ACCURACY OF THE SENSEWEAR PRO ARMBAND™ DURING SHORT BOUTS OF EXERCISE

by

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Abstract

Due to the limitations of traditional metabolic measuring systems and other devices used to measure energy expenditure, new technologies that are more mobile and comfortable are being designed for use in the physical activity monitoring. One product in particular, developed by Body Media, is known as the SenseWear Pro Armband™. The device, worn around the subject's upper arm, collects information through sensors that measure heat flux, skin temperature and response, and body temperature. Along with demographic information, this information is used to calculate the energy expenditure. The SenseWear Pro Armband™ is wireless, which makes energy expenditure measurements in the lab easier to obtain. However, it is still a relatively recent innovation. More testing is needed, especially during short bouts of activity, to confirm its validity for energy expenditure measurement. The purpose of this study was to compare the energy expenditure data obtained from the SenseWear Pro Armband™ to indirect calorimetry in a cross sectional cohort study during five exercise intensities: walking at preferred speed, running at preferred speed and running at speeds corresponding to 75%, 85% and 95% of predicted VO_2max. Participants (n=10) were fitted with the SenseWear Pro Armband™ and equipped for indirect calorimetry assessment. Minute-by-minute data was exported from each device for all 4-minute exercise conditions. Total energy expenditure in the form of average and peak kilocalories expended was compared between the two devices. The SenseWear Pro Armband™ had a statistically significant overestimation in the preferred walking condition in both average (38%) and peak (45%) kilocalories burned per minute. There was also an observable underestimation by the armband in the 95% pVO_2max

condition in both the average (14%) and peak (12%) kCal/min. Minimal difference were

noted during the moderate intensity running conditions (1-7%).

BACKGROUND

According to the American College of Sports Medicine, physical activity is known as "any bodily movement produced by the contraction of skeletal muscles that results in a substantial increase in caloric requirements over resting energy expenditure".[1] The closely related term "exercise" occurs when physical activity in the form of repetitive body movements is planned out and structured as a means of improving physical health and fitness.[1] Physical activity and exercise are both important factors to our overall health. Researchers are constantly investigating the effects that physical activity and exercise, can have on the human body. Much research has been done and continues to be conducted in this field in order to discover what kinds of physical activity and exercise can provide certain populations with the most health benefits possible.

One particular hot topic in the exercise field right now is high intensity interval training. High intensity interval training can be loosely defined as repetitive, short bouts of high-intensity exercise with recovery breaks in between each bout.[2] These relatively brief and intense interval programs are designed to stress the oxygen transport system, recruit large motor units, and reach maximal cardiac output in order to improve maximal oxygen uptake (VO_2max).[3] When compared to periods of prolonged, moderate-intensity exercise, these high-intensity interval protocols have been shown to have many health benefits. Helgerud et al. (2007) found that subjects who completed 8 weeks of interval training protocols had significantly improved their VO_2max, or aerobic capacity for exercise, when compared to subjects who completed low-intensity exercise protocols.[4] Another study, Talanian et al. (2006), found that performing just two weeks of high-intensity interval training increased whole body fat oxidation in recreationally active females.[5] High-

intensity interval training may also have to potential to positively influence bone and joint health. In one study, subjects who participated in an interval training protocol had decreases in their body fat when measured using skinfold assessment, suggesting that high intensity interval training could have a positive effect on overall body composition.[6] To our knowledge, the benefits that interval training could have on bone and joint health have not been heavily investigated. One could speculate that interval training could be beneficial for bone health because high impact exercise has been proven to increase bone density and bone strength.[7]

In order for researchers to examine the effects of interval training on bone and joint health, both biomechanical and physiological data are needed. Biomechanical data obtained from motion capture and force plate is needed to calculate loads on the joints of interest; physiological data is required to monitor the intensity of the exercise to ensure it is meeting the high level requirements of interval training and guide exercise design. Biomechanical data is commonly collected through the use of 3-dimensional motion capture analysis. These systems use multiple small reflective markers adhered to the subject, while cameras around the testing area record the markers' movements. The images recorded from the markers are transformed into a three dimensional model using a computer software. Subjects are often fitted with over 50 of the reflective markers during a single data collection, which has the potential of exacerbating the seemingly unnatural setting of the laboratory for the study of human movement. Physiological data is commonly collected through indirect calorimetry via a metabolic cart. This equipment measures the oxygen inspired and carbon dioxide expired by the subject during activity to calculate the energy they are expending in the form of Metabolic Equivalents (METs) and kilocalories

burned per minute (kcal/min).[8] The metabolic cart, while being one of the gold standards for measuring energy expenditure, involves cumbersome equipment. The facemask, covering the nose and mouth of the wearer, can become very hot and can make the wearer feel claustrophobic. The mask is also tethered to the cart via a flexible hose, restricting how far the wearer can move away from the cart. Data collected from both of the biomechanical and metabolic technologies described are imperative for a study investigating effects of interval training on bone loading, but the combination of the motion capture and metabolic cart equipment is burdensome for the researcher and the participant to use simultaneously to collect accurate data.

Fortunately, there has been a rise in the development of new energy expenditure measuring technologies that are allowing researchers to collect data in a more natural environment. These devices are smaller, more mobile, and overall more comfortable for the wearer, allowing the physiological data to be collected without biasing the data due to an unnatural laboratory setting. One tool in particular is the SenseWear Pro Armband™, developed by BodyMedia. This device is worn on the upper left arm during physical activity. Through sensors on the armband, it takes in information from the wearer's locomotion, skin temperature, heat flux, and Galvanic skin response, along with subject demographic data, to calculate the energy expended in the form of METs and kilojoules burned per minute.[9] The data collected from the armband can be exported into accompanying computer software for analysis, making it a very easy-to-use tool for researchers.

The SenseWear Pro Armband™, while convenient for use in a biomechanical study, is still a relatively new tool for measuring physiological output. Studies have been conducted to determine the armband's validity when compared to the current standards for metabolic measurements, but many of these studies test the armband out in long periods of continuous physical activity and exercise.[9] To determine if the SenseWear Pro Armband™ is a reliable tool for measuring energy expenditure during an interval training protocol, the validity of the armband needs to be assessed during short bouts of exercise at varying intensities.

PURPOSE OF STUDY

The purpose of this study is to compare the energy expenditure data obtained from the SenseWear Pro Armband™ to indirect calorimetry during low, moderate, and high-intensity exercise intervals. This experiment aims to determine the accuracy of the SenseWear Pro Armband™ in short bouts of exercise to determine if it will suffice as a tool for measuring physiological data during a high-intensity interval training protocol.

METHODS

Participants

Ten healthy young adults, five males and five females ranging in age from 20 to 30 years old, participated in this study. All participants were free of any known cardiovascular problems, neuromuscular, musculoskeletal, or rheumatoid disorders exacerbated by exercise, uncontrolled metabolic disease, chronic infectious disease, mental or physical impairment that restricts ability to exercise, or current pregnancy. All volunteers were required to be recreationally active runners, with a Perceived Functional Ability (PFA) score of ≥16/26 (11-12 minutes per mile pace), a Physical Activity Rating (PA-R) of ≥6/10 (Runs ≥5 miles per week), and a treadmill comfort score of ≥7/10 (completely comfortable).

Protocol

Testing was completed in one visit to the Human Performance Laboratory located in Ward Sports Medicine Complex at East Carolina University. Prior to participation, subjects were screened for all inclusion criteria and were interviewed using the AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire to ensure low risk classification according to the AHA/ACSM Risk Stratification guidelines. Informed consent was also obtained prior to participation. After successful clearance for exercise testing, participants began the testing protocol. Participants were equipped with the SenseWear Pro Armband™ (BodyMedia, Pittsburgh, PA) worn on the triceps of their non-dominant arm, which was calibrated prior to testing using demographic data provided by the subject. They were also fitted with a facemask, which was connected to the metabolic cart (ParvoMedics Metabolic Measuring Systems, Sandy, UT) in order to measure their oxygen

intake and carbon dioxide output levels through indirect calorimetry. The participants'

VO$_2$maxes were predicted using the George Non-Exercise Test (R = 0.86 and SEE = 3.34).

The equation (Figure 1) factors in the subject's sex, body mass index (BMI), and PFA and

PA-R scores to determine the predicted VO$_2$max.[10]

Predicted VO$_2$max equation:

$$pVO_2max = 45.513 + (6.564 \times Sex) - (0.749 \times BMI) + (0.724 \times PFA) + (0.788 \times PAR)$$

Where: Sex = 1 for males, 0 for females

Metabolic equivalent running equation:

$$\%VO_2 = (0.2 \times speed) + (0.9 \times speed \times grade) + 3.5$$

Figure 1. Metabolic equations for predicting VO$_2$max and corresponding speeds.

Prior to initiating the exercise data collection, participants were asked to warm up by

walking on the treadmill for five minutes. Data from the SenseWear Pro Armband™ and

the metabolic cart were continuously recorded as the subjects completed 5 short

conditions: walking at a preferred pace, running at a self-selected training pace, and

running at speeds corresponding to 75, 85, and 95% of their VO$_2$max, which were

calculated using a metabolic equivalent running equation (Figure 1).[1] Each condition lasted

for a period of four minutes, and there was an active recovery period of at least three

minutes in between each condition. During this period, participants walked at their pre-

determined preferred walking speed. All condition orders were randomized for each

participant in order to minimize fatigue effects. During testing, heart rate (HR) was

recorded at each minute and Ratings of Perceived Exertion (RPE) were recorded at the end

of each condition.

Data Analysis

Energy expenditure (kCal) collected simultaneously from the SenseWear Pro Armband and the metabolic cart were exported from the SenseWear Pro software (Version 8.1) and the Parvo Medics software. Data from both technologies were collected continuously with both devices and time stamped for synchronization. Time interval data from each condition were extracted for analysis (Figure 2). For the 4 minute intervals, average kCal expended and peak kCal expended per minute were analyzed. Paired sample T-tests were used to determine energy expenditure differences between the two technologies for each condition as well as the total interval session. For each condition, intraclass correlations (ICC) were computed to examine level of consistency between the technologies for average kCal/minute, peak kCal/minute, and total kcal expended for the interval session. All analyses were performed in SPSS version 22. Bland-Altman methods were employed to graphically examine level of agreement across the range of exercise intensities and examined and total kcal expended.
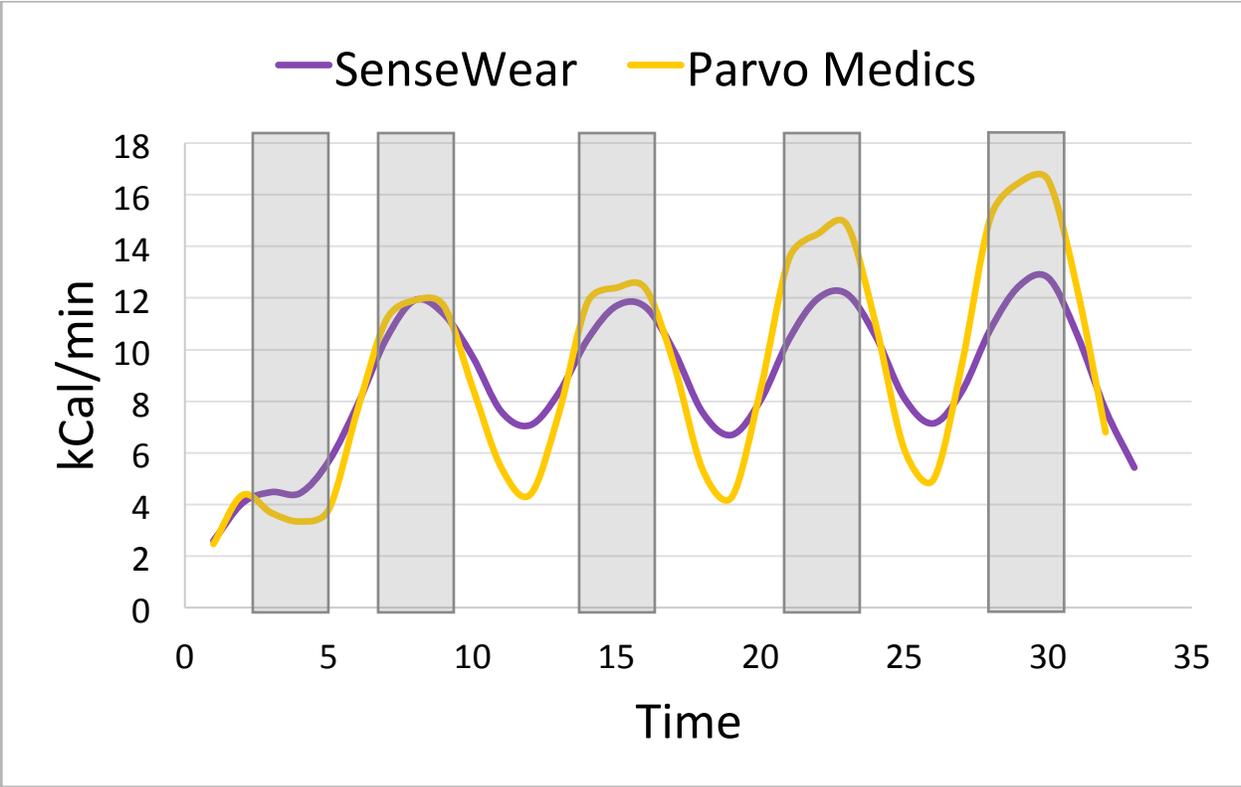
Figure 2. Graphical illustration of SenseWear Pro Armband™ and metabolic cart data collected during a single protocol. Gray boxes represent the time intervals extracted for analysis for each condition. From left to right, the conditions are as follows: preferred walking, preferred running, 75% pVO₂max, 85% pVO₂max, and 95% pVO₂max.

RESULTS

A total of ten subjects, five males and five females, completed our protocol (Table 1). Overall, the male participants were older and had higher body mass indexes (BMI) and predicted VO$_2$maxes (pVO$_2$max). Female subjects had higher self-selected walking and running paces, while males had higher calculated speeds for the 75, 85, and 95% intensity intervals.

Table 1. Demographic data of study participants.

Variable	Male (n=5)	Female (n=5)	Total (n=10)
Age (years)	26.4 (±2.3)	23.0 (±4.1)	24.7 (±3.6)
Height (cm)	175.7 (±6.2)	168.7 (±7.0)	172.2 (±7.3)
Weight (kg)	77.5 (±11.8)	63.2 (±9.2)	70.4 (±12.5)
BMI (kg/m^2)	25.0 (±3.3)	22.3 (±2.2)	23.6 (±3.0)
PFA	21.4 (±1.3)	21.0 (±2.8)	21.2 (±2.1)
PA-R	7.0 (±1.0)	7.4 (±1.9)	7.2 (±1.5)
pVO$_2$max (ml/kg/min)	53.2 (±4.1)	48.1 (±5.9)	50.6 (±5.5)
Preferred Walking Speed (mph)	2.6 (±0.3)	3.2 (±0.5)	2.9 (±0.5)
Preferred Running Speed (mph)	6.3 (±0.7)	6.4 (±1.1)	6.3 (±0.9)
75% pVO$_2$max Speed (mph)	6.8 (±0.6)	6.1 (±0.8)	6.4 (±0.7)
85% pVO$_2$max Speed (mph)	7.8 (±0.7)	6.9 (±0.9)	7.3 (±0.9)
95% pVO$_2$max Speed (mph)	8.7 (±0.7)	7.3 (±1.3)	8.0 (±1.2)

Paired t-tests were conducted to examine the differences in measurements of kilocalories expended per minute (kCal/min) in the SenseWear Pro Armband™ and metabolic cart. Analyses were conducted on both the average (Figure 3) and peak (Figure 4) kilocalories burned per minute during each condition. There was a statistical difference

of the two measurements for the average kCals/min observed in the preferred walking speed (p = 0.001) and the 95% pVO_2max conditions (p = 0.01). The armband tended to overestimate the average kilocalories per minute by 1.5 kCal/min (38%) in the preferred walking condition, and underestimate the 95% running condition by 2 kCal/min (14%). Similarly, there was a statistical difference observed between the armband and metabolic cart for the peak kilocalories expended per minute in the preferred walking condition (p < 0.001) and the 95% pVO_2max condition (p = 0.01). Again, the armband significantly overestimated the kilocalories burned per minute in the preferred walking speed by 2 kCal/min (45%), and underestimated the kCal/min in the 95% pVO_2max condition by 1.8 kCal/min (14%). While these differences were observed in the extreme low and high intensity conditions, there were minimal differences noted during the moderate intensity running conditions for both average and peak kilocalories, ranging in a difference of 0.1 to 0.9 kCal/min (1-7%). When the total energy expenditure was examined, there was no statistical difference between the devices when measuring the cumulative kilocalories expended over the entire testing protocol (p = 0.078).
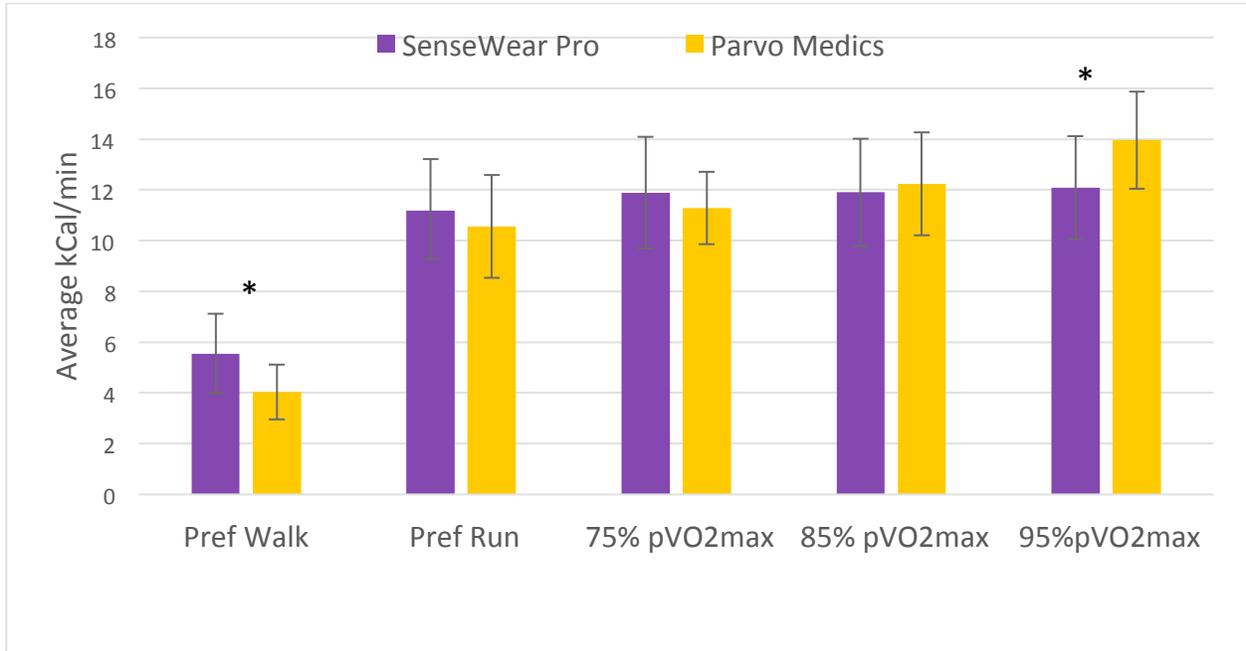
Figure 3. Graphical illustration of the mean average kilocalories expended per minute in each condition across subjects from the SenseWear Pro Armband™ and the Parvo Medics metabolic cart. Error bars indicate standard deviations. Asterisks indicate significant differences between devices ($p > 0.05$)
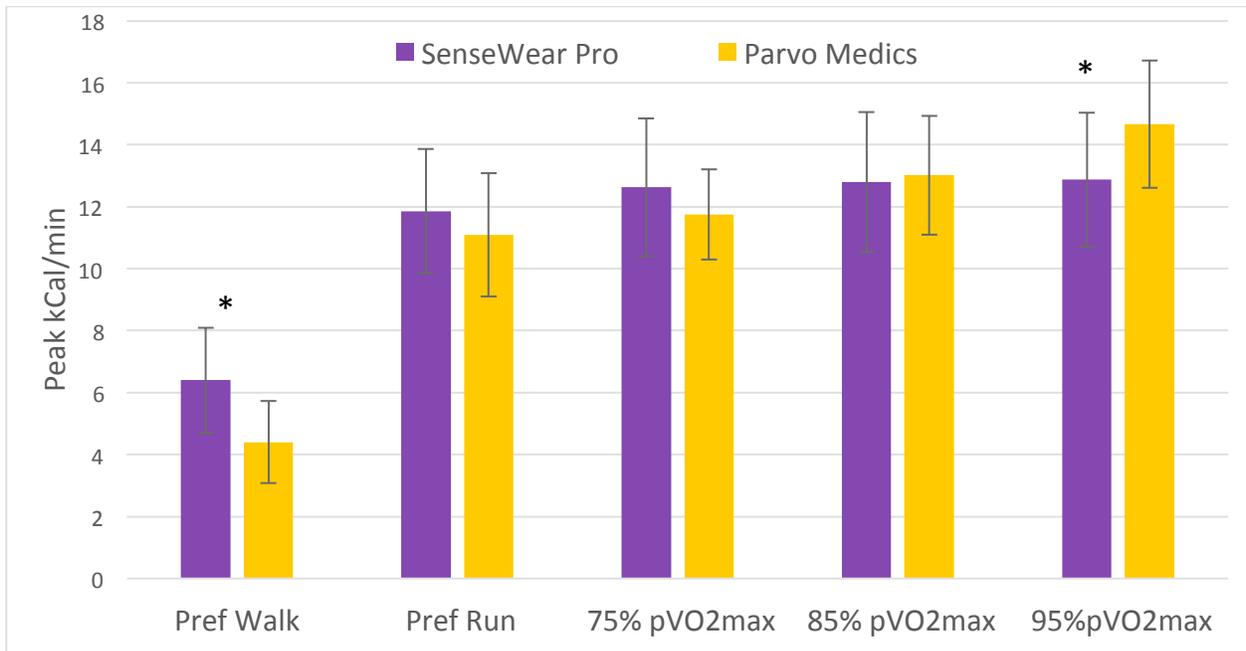

Figure 4. Graphical illustration of the mean peak kilocalories expended per minute in each condition across subjects from the SenseWear Pro ArmbandTM and the Parvo Medics metabolic cart. Error bars indicate standard deviations. Asterisks indicate significant differences between devices ($p > 0.05$)

Intraclass correlations (ICCs) were calculated for each condition to determine the level of consistency between the SenseWear Pro Armband™ and the metabolic cart. Single and average ICCs were computed for the average and peak kCal/min for each condition, as well as the cumulative kilocalories over the entire protocol. The ICC values can be seen in Table 2. Overall, average ICC values were higher than single values for average, peak, and cumulative kCal. The ICCs favored the peak kCal/min in all conditions except the preferred running condition when compared to average kCal/min.

Table 2. Intraclass correlation values for average, peak, and total kCal/min representing the level of consistency between the SenseWear Pro Armband™ and metabolic cart.

| Condition	Average		Peak	
	Single	Average	Single	Average
Preferred Walking	0.722	0.838	0.779	0.876
Preferred Running	0.568	0.724	0.565	0.722
75% pVO2max	0.681	0.810	0.720	0.837
85% pVO2max	0.584	0.737	0.729	0.844
95% pVO2max	0.561	0.719	0.612	0.759

**Cumulative exercise kcal Single ICC = 0.84 and Average ICC =0.891

Bland Altman plots were graphed to examine the level of agreement across all the conditions for average and peak kCal/min. The overestimation by the SenseWear Pro Armband of kilocalories expended in the preferred walking conditions can be observed in both the average (1.5 kCal/min, 95% CI: 0.8, 2.2) and peak (2 kCal/min, 95% CI: 2.7, 1.3) plots. The underestimation by the armband in the high intensity 95% pVO_2max condition can also be observed in the average (-2 kCal/min, 95%CI: -3.2, -0.5) and the peak (-1.8 kCal/min, 95% CI: -3.1, -0.5) plots.

Figures 5-9. Bland Altman
Plots of the average kCal/min
Solid line indicates the mean
difference between the
Sensewear Pro Armband
(SWA) and Parvomedics
indirect caloriometry (PIC).
Dashed lines represent the
limits of agreement.

Preferred Walking

Preferred Running

75% pVO2max

85% pVO2max

95% pVO2max
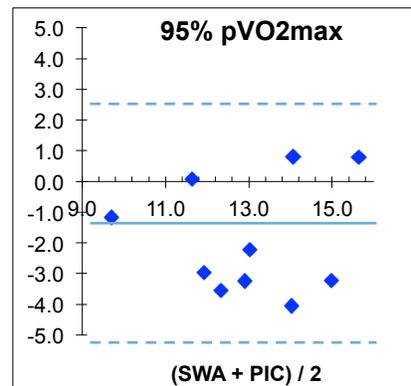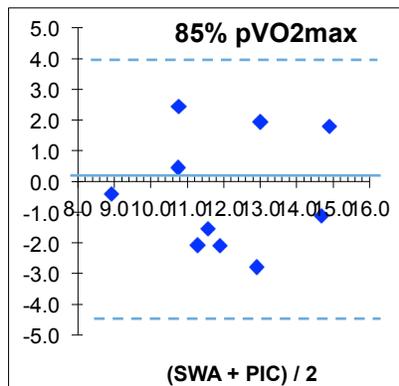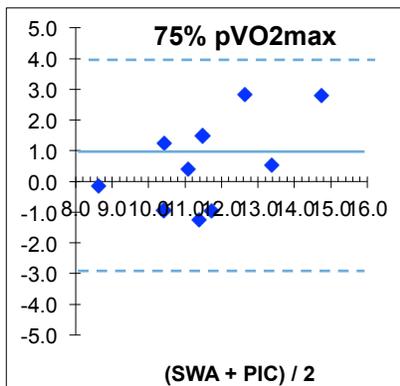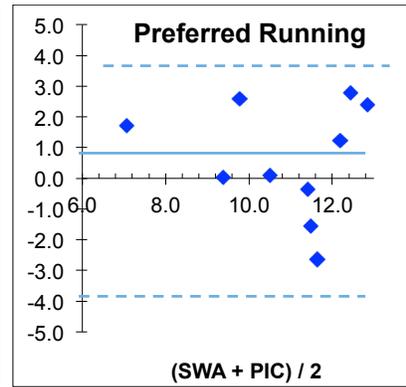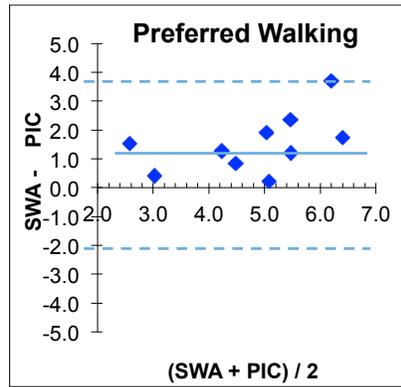
Figures 10-14. Bland Altman
Plots of the peak kCal/min.
Solid line indicates the mean
difference between the
Sensewear Pro Armband
(SWA) and Parvomedics
indirect caloriometry (PIC).
Dashed lines represent the
limits of agreement.

Preferred Walking

Preferred Running

75% pVO2max

85% pVO2max

95% pVO2max
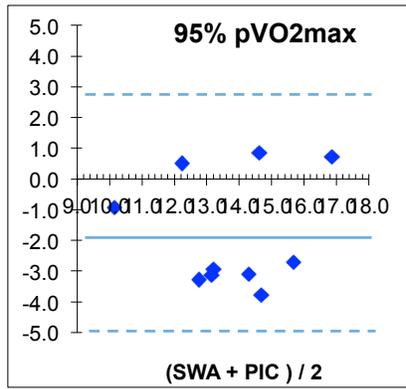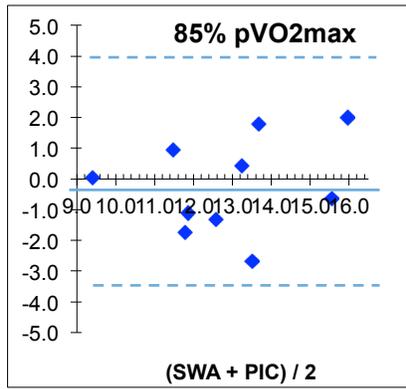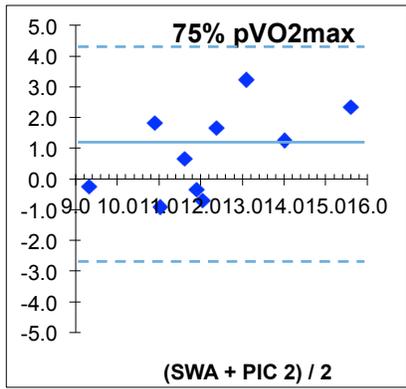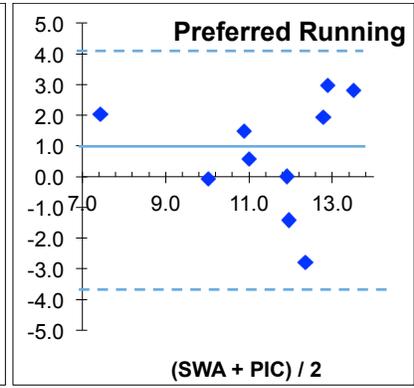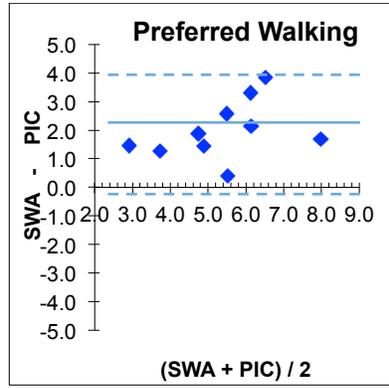
DISCUSSION

The aim of this study was to compare the energy expenditure measurements between the SenseWear Pro Armband™ and indirect calorimetry during short conditions of varying intensities. Our aim was to find a mobile, yet reliable device for measuring energy expenditure so that it could be utilized in a biomechanical study focusing on the health effects of high intensity interval training on bone. Data was collected and analyzed from both the armband and the metabolic cart, and the average, peak, and total kilocalories expended per minute were compared between the two devices. It was determined through paired t-tests, intraclass correlations, and Bland Altman plots that the SenseWear Pro Armband™ overestimated kilocalories expended at low intensity walking conditions, and underestimated kCal/min in high intensity running conditions. However, during moderate intensity running conditions, the SenseWear Pro Armband™ was seemingly valid for measuring energy expenditure when compared to the metabolic cart. Over the total exercise period the SenseWear Pro Armband™ also appeared to capture energy expenditure with good accuracy and consistency.

Our findings were consistent with similar previous studies conducted to test the validity of the SenseWear Pro Armband™. Drenowatz et al. (2010) compared the armband to indirect calorimetry in three running conditions of varying intensities, and also found that the armband was not an accurate estimator of energy expenditure at very high intensities of running.[9] This study examined the armband's validity at longer bouts of exercise (10 minutes per condition) than our protocol, yet they still had similar conclusions. A need exists for improved exercise specific algorithms to be developed by the manufacturer to enhance the validity of the armband at low and high intensity levels to

potentially make the armband a more reliable tool for short bouts of exercise. Other authors have used this approach with improvement in prediction reported. Jakacic et al. found that the armband tended to underestimate energy expenditure during walking using a generalized proprietary algorithm. However, when an exercise specific algorithm was applied, devices differences disappeared.[11] Data analysis suggested that examining peak kCal/min values for each condition tended to be more accurate than the average kCal/min, but the development of improved algorithms could potentially improve the average kilocalorie values.

The underestimation of energy expenditure at high intensity exercise by the SenseWear Pro Armband™ was expected based on previous literature, and could have been caused by a number of factors.[9] Overall, the small sample size had the potential to bias the data. Factors such as sex, body mass index, body composition, and exercise capacity could have impacted results. A larger sample size is needed to more fully explore the influence of these factors on the armband measures. Also, the use of the prediction equations for determination of VO_2max could have resulted in speeds that were not fully representative of the subject's actual oxygen capacity thus leading to confounding degrees of exercise intensities between individuals. While the underestimation at the high intensity speeds was previously observed, the overestimation at the low intensity walking speeds was surprising. Not only did the armband significantly overestimate the kilocalories during the preferred walking condition, which was used as a warm-up period for the participants before the running conditions began, but it frequently overestimated the energy expended during the recovery walking phases in between each condition (see Figure 2). The armband uses a variety of sensors that take in information regarding the wearer's skin temperature,

heat flux, and Galvanic skin response (rate of perspiration). It is likely that this overestimation between each condition occurred because the subject was still hot and sweaty from the previous running condition, an effect that was also observed in the Drenowatz study[9]. This, however, does not explain the overestimation during the warm-up phase before the subjects had any running conditions. More detailed analysis of walking data throughout our data collection period is needed. The possibility exists that the armband's, as well and the metabolic cart's, prediction algorithms are less accurate during this phase due to online adjustment and calibration, however this is speculative and we currently do not have data to support this.

While the SenseWear Pro Armband™ did not show adequate accuracy for some conditions of our protocol, the portable device still has potential to be utilized in a biomechanical study on interval training and its effects on bone health. The armband was comparable to indirect calorimetry for the moderate intensity running conditions. Further testing could be done with more subjects to increase the amount of data and potentially help eliminate outliers. Importantly, other factors such as heart rate and rate of perceived exertion could be included in prediction algorithms using regression analysis to further improve the accuracy of the data collected from the armband. Similarly other factors that could influence predictions, such as sex, exercise capacity, body composition, and body mass index, could be assessed for contributions to energy expenditure. Use of such variables along with armband data may improve energy expenditure estimates.

In conclusion, we found that the SenseWear Pro Armband™ adequately assessed energy expenditure during short bouts of moderate intensity running. Further prediction

equations need to be developed in order to improve energy expenditure predictions for short bouts of low and high intensity treadmill exercise using a larger sample size. This capacity will markedly enhance our ability to use the SenseWear Pro Armband™ as surrogate to track energy expenditure during high intensity interval training.

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