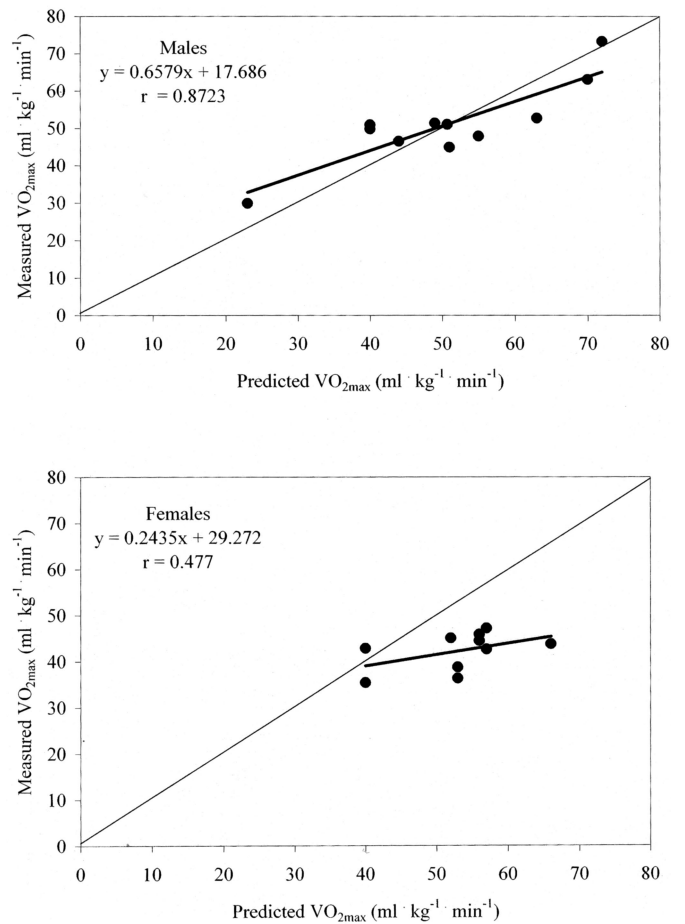


FIGURE 5—Relationship between measured and predicted $\dot{V}O_{2max}$ (mL \cdot kg $^{-1}$ \cdot min $^{-1}$) for males and females.

Polar watch can only estimate EE during exercise when the HR is \geq 90 bpm or \geq 60% of the individual's HR_{max} . Thus, the Polar watch fails to record EE data at rest and during light-intensity physical activity. For this reason, we considered the possibility that the Polar HR monitor measures net EE, but our analyses showed that it more closely approximates gross EE (data not shown).

A practical application of the Polar S410 is that it provides reasonable estimates of gross EE during exercise when using an individual's measured $\dot{V}O_{2max}$ and HR_{max} . There is an emerging belief that a combination of devices may yield more accurate estimates of EE than any single method (10,14). The use of a Polar HR monitor to capture exercise plus motion and position sensors to capture ubiquitous PA (summed together) could be a good way to estimate total EE. Previously, Levine et al. (17) have shown that by using accelerometers and inclinometers to capture body motion and position, they can account for 85% of nonexercise activity thermogenesis (NEAT). NEAT is comprised of several components such as occupational work, walking, sitting, standing, and any other nonexercise movement performed throughout the day. Thus, a person could wear the motion and position sensors throughout the day and remove them and put on the HR monitor when performing structured exercise.

The Polar S410 accurately predicted $\dot{V}O_{2\max}$ in males, but not in females. It is difficult to draw conclusions about this due to the small sample size, but it may be important in explaining some of our results. In addition, Polar uses a proprietary algorithm for estimating $\dot{V}O_{2\max}$, HR_{\max} , and exercise EE. The Polar S410 significantly overestimated the female $\dot{V}O_{2\max}$ by $10.8 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, which led to a greater overestimation of EE than when the actual values were used. In females, but not males, the use of measured $\dot{V}O_{2\max}$ and HR_{\max} significantly improved the mean estimate of EE during exercise. Since there was no difference between the predicted and actual $\dot{V}O_{2\max}$ in males, both watches gave similar mean values for EE. However, in both the males and females the use of measured $\dot{V}O_{2\max}$ and HR_{\max} provided a tighter prediction interval around zero, which indicates that the actual values must be programmed into the watch for greater accuracy. A limitation of this study is that it examined only healthy college aged students. Thus, the results may not be applicable to individuals who fall outside the age and fitness range of the participants we examined.

In an effort to understand how the Polar S410 estimates EE, we examined the relationship between estimated EE and HR, when the actual $\dot{V}O_{2\max}$ and HR_{\max} were programmed into the watch. Figure 6 is a representative graph for two participants (one male and one female), showing that there is a strong linear relationship ($r = 0.99$) between HR and estimated EE, but it is unique to each participant. Therefore, we reasoned that the Polar heart watch must be taking into account the individual's HR_{\max} and $\dot{V}O_{2\max}$. Figure 7 illustrates the positive, linear relationship between the percentage of HR_{\max} and the percentage of maximal energy expenditure for the same two participants in Figure 6. This time, the regression line was nearly identical for each participant, and it

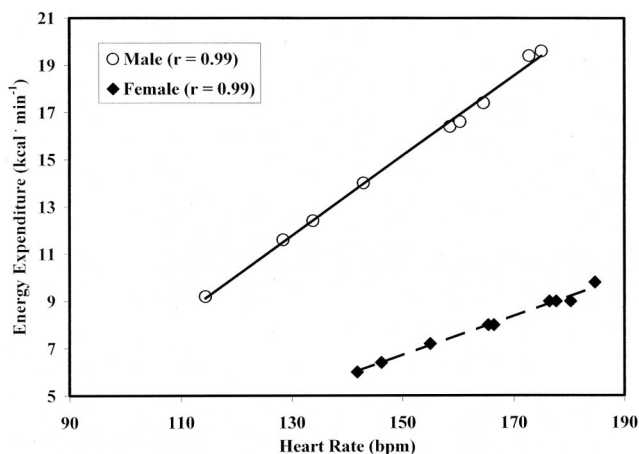


FIGURE 6—Representative data for two participants (one male and one female), showing the relationship between predicted energy expenditure and heart rate. Male: *open circles* with solid regression line ($\dot{V}O_{2\max} = 52.7 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $HR_{\max} = 186 \text{ bpm}$, Fitness level = top). Female: *closed diamonds* with dashed regression line ($\dot{V}O_{2\max} = 42.8 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $HR_{\max} = 198 \text{ bpm}$, Fitness level = middle).

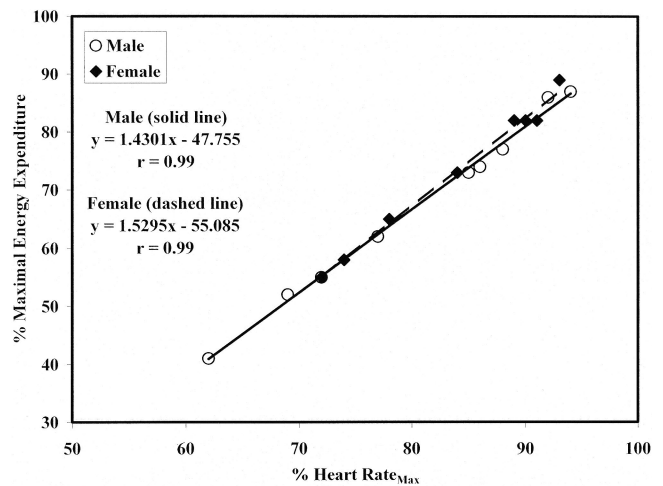


FIGURE 7—Representative data for two participants showing the relationship between the percent of maximal energy expenditure and the percent of maximal heart rate. Male: *open circles* with solid regression line ($\dot{V}O_{2\max} = 52.7 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $HR_{\max} = 186 \text{ bpm}$, Fitness level = top). Female: *closed diamonds* with dashed regression line ($\dot{V}O_{2\max} = 42.8 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, $HR_{\max} = 198 \text{ bpm}$, Fitness level = middle).

was similar for all participants, regardless of fitness level, gender, or other variables. Thus, it appears that the Polar S410 is using the percentage of HR_{\max} to estimate the percentage of $\dot{V}O_{2\max}$, which is then converted to caloric expenditure.

An important consideration if using a Polar HR watch is that the “OwnCal” software is only available with certain Polar watches. The S-Series watches (used in the present study) have the capability to program in measured $\dot{V}O_{2\max}$ and HR_{\max} . The S-Series watches range in price from \$179 to \$400, depending on the features of the watch. There are two M-Series watches (M91Ti and M61) that estimate exercise EE, but they utilize gender, body weight, and exercise heart rate. The M-Series watches range in price from \$169 to \$249, so at the same price the S-Series can provide additional features to improve the accuracy of the estimated exercise EE.

In conclusion, when the predicted values of $\dot{V}O_{2\max}$ and HR_{\max} are used, the Polar S410 HRM provides a rough estimate of EE during treadmill, cycling, and rowing. For males, the use of predicted values resulted in a mean error of 2% ($SD \pm 18\%$), whereas in females the mean error was 33% ($SD \pm 20.9$). To improve on the accuracy, the actual measured values for $\dot{V}O_{2\max}$ and HR_{\max} should be used. For males, this resulted in a 4% error ($SD \pm 10\%$), whereas in females the mean error was improved to 12% ($SD \pm 13\%$). In addition, the Polar S410 has an important advantage over motion sensors in that it is applicable to a variety of exercise modes.

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