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Validation of a Physical Activity Monitor as an Estimation of Energy Expenditure During a Circuit-Style Workout with Females who are Overweight or Obese

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Abstract

Background: While the SenseWear Armband (SWA) has been validated for a variety of physical activities, it has not been validated with circuit-style exercise for individuals who overweight (25-29.9 kg/m^2) or obese (≥ 30 kg/m^2).

Purpose: The purpose of this study was to validate the SWA for measuring energy expenditure in overweight or obese females during circuit-style training.

Methods: Overweight and obese females, $N = 40$, 20-59 years of age, completed a pre-recorded circuit-style exercise session DVD consisting of eight exercises. An SWA and portable metabolic analyzer were worn by each participant throughout the exercise session to measure energy expenditure.

Results: While the total overall energy expenditure between devices was not significantly different ($p = 0.882$), both energy expenditure excluding rest periods ($p < 0.001$) and rest periods between exercises ($p = 0.007$) were significantly different when the SWA was compared to the portable metabolic analyzer. The SWA overestimated exercise energy expenditure, but underestimated rest period energy expenditure compared to the portable metabolic analyzer.

Conclusion: The results suggest females who are overweight or obese could use a SWA to aid in tracking caloric expenditure with circuit-style training. However, care must be used if looking at individual exercise components.

Keywords

SenseWear armband, Physical activity, Circuit training

Introduction

In the United States, the prevalence of obesity remains a major health concern with 154.7 million adults who are overweight (Body Mass Index [BMI] ≥ 25 kg/m^2) or obese (BMI ≥ 30 kg/m^2) [1]. Sedentary behaviors along with lack of physical activity and an increase in high fat diets result in an imbalance between energy intake and expenditure resulting in overweight and obesity. Individuals who are overweight or obese have an increased risk for heart disease, type 2 diabetes, hypertension, arthritis, and cancer [2]. In 2008, $209.7 billion was spent nationally to treat obesity-related illness in adults, with women who are overweight or obese having an added annual medical cost of $3,613 [3].

Fortunately, a reduction in disease risk and health care costs can be achieved with weight loss through interventions aimed at increasing physical activity [4]. It has been reported that active individuals (i.e., meeting the federal physical activity recommendations) have at least a 50% reduction in cardiovascular disease or all-cause death [5]. However, only 21.3% of overweight

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females and 16.1% obese females met the 1995 federal dietary guidelines for Americans physical activity recommendation of accumulating 30 minutes of moderate intensity physical activity on five or more days per week [6], current at the time of study. Since these guidelines were updated to non-gender specific recommendations in 2008 of 150 minutes moderate intensity activity per week, it is plausible even fewer overweight and obese females meet current physical activity guidelines [7]. To help initiate exercise and meet the current physical activity guidelines, circuit-style exercise may be beneficial for women who are overweight or obese because it allows performance of more total work (i.e., higher caloric expenditure) and includes built-in rest periods in comparison to continuous aerobic activity [8]. Individuals can track total work performed in circuit-style exercise through measuring energy expenditure. A simple way for individuals to track energy expenditure during a circuit-style workout is by wearing an activity monitor.

Although there are no universally accepted degrees of error for physical activity monitors past research suggest ± 3% for research purposes [9,10], ± 10% in free-living conditions [9,10], and < 20% when used in a clinical condition [11] are acceptably valid. The SenseWear™ Armband (SWA) is a non-invasive, light weight activity monitor that is worn on the upper left arm that has been validated to measure energy expenditure during exercise [12-14] and at rest [12,14-16]. While the armband has been validated for free-living activities [17], a variety of indoor home-based activities [18,19], outdoor aerobic activities [18], and continuous exercise [13], it has not been validated for measuring energy expenditure during circuit-style workouts with people who are overweight or obese. If the energy expenditure estimates from the SWA are shown to be valid during circuit-style training with individuals who are overweight or obese, it could accurately be used as a tool to assist with weight loss or weight management programs that use this mode of activity. Therefore, the purpose of this study was to validate the SWA in measuring energy expenditure in overweight or obese females during circuit-style training.

Methods

Participants

Females (N = 40) who were overweight or obese as defined by a BMI of 25 kg/m^2 or greater and between the ages of 20 years and 59 years of age, participated in this study. Each participant was risk classified as low or moderate risk by American College of Sports Medicine (ACSM) guidelines in order to participate [7]. Participants were able to perform 30 minutes of continuous walking (self-reported) to be eligible to participate.

Instrumentation

Anthropometric measurements: A digital scale (SECA Corporation, Model 770, and Germany) was used to assess body mass to the nearest 0.1 kg. Height was assessed using a stadiometer (SECA Corporation Model 222, Germany) to the nearest 0.1 cm. Participants wore gym shorts and t-shirts, without shoes, during anthropometric measurements. Body mass index was calculated as body mass divided by height in meters squared.

Single stage treadmill test: Maximal oxygen consumption (ml/kg/min) was estimated, to characterize the sample, using the single stage treadmill test [20]. The test was completed with participants wearing gym shorts, t-shirts, and tennis shoes. The test began with a warm-up speed between 2 mph and 4.5 mph and a 0% grade that elicited a heart rate between 50% to 70% of each participant's age-adjusted maximal heart rate calculated as 220-age [21]. After walking for 4 minutes, participants continued walking at the same speed with a 5% grade for an additional 4 minutes. Maximal oxygen consumption was estimated using each participant's age, final recorded heart rate, and treadmill speed in the prediction equation [20].

SenseWear™ Armband (SWA): The SWA (BodyMedia, Inc., Model MF-SW, Pittsburgh, PA, USA) armband was used to assess energy expenditure during the exercise session. The armband was worn on the upper left arm (over the triceps muscle), halfway between the acromion and olecranon processes. The armband was programmed with each participant's sex, age, height, and body mass prior to the exercise session. Several sensors on the SWA device (i.e., accelerometer, skin temperature sensor, galvanic skin response, and heat flux) gathered information to determine energy expenditure [22]. Proprietary algorithms (software version 7.0, firmware 9.02.22) were used to estimate the minute-by-minute energy expenditure (1 minute epoch) that was compared to the energy expenditure derived from the Oxycon Mobile™.

Oxygen consumption: The Oxycon Mobile™ (CareFusion, Hoechberg, Germany) measured oxygen consumption during the exercise sessions. The Oxycon Mobile™ is a portable open-circuit indirect calorimetry system that can measure volume of expired oxygen and carbon dioxide in breath-by-breath ventilation. This system allows participants to move in a free-living environment wearing only a light weight, small pack (950 g) and mask. Prior to each exercise session, the Oxycon Mobile™ was calibrated using an automatic gas analyzer and volume calibration unit. After calibration, participant height, body mass, and age were entered into the software system. Oxygen consumption (VO_2), Carbon Dioxide production (VCO_2), Respiratory Exchange Ratio (RER), and energy expenditure (kcal/min) were recorded throughout the exercise session. Energy expenditure was derived as kcal/min from the gas exchange data throughout the exercise session. The Oxycon Mobile™ was used as the criterion measure of energy expenditure.

Procedures

Pre-participation assessment: Participants signed a written informed consent approved by the University Institutional Review Board prior to data collection. Following 5 minutes of seated rest, resting blood pressure was assessed using an aneroid sphygmomanometer (Adcuff, American Diagnostic Corporation, New York) and stethoscope. Blood pressure was assessed with the arm at heart level on the right side of the body for risk classification. Height and weight measurements were used to calculate BMI. All participants were risk classified using ACSM's [7] risk classification to assure they were not high risk.

Exercise session: Participants completed one circuit-style exercise session. Each exercise session was completed following a pre-recorded circuit-style workout DVD each time. Each participant was asked to refrain from eating or drinking, with the exclusion of water, 2 hours prior to reporting to the lab for the exercise session. All exercise sessions took place in the same enclosed room with participants wearing both the SWA and Oxycon Mobile™ throughout the entire session. The exercise session began with a dynamic warm-up, lasting 8 minutes. The warm-up consisted of eight exercises (i.e., grapevine with a hamstring curl, swing kicks, boxer shuffle, windmills, wall push-ups, knee-ups, step-ups, and vertical punches) with each exercise lasting 1 minute. Following the warm-up, participants completed the workout that consisted of identical exercises to the warm-up. Throughout the workout portion of the session, each exercise was performed twice in sequential order, for 1 minute, followed by 1 minute of rest. The workout portion of the session lasted approximately 32 minutes.

Statistical analysis

International Business Machines Corporation Statistical Packages for the Social Sciences (version 19.0) software was used to conduct data analysis. Descriptive statistics for participants and for energy expenditure were calculated as means and standard deviations. Pearson correlations between SWA and Oxycon were reported for each exercise. Bland-Altman plots were constructed to assess the agreement of the Oxycon and SWA [23]. Two-way repeated measures ANOVAs, with a Greenhouse-Geiser adjustment, were used to compare energy expenditures excluding rest periods and energy expenditures including rest periods by device (Oxycon, SWA) and exercise (knee-ups, vertical punches, boxer shuffle, wall push-ups, grapevine, step-ups, windmills, and swing kicks). A one-way repeated measures ANOVA was used to compare differences in rest period energy expenditure between the SWA and the Oxycon Mobile. A difference score (comparison-criterion) was determined for the entire exercise session including rest periods, exercise session excluding rest periods, and rest periods only. The alpha level was set at $p \leq 0.05$ for the ANOVA's. Post-hoc simple effect tests were performed using the paired samples *t*-test and an alpha of 0.01 per test.

Results

Overall results

Participant's descriptive statistics are available in Table 1. Pearson correlations of energy expenditure for each exercise from both measurement devices are included in

Table 1: Descriptive characteristics of participants (N = 40).

	M	*SD*
Age (yrs)	38.3	14.22
Height (cm)	162.67	5.91
Body mass (Kg)	82.59	16.18
BMI (kg/m²)	31.23	5.96
Single stage VO_2max (ml/kg/min)	30.31	7.71

Note: BMI: Body Mass Index; VO_2max: Maximal Oxygen Consumption.

Table 2: Pearson correlations between Oxycon EE and SWA EE by exercise.

Exercise	*Exercise periods*		*Rest periods*		*Total exercise periods*	
	r	*p*	*r*	*p*	*r*	*p*
Knee-ups	0.18	0.279	0.11	0.521	0.28	0.084
Vertical punches	0.26	0.103	0.34*	0.033	0.44*	0.004
Boxer shuffle	0.43*	0.005	-0.04	0.828	0.24	0.134
Wall push-ups	0.17	0.288	0.01	0.94	0.09	0.588
Grapevine	0.19	0.242	0.01	0.938	0.09	0.568
Step-ups	0.40*	0.011	0.11	0.516	0.29	0.07
Windmills	-0.02	0.895	0.07	0.684	-0.04	0.83
Swing kicks	0.2	0.226	0.1	0.524	0.17	0.296
Total EE	0.28	0.075	0.09	0.599	0.2	0.22

Note: *$p < 0.05$; SWA: SenseWear™ Armband; EE: Energy Expenditure; Total exercise period = exercise + rest; N = 40.

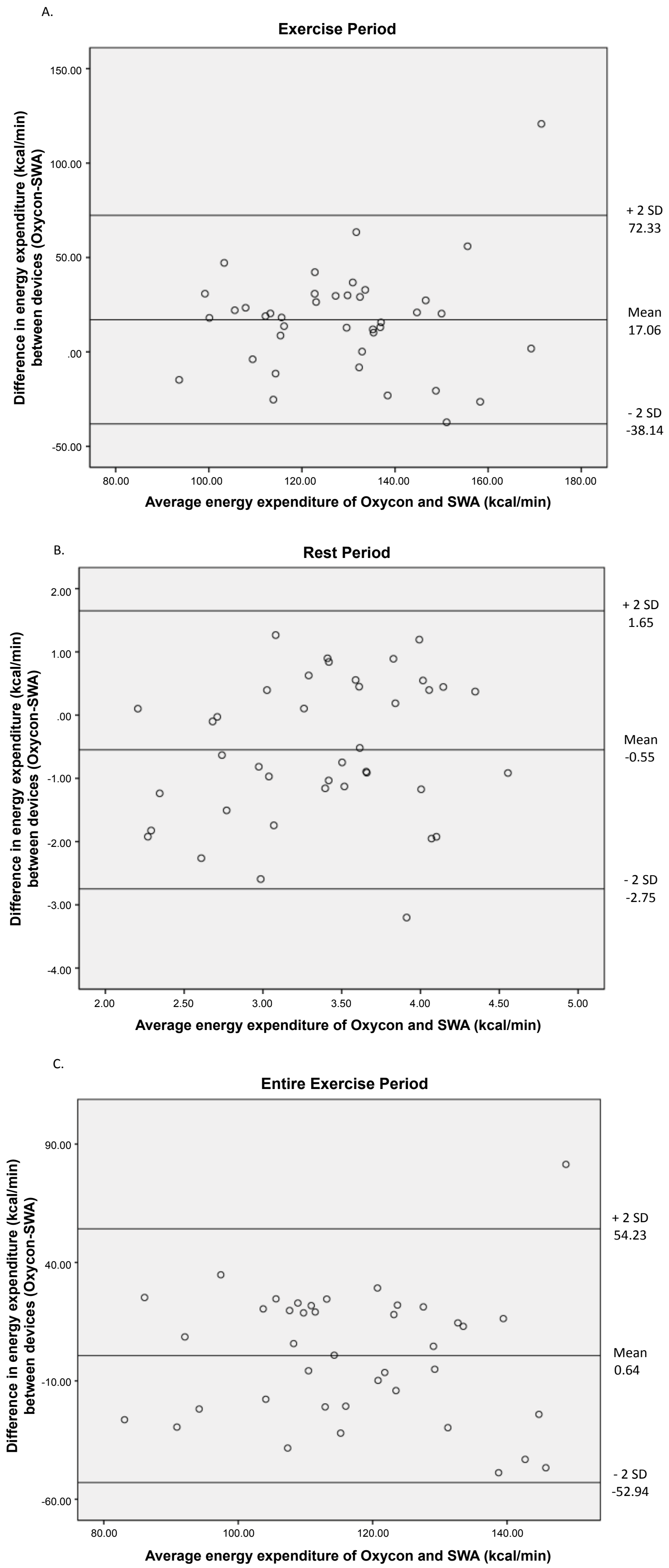

Figure 1: Bland-Altman plots of mean differences between measurement devices A) Exercise period only; B) Rest period only; C) Entire exercise period (exercise and rest). SWA: SenseWear Armband.

Table 2. Bland-Altman plots visually indicated agreement between energy expenditure from the Oxycon Mobile to the SWA (Figure 1). The average energy expenditure, excluding rest periods, differed between Oxycon (*M* = 3.88 *kcal/min*) and *SWA* (*M* = 4.43 *kcal/min*) devices, F (1,39) = 14.65, $p < 0.001$, $\eta_p^2 = 0.273$, which equates to average energy expenditures for the session of 62.02 kcals (*SD* = 11.45) for Oxycon and 70.82 kcals (*SD* = 12.81) for SWA. The main effect for exercise was significant, F (4.3,167.9) = 81.08, $p < 0.001$, $\eta_p^2 = 0.675$. Importantly, a significant interaction indicated the amount of difference between the devices varied by exercise, F (4.3,167.2) = 14.49, $p < 0.001$, $\eta_p^2 = 0.271$.

Inclusion and exclusion of rest periods

When rest periods were included in the analysis, results were similar in that there was a significant interaction between the device and exercise, F (5.1,198.2) = 22.96, $p < 0.001$, $\eta_p^2 = 0.371$. However, while the main effect for exercise was significantly different, F (4.9,191.3) = 99.85, $p < 0.001$, $\eta_p^2 = 0.719$, the main effect for device was not significant, F (1,39) = 0.02, $p = 0.882$, $\eta_p^2 = 0.001$. Because there were significant interactions, paired samples *t*-tests (alpha = 0.01 each) were used to compare caloric expenditure between device methods (i.e. the Oxycon and the SWA) for each exercise; see Table 3. The difference score of 0.55% revealed that the SWA slightly overestimates caloric expenditure compared to the Oxycon. When rest periods were excluded, significant differences in energy expenditure between the Oxycon and SWA existed in vertical punches, boxer shuffle, and windmills (Table 3). Comparing caloric expenditure with rest periods included, however, indicated the devices differed only for vertical punches and swing kicks (Table 3). A positive difference of 14.2% when rest periods were excluded from energy expenditure represents an overestimation when the SWA is compared to the Oxycon.

Rest period only energy expenditure between the Oxycon and the SWA was significantly different, F (1,39) = 8.06, $p = 0.007$, $\eta_p^2 = 0.171$. Resting energy expenditure was under predicted by the SWA (*M* = 3.10 kcal/

Table 3: Paired samples *t*-Tests and descriptive statistics for Oxycon EE versus SWA EE.

			Oxycon		***SWA***	
Variable	***t***	***p***	***M***	***SD***	***M***	***SD***
EE exercise periods						
Knee-ups	-0.96	0.344	5.04	0.92	5.3	1.58
Vertical punches	-9.05**	< 0.001	2.92	0.61	4.22	0.85
Boxer shuffle	-7.37**	< 0.001	4.55	0.91	6.06	1.4
Wall push-ups	-1.76	0.087	2.95	0.64	3.29	1.18
Grapevine	-0.57	0.572	3.69	0.76	3.81	1.25
Step-ups	-2.04*	0.049	4.53	0.86	4.93	1.3
Windmills	-3.20**	0.003	3.32	0.69	4.05	1.25
Swing kicks	1.46	0.153	4	0.75	3.75	0.98
All exercises	-3.83**	< 0.001	3.88	0.72	4.43	0.8
EE rest periods						
Knee-ups	3.72**	0.001	4.26	0.89	3.46	1.12
Vertical punches	-2.87**	0.007	2.86	0.57	3.5	1.51
Boxer shuffle	2.65*	0.012	4.29	1.01	3.5	1.54
Wall push-ups	1.36	0.18	2.91	0.57	2.64	1.14
Grapevine	2.43*	0.02	3.63	0.82	3.1	1.12
Step-ups	4.67**	< 0.001	4.19	0.93	3.21	1.03
Windmills	2.83**	0.007	3.13	0.65	2.66	0.88
Swing kicks	6.02**	< 0.001	3.93	0.89	2.72	0.99
All exercises	3.09**	0.004	3.65	0.74	3.1	0.91
EE entire exercise						
Knee-ups	1.71	0.096	4.65	0.88	4.38	0.79
Vertical punches	-7.45**	< 0.001	2.89	0.58	3.86	0.9
Boxer Shuffle	-2.06*	0.047	4.41	0.92	4.78	0.9
Wall push-ups	-0.2	0.84	2.93	0.59	2.97	0.99
Grapevine	1.02	0.312	3.66	0.78	3.45	1.07
Step-ups	1.59	0.121	4.36	0.86	4.07	1.04
Windmills	-0.8	0.427	3.23	0.65	3.36	0.75
Swing kicks	3.73**	0.001	3.98	0.77	3.41	0.73
All exercises	-0.15	0.882	3.76	0.71	3.78	0.68

Note: df = 39, *p < 0.05, **p < 0.01, EE: Energy Expenditure (kcal/min); SWA: SenseWear™ Armband.

min, *SD* = 0.91) in comparison to the Oxycon (*M* = 3.65 kcal/min, *SD* = 0.74). When only rest periods are examined, a -13.77% difference represents an underestimation of caloric expenditure when comparing the SWA to the criterion measure.

Discussion

Circuit-style exercise may be more beneficial for women who are overweight or obese as it allows for greater caloric expenditure than continuous exercise and includes built in rest periods [8]. In the current study, each participant completed a circuit-style exercise session while wearing an SWA and an Oxycon Mobile device. The estimated energy expenditure from the SWA was not significantly correlated to indirect calorimetry values. The SWA overestimated exercise energy expenditure, especially for exercises that isolated muscle movements such as vertical punches, boxer shuffle, and windmills. Further, rest period energy expenditure was significantly under predicted. After combining these two measurements (i.e., exercise and resting period energy expenditures), total energy expenditure estimates were not significantly different between the SWA and indirect calorimetry (Table 3). These findings are similar to those of Dudley, et al. [18] that showed the SWA overestimated energy expenditure during light office and house work. Furthermore, in an investigation by Jakicic, et al. [13] energy expenditures were significantly overestimated during arm ergometry when using the proprietary equations developed by the manufacturer. In the current study the SWA specifically overestimated exercise energy expenditure during vertical punches, the boxer shuffle, and windmill exercises. Two of these movements (i.e., vertical punches and windmills) use arm movements similar to arm ergometry. These data suggest that repetitive arm movements cause an overestimation of the SWA's energy expenditure estimate. In addition, it has been suggested that the SWA will overestimate energy expenditure in individuals who are obese due to excessive body movement [14]. The current study not only suggests an overestimation of energy expenditure during exercise, but also an underestimation of energy expenditure during rest periods.

Few studies have been performed to validate the SWA specifically for standing rest periods. In one study, Reese, et al. [24] documented significantly underestimated energy expenditure by the SWA during standing rest. This consistent underestimation by the SWA during low activity periods is particularly important for energy expenditure assessments when using the SWA during circuit- or interval-style training which may incorporate periods of standing rest.

Papazoglou, et al. [14] examined the validity of the SWA during rest and three modes of activity (cycle ergometry, stair stepping, and treadmill walking). Their outcomes mirror those of the current investigation with the SWA producing an underestimation of resting energy expenditure and overestimates of energy expenditure during the exercise conditions. Potential excess body motion in individuals who are overweight or obese in conjunction with reduced mechanical efficiency may contribute to the overestimation of the SWA during exercise in this population [14]. Another likely explanation for overestimation of energy expenditure is the brief time span of the individual exercises [19]. The current study and Papazoglou, et al. [14] reported overestimation of energy expenditure with short durations with an overweight and obese population; whereas, Paris, et al. [19] found small biases between the armband and indirect calorimetry when using longer time periods with a similar population.

While the current study included both upper and lower body exercises, results are limited to the exercises selected for the circuit. Another potential limitation is measurement of energy expenditure in postmenopausal women by the SWA. However, the effect on energy expenditure would be minimal with 73% of participants being under the age of 51, the average age of menopause. Future studies should also be conducted to evaluate any sex-specific differences in current physical activity monitors. Furthermore, in addition to issues associated with excess body movement in overweight or obese individuals during exercise, the existing SWA manufacturer algorithms may not account for the increased heat flux during exercise associated with excess body fat. Further research is suggested on the continued need for population-specific algorithms. Additionally, overweight and obese individuals would benefit from extended research in the area of commercially available physical activity monitors in circuit-style training.

In conclusion, estimated energy expenditure from the SWA was not correlated to indirect calorimetry during circuit-style exercise with overweight and obese females and did not accurately assess the exercise or rest components of the exercise session. It is important to understand as overall energy expenditure estimates do not vary when comparing the SWA to indirect calorimetry in the current study due to equal time periods between exercise and rest. One should note if time periods were unequal between rest and exercise overall energy expenditure would vary. In comparison to suggested acceptable measurement error the SWA would not meet the recommended ± 3% for research purposes [9,10] but would satisfy the < 20% for use in a clinical purpose [11]. Therefore, females who are overweight or obese can wear a SWA to assist in overall tracking of energy expenditure of a circuit-style exercise session, but must use care if looking specifically at the exercise components of a workout.

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