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Evaluating Energy Expenditure Estimated by Wearable Technology During Variable Intensity Activity on Female Collegiate Athletes

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ABSTRACT

International Journal of Exercise Science 11(7): 598-608, 2018. Monitoring an athlete's energy intake and energy expenditure (EE) is an important consideration of nutritional planning for sport conditioning and peak performance. In order to provide appropriate recommendations regarding nutritional requirements and caloric needs, an accurate determination of energy requirements is necessary. By knowing an individual's EE, a coach, athletic performance staff or trainer can effectively determine training loads and volumes necessary for periodization and seasonal planning for a particular sport. The purpose of this study is to examine the accuracy of the BodyMedia Mini armband while measuring EE in female basketball players during various-intensity game-like conditions. This investigation required three testing sessions: an orientation session, and two randomized experimental trials. Trials included a maximal multistage 20-m shuttle run (Trial I) and 30-minute basketball skills session (Trial II). The independent variable for this investigation was EE estimated by the Mini armband. The dependent variable was EE determined by the Cosmed K4b2 indirect calorimetry (IC) method. EE assessed with the Mini and EE measured with the IC method was significantly correlated for both Trial I (r= 0.839) and Trial II (r= 0.833). EE calculated by the Mini was significantly underestimated in both Trial I (9.41 ± 26.1 total kcals) and Trial II (56.71 ± 14.1 total kcals). During Trial I the underestimation of EE increased with a rise in test level and intensity ($p<.05$). Due to the underestimation of EE by the Mini, the development of exercise specific algorithms to improve the estimation of EE during intermittent exercise in basketball players is warranted.

KEY WORDS: Women's basketball, wearables, energy expenditure

INTRODUCTION

Monitoring an athlete's energy intake and energy expenditure (EE) is an important consideration of nutritional planning for sport conditioning and peak performance. In order to provide appropriate recommendations regarding nutritional requirements and caloric needs, an accurate determination of an individual's energy requirements is necessary. By knowing an individual's EE, a coach, athletic performance specialist, or trainer is effectively able to determine training loads, volumes necessary for periodization, and seasonal planning for a particular sport. When caloric intake is not appropriate, changes in body composition may negatively impact overall health and athletic performance (28).

For practical purposes, methods of EE assessment should be convenient, reliable, and accurate (22). Presently, EE assessment tools include: 1) accelerometers; 2) pedometers; 3) portable metabolic systems; 4) indirect calorimetry (IC); 5) heart rate (HR); 6) doubly-labeled water (DLW), and 7) wearable forms of technology. Despite the potential advantages of each technique, limitations associated with a lack of validity, reliability, or practicality, and use in high intensity free living environments have been shown in studies using free living environments (2, 3, 6, 9, 12, 14, 25, 26, 28, 31, 32). The increase in interest of commercial wearable technology to easily assess energy expenditure across all populations allows for several options of wearable devices (26). To date, few studies have examined the accuracy of assessing EE using athletic populations in sports specific environments. This demonstrates a need to identify accurate methodology that can assess EE for athletes while performing sports specific tasks.

The SenseWear Mini Armband (Mini) (BodyMedia®, Inc., Pittsburgh, PA), a multi sensor device worn on the upper arm, provides measures of EE during periods of physical activity. To increase the accuracy of predicting EE, the Mini utilizes a combination of physiological and mechanical measurement systems. This wearable device collects data through a variety of sensors that include: accelerometry, galvanic skin response, near-body ambient temperature, skin temperature, and heat flux (1). Participant data may be uploaded and analyzed providing a breakdown of energy requirements for all physical activities performed (1). The Mini has been examined in adults, children, and clinical patients giving it a more robust background in ability to be used for research (15, 16, 23, 24, 29). However, few investigations have explored the validity of this instrument using intensities similar to a specific athletic event, or in free-living environments. This includes athletes who engage in intermittent play at varying intensities such as basketball players.

Therefore, the purpose of this investigation was to validate the Mini as a wearable measure of EE during variable intensity basketball game-like conditions using a sample of female basketball players.

METHODS

Participants

Sixteen female college basketball players (aged 18-23 years) at the University of Pittsburgh (Pitt) and Carnegie Mellon University (CMU) participated in this investigation. The racial, gender, and ethnic characteristics of the participants reflected the demographics of female basketball players recruited to participate in NCAA collegiate female basketball. Descriptive characteristics are explained in Table 1. In order to participate, subjects were: 1) healthy; 2) currently eligible for college athletics and participating on a collegiate basketball team; and 3) able to complete an orientation and two experimental trials. Subjects were healthy females free from any disease or conditions that would limit their participation in physical activity. The

University of Pittsburgh Institutional Review Board approved this investigation and informed consent was received from all participants.

Table 1. Descriptive characteristics of subjects.

	Pitt (n=8)	CMU (n=8)
Age (yrs)	18.9 ± 1.1	19.5 ± 1.2
Weight (kg)	75.5 ± 17.2	75.6 ± 8.1
Height (cm)	178.6 ± 9.1	176.3 ± 5.6
BMI (kg·m^2)	23.4 ± 3.5	24.5 ± 3.4
Body Fat (%)	23.3 ± 3.5	24.1 ± 5.9

Protocol

A cross-sectional counterbalanced correlational design with multiple observations was employed. This investigation required three testing sessions: 1) Orientation session; 2) Experimental Trial I; and 3) Experimental Trial II. Experimental Trials I and II were randomized and included: 1) a maximal multistage 20-m shuttle run; and 2) a 30-minute basketball specific individual training session. The two experimental trials were separated by approximately 24-72 hours.

Indirect Calorimetry: Indirect Calorimetry (IC) was used as the criterion measure of EE (19). The Cosmed K4b^2 Mobile Metabolic Measuring System (COSMED, Inc., Rome Italy) was used to assess EE during each experimental trial, while VO_2 (ml·kg·min^{-1}), VCO2 (L·min^{-1}), and VE (L·min^{-1}) were collected every 15 seconds.

SenseWear Mini Armband: Energy expenditure during exercise was computed at one minute intervals. The measured exercise outcome data was converted to energy expenditure (kcal·min^{-1}) using a generalized proprietary algorithm in BodyMedia's InnerView® Research Software Version 7.0 (1).

Experimental Sessions: Following the orientation session, subjects were randomized into both experimental Trials I and II. Prior to participation in exercise trials, subjects were asked to abstain from caffeine intake for four hours. All subjects were dressed in standard athletic clothing (short sleeve cotton t-shirt or mesh practice jersey and shorts) during each exercise session. For each experimental session, IC and the Mini measured EE. Each subject was tested individually.

Upon arrival to each experimental trial, anthropometric measures were obtained including height (cm), body weight (kg), fat free mass (kg), and fat mass (% and kg). Height (cm) and weight (kg) were measured using a physician's scale. Body composition was assessed using a Tanita (Arlington Heights, IL) bioelectrical impedance analyzer (BIA) scale.

Participants were fitted with the Cosmed K4b^2 unit, and Mini, and sat in a resting position for 15 minutes to allow the Mini to acclimate to each subject. Following the resting period, subjects engaged in a standardized five-minute dynamic warm-up protocol. Three stopwatches were used for each session to officially track experimental total session time, actual time for start

and finish of each drill, and standardized length of each exercise and rest period. This served as a backup to time recorded on the Cosmed $K4b^2$ unit. Upon completion of the experimental trial, subjects participated in a five-minute cool-down with a standardized static stretching routine. Time on task was recorded to the nearest second to track transition time, test trial time, and total time to completion for each subject. The 30-minute experimental trial total time required was held consistent for all subjects.
Experimental Trails I and II

20-m Shuttle Run (Trial I): Created by Leger et.al., the 20-meter shuttle run was intended to test cardiovascular fitness. As a continuous running aerobic test that corresponds well with the stop and go nature of sports specific activities such as basketball, it has similar characteristics as the children's Fitnessgram PACER test for cardiovascular function (20). The predicted VO_2 max from the 20-m shuttle has demonstrated validity (r = 0.84, SEE 5.4 $ml \cdot kg^{-1} \cdot min^{-1}$) when compared to the Balke treadmill protocol to measure VO_2 max, as well as reliability (r = 0.95) when tests were conducted one week apart (20).

The 20-m shuttle run employs up to 22 levels, consisting of short running stages within each level. The levels gradually progress in speed and overall intensity as the subject transitions through each phase. To prepare for the test, two lines are established on a basketball court exactly 20 meters apart. Participants stood behind the first line facing the second line and began running when instructed by a recording. After reaching the second line, they returned to the first line when signaled by a recorded (beep). At each minute, the sounds reflected an increase in speed, and duration of time between beeps decreased and this continued each minute (level). If a line was not reached in time for a beep, a subject would run to the line, turn, and attempt to catch up with the pace within 2 more 'beeps'. If the subject reached a line before a beep sounded, the subject waited until the beep prior to starting again. A test was stopped if a subject failed to reach the line for two consecutive beeps. The level at which each subject stopped was recorded. VO_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$) was then predicted for the level obtained on the test using the regression equation validated by Leger and colleagues (20). Intensity for each level of the test ranged from 4 - 20 METs depending on stage of termination.

30-Minute Basketball Workout (Trial II): The athlete performed a 30-minute basketball specific workout. The 30-minute basketball workout was created to simulate the high intensity environment of a collegiate practice or game. The drills were selected to reflect the major skills needed to play the game of basketball. Each drill was also chosen because of its widespread use in the college basketball setting. The drills included progressive defensive slides, half court speed lay-ups, Mikan drill, half court dribbling drill, toss out shooting drill, medicine ball plyometrics, free throws, and conditioning sprints (Table 2). EE ($kcal \cdot min^{-1}$ and total kcals) during this activity was measured simultaneously using IC (Cosmed $K4b^2$) and the Mini (BodyMedia, Inc.). Devices were time stamped at the beginning and end of each drill.

Statistical Analysis
Statistical analyses were performed using IBM SPSS Statistics (Version 20.0) with level of significance set at $p < 0.05$. Power analysis showed that given a one-tailed alpha of .05 and a

correlation (r) of at least .60 between the Cosmed K4b² and the Mini armband, a sample of 16 participants would result in a power of at least 80 %. Descriptive characteristics of subjects are presented as means ± standard deviations (Table 1). Data was analyzed separately for each exercise trial. A dependent t-test was used to compare energy expenditure in total kcals, METS, and kcal $\cdot$min^{-1} during both experimental trials. To test the primary hypotheses Pearson correlation coefficients were calculated. The relationship between total energy expenditure (Mini vs. IC) at the end of the 30-minute basketball skills session was evaluated first. The second evaluation looked at the same relationship at the end of the 20-meter shuttle run. Bland Altman plots were also used to assess agreement between IC and Mini. Outcome variables measured at rest and throughout all exercise trials included: 1) total kilocalories (kcal); 2) calories per minute (kcal $\cdot$min^{-1}); and 3) average METs.

Data was tested for normality and homogeneity. A two-way (method by time (intensity level)) analysis of variance (ANOVA) was performed for the 20-meter shuttle run session using minute-by-minute data during each session. The purpose of this analysis was to examine consistency between the instruments in tracking changes in energy expenditure over the course of a session.

RESULTS

The primary aim of this study was to examine the validity of the Mini to assess EE during variable intensity basketball skill and game-like conditions in female basketball players. Descriptive characteristics of each trial can be seen in Tables 2 and 3.

Table 2. Descriptive characteristics of 30-minute basketball skills session.

	VO_2 (ml $\cdot$kg $\cdot$min^{-1})	METs	kcal $\cdot$min^{-1}	HR(b $\cdot$min^{-1})
Progressive Defensive Slide	28.9 ± 3.9	7.98 ± .93	10.72 ± 3.6	165.2 ± 13.4
Mikan	27.8 ± 3.4	8.05 ± .93	11.17 ± 2.19	170.7 ± 10.7
Speed Lay-Up	28.6 ± 3.3	8.32 ± .91	11.18 ± 2.61	173.5 ± 9.2
Victory	29.1 ± 3.6	8.41 ± 1.1	11.58 ± 2.38	177.8 ± 8.9
Free Throw (1)	19.3 ± 3.8	5.9 ± 1.2	7.96 ± 1.77	163.9 ± 15.9
Medicine Ball Plyometrics	20.0 ± 4.1	6.4 ± 1.2	8.21 ± 2.01	155.2 ± 13.1
½ Court Dribbling Drills	25.0 ± 6.4	7.7 ± .86	10.14 ± 2.02	172.5 ± 10.8
Toss Out Shooting Drill	24.9 ± 2.7	7.2 ± .86	9.65 ± 1.7	172.1 ± 10.8
Free Throws (2)	19.1 ± 3.2	5.2 ± .86	6.79 ± 1.58	144.1 ± 57.4

Table 3. Descriptive characteristics 20-meter shuttle run test.

	Mean (± S.D)
Level Completed	6.8 ± 1.4
Total Time (min:sec)	6:52 ± 1:25
Predicted VO_2 max (ml ·kg ·min^{-1})	35.7 ± 4.8
Total kcal (Cosmed)	87.2 ± 25.8
Total kcal (Mini)	77.8 ± 20.6
Peak Heart Rate (b ·min^{-1})	188.6 ± 8.1
Session RPE	5.8 ± 1.0
Peak VO_2 (ml ·kg ·min^{-1}) (Cosmed)	37.29 ± 4.87

Values are presented as Mean ± Standard Deviation.

Results indicated the Mini significantly underestimated total kcals of the 30-minute basketball skills session (Figure 1). However, results demonstrated a strong relation between energy expenditure from IC and the Mini for the 30-minute basketball skills session ($r = 0.833$, $p = < .0005$, SEE = 26.74 kcals).

A secondary aim of this study was to examine the accuracy of the Mini to assess EE during a 20-meter shuttle run test in female basketball players. Similar to the 30-minute basketball skills session, results indicated that the Mini significantly underestimated energy expenditure during the 20-meter shuttle run test ($p<.05$). (Figure 2).

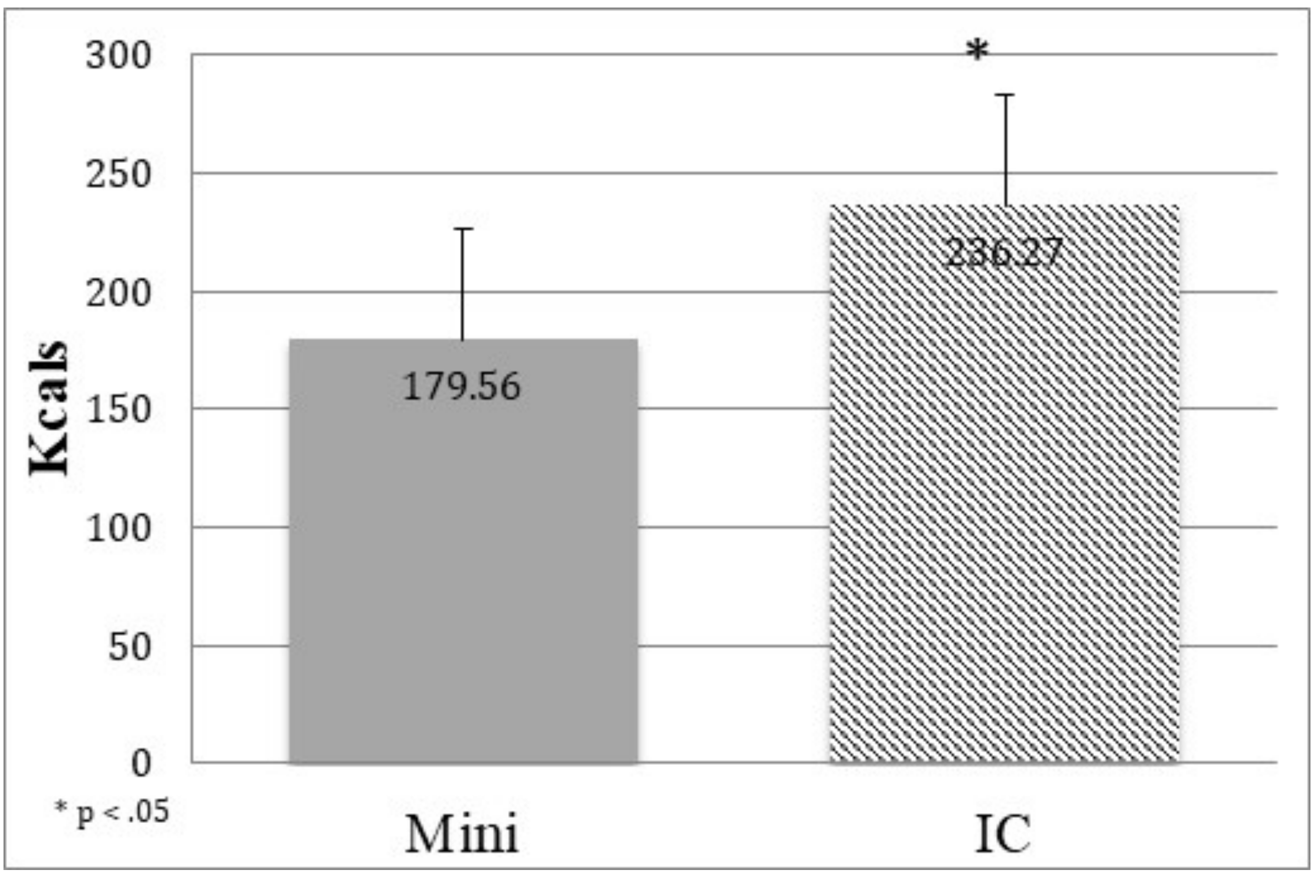

Figure 1. Comparison of EE (kcals) for 30-Minute Basketball Skills Session. Values are presented as Mean Error Bars Represent 1 Standard Deviation.

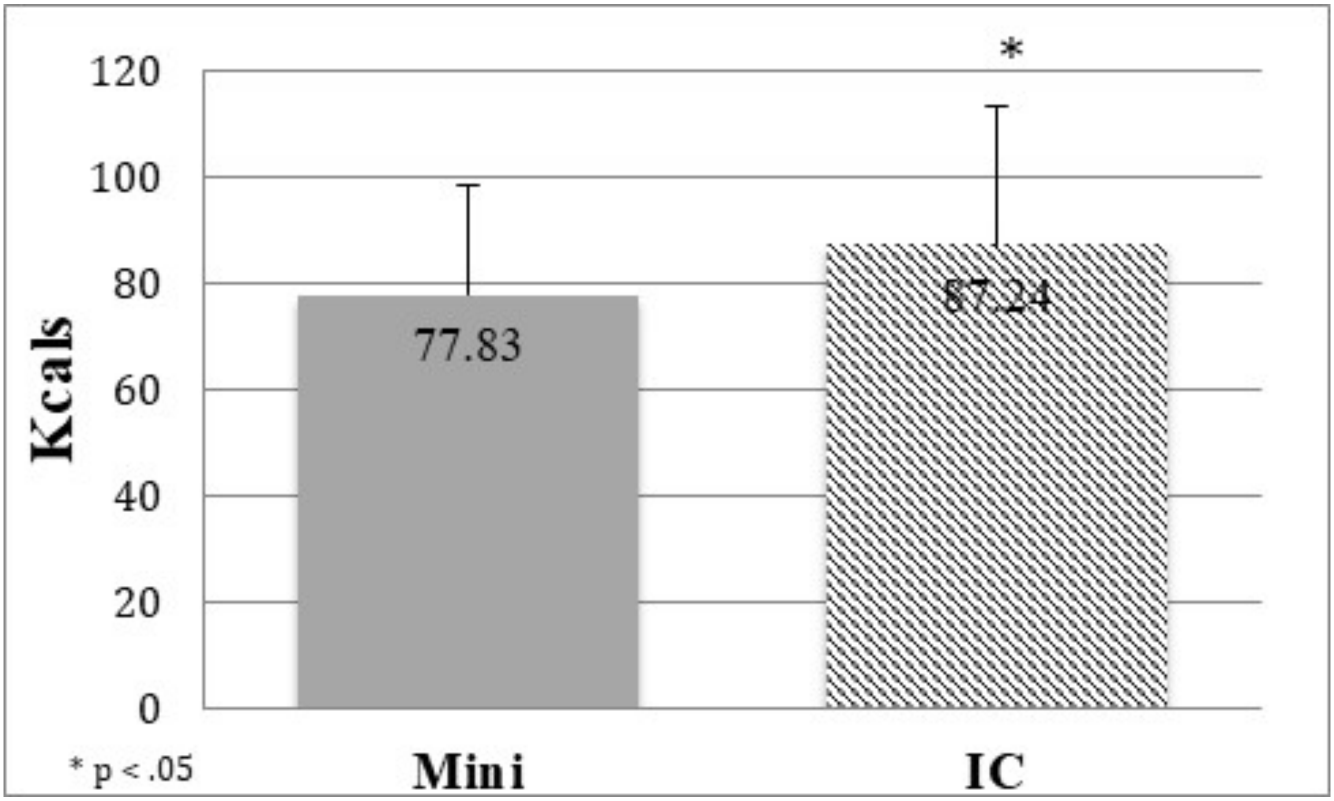

Figure 2. Comparison of EE for 20-meter shuttle run test. Values are presented as Mean Error Bars Represent 1 Standard Deviation.

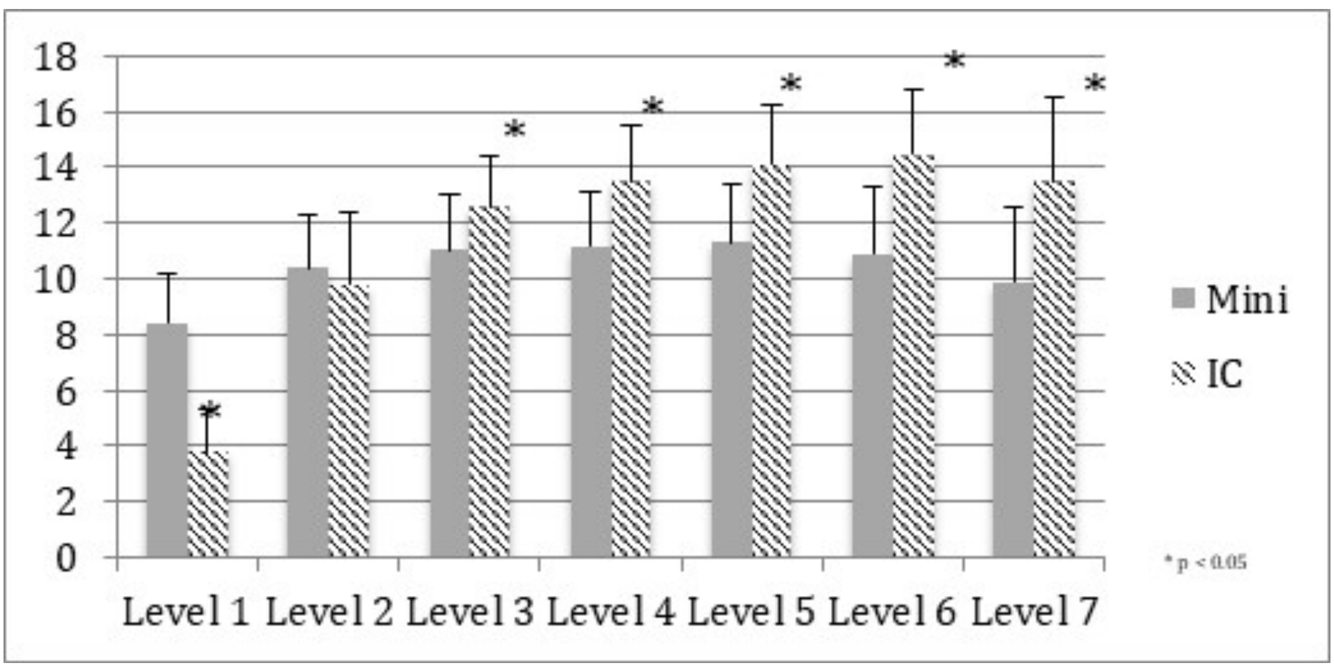

Figure 3. Mean EE estimates of mini and IC compared throughout 20-meter shuttle run test. Values are presented as Mean Error Bars Represent 1 Standard Deviation.

A strong relationship between energy expenditure from IC and the Mini for the 20-meter shuttle run test was observed (r = 0.839, p = .000, SEE= 14.53 kcal). A method x level ANOVA was also performed to examine the consistency between the instruments in tracking changes in energy expenditure over the course of the 20-meter shuttle run test. The ANOVA showed that the Mini underestimated EE over a course of the 20-meter shuttle run test, with significant differences occurring at higher (more intense) levels (Figure 3).

DISCUSSION

A primary finding of this investigation showed that the Mini significantly underestimated total EE for the 20-meter shuttle run test and the 30-minute basketball specific skills session when compared to indirect calorimetry. The findings do not support the hypotheses that energy expenditure measured by the BodyMedia® FIT Armband Mini during variable intensity game-like activity would be similar to EE measured by indirect calorimetry. Therefore, the primary and secondary aim of this investigation were not supported due to the armband significantly underestimating total EE during the 20-meter shuttle run test and the 30-minute basketball skills session by 9.4 ± 14.1 kcals and 56.7 ± 26.1 kcals respectively, when compared to indirect calorimetry. However, a secondary finding of the study did support that significant correlations occurred between the Mini and IC for both the 20-meter shuttle run test and the 30-minute basketball skills session.

Results are consistent with previous research for wearable technology. A study by Sasaki et. al showed that Fitbit wireless activity monitor to significantly underestimate EE of activities with variability in underestimation of EE for different activities (26). A study done by Drenowatz and Eisenmann (7), showed that the SenseWear Pro Armband significantly underestimates energy expenditure in endurance trained athletes working at 10 MET's or above. Similarly, Koehler et al., found the SenseWear Pro Armband to consistently underestimate energy expenditure at higher running speeds (18). The SenseWear Pro Armband significantly underestimated energy expenditure for most exercise intensities, and the underestimation increased as exercise intensity increased (18). Similarly, the findings of this current investigation demonstrate that the armband underestimated total energy expenditure for both sessions, and that the underestimation increased as exercise intensity/level increased during the 20-m shuttle run test. Possible mechanisms underlying the underestimation of EE are complex but may include: 1) the use of generalized exercise algorithms to predict all types of physical activity; 2) the delay in detecting body heat transfer to the skin; and 3) an inaccuracy of the accelerometer during certain basketball related movements. This may require that additional research be conducted to allow for refinement of the prediction algorithms applied to subjects.

Although the present investigation is not without limitations, this is the first study to investigate the accuracy a wearable to estimate EE in variable intensity exercise. It is also the first study to examine the accuracy of the Mini during activities that simulate game-like situations for athletes. These findings are an important first step in validating wearable technology for use in sports of an intermittent nature. The outcomes of the present study will help to provide athletes, coaches, and trainers with an option to estimate the caloric demands of collegiate female basketball players during simulated game-like conditions. In addition, results of this study express the energy demands associated with anaerobic and aerobic training drills and sets. This will provide insight to coaches when considering metabolic demands of specific workout components, and contribute to improved workout designs and the assessment of recovery needs. Through the quantification of energy requirements, the armband may assist with the determination of caloric needs to properly monitor and help to maintain body composition throughout a competitive season. It could also provide insight as to the intensity level. For example, a combination of Mini, heart rate, and perceived exertion monitoring can provide valuable information on "how hard" an athlete is working and/or if this should be adjusted throughout a season.

These findings impose limitations on the use of the Mini during variable intensity activities. Further research and refinement on the Mini algorithms are needed before this device can be used to estimate EE during variable intensity exercise in a free-living environment. It is proposed that data from this investigation could potentially assist with the development of exercise specific algorithms for intermittent activities that are a standard feature for the armband system. A valid physical activity monitor, that is able to accurately measure physical activity EE should be studied further to answer long-standing questions about energy needs, and requirements in athletes whose sport requires variable intensity and intermittent activity.

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