ENERGY EXPENDITURE OF TYPE-SPECIFIC SEDENTARY BEHAVIORS ESTIMATED USING SENSEWEAR MINI ARMBAND: A METABOLIC CHAMBER VALIDATION STUDY AMONG ADOLESCENTS

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Abstract:

SenseWear Mini Armband, an accelerometer with multiple physiological sensors, could be a practical means to estimate energy expenditure (EE) of children and adolescents, but its validity reported for these age groups has not been consistent within the literature. EE of twenty-six healthy Chinese 12-year-old adolescents was measured simultaneously using both SenseWear Mini Armband (SWMA) and metabolic chamber (MC) during a 16-hour stay in a MC. SWMA systematically underestimated the adolescents' EE during sedentary behaviors, resting metabolic rate (RMR), basal metabolic rate (BMR), and total EE, with the absolute error rate ranging from 14.85% to 28.65%. The SWMA significantly underestimated EE compared with MC in Chinese adolescents. However, the amount of error can be reduced by applying correction equation proposed in this study.

Key words: *sitting, physical inactivity, accelerometer, activity monitor, whole-room calorimetry*

Introduction

Physical inactivity and sedentary behavior may play an important role in the development of obesity, metabolic syndrome, and cardiovascular diseases (Lee, et al., 2012). An understanding of energy expenditure (EE) in sedentary behavior may provide new avenues for obesity research and chronic disease control. However, measuring physical activity (PA) and EE, particularly in children and adolescents, is still challenging although numerous methods and devices have been developed since the 16th century to address this measurement issue. Whole-room calorimetry, i.e., using a metabolic chamber (MC), is considered to be the gold standard for EE assessment (Leonard, 2012). The feasibility and high validity of MC in measuring EE of young children under free-living conditions has been demonstrated (Leonard, 2012). Yet, MC usage is too costly and complicated for large sample research. Thus, more practical and less expensive methods, such as accelerometers, pedometers, and heart rate monitors, have been widely used to estimate EE by assessing intensity, duration, frequency and total amount of PA performed (Pedisic & Bauman, 2015).

A new, better generation of PA monitors that combine accelerometer and multiple physiological signal sensors has been developed. One of these is the SenseWear Mini Armband (SWMA: BodyMedia Inc., Pittsburgh, USA), which integrates a three-axis accelerometer with heat flux, skin temperature, and galvanic skin response sensors (Johannsen, et al., 2010). The validity of SWMA in measuring EE has not been consistent within the literature. While some studies reported that the SWMA and its earlier models SenseWear Armband (SWA) are valid in estimating daily EE when checked against Doubly Labeled Water (DLW) (Arvidsson, Slinde, & Hulthén, 2009) and Indirect Calorimetry (IC) (Malavolti, et al., 2007), some researchers suggested that SWMA underestimated daily free-living EE when compared with DLW data (Johannsen, et al., 2010). Vernillo, Savoldelli, Pellegrini, and Schena (2014) reported that SWMA might not be valid in estimating EE during pole walking activities when compared with IC as the criterion measure. It was noticed that none of the previous SWMA and SWA studies used MC, the gold standard measure of EE, as the criterion measure. In addition, few studies evaluated the device for children and adolescents.

Therefore, the purpose of this study was to examine the validity of SWMA in measuring EE of adolescents' sedentary behavior by using MC as the criterion measure.

Methods

Participants

Twenty-six adolescents (age: 150±4 months; 16 boys and 10 girls) were recruited from an elementary school in Shanghai, China. After receiving information about the purpose, method, benefits and risks of the study, parents/guardians signed an informed consent and the adolescents assented to participate. The study was approved by the Ethics Advisory Committee in Shanghai University of Sport, China.

Body weight and height were measured using a digital scale (Tanita, DC-250). Resting heart rate was measured by a telemetry central monitor (WEP-5204C, Nihon Kohden, Tokyo, Japan), and body composition was measured by Dual-Energy X-ray Absorptiometry (DEXA; Lunar Prodigy, GE Medical Systems, Madison, WI). The participants' characteristics are presented in Table 1 along with descriptive anthropometric data.

The study was conducted in a MC (Fuji Human Calorimeter model: FHC-20S), which is an open-circuit indirect room calorimeter, which includes an airtight room (24000L), equipped with a bed, desk, chair, telephone, toilet, and sink. The temperature and relative humidity in the room were controlled at 25°C and 55%, respectively. The oxygen and carbon dioxide concentrations of the air supply and exhaust were measured by mass spectrometry. For each measurement, the gas analyzer (Thermo Scientific™ Prima PRO Process Mass Spectrometer) was initially calibrated by using four certified gas mixtures. The flow rate exhausted from the chamber was measured by a flow meter (Yamatake-CMS0200). EE was estimated from VO_2 and VCO_2 using Weir's equation (Weir, 1949). The validity and precision of the metabolic chamber for measuring EE as determined by the alcohol combustion test was 99.7%±0.4% (M±SD) over three hours and 100.2%±1.4% over 30 minutes. Indirect room calorimeters were used to determine 16-hour EE in the controlled environment of a metabolic chamber for each participant.

Study protocol

The whole protocol took about 18 hours, including a two-hour preparation and 16 hours of discretionary activity in the MC. The preparation included the anthropometric examination, taking a shower, changing clothes, and eating dinner. Prior to entering the MC, the participants put the SWMA on the back of their upper non-dominant arm (triceps). The participant entered the MC and followed a structured activity protocol illustrated in Table 2.

Data processing and analysis

Minute-by-minute values from SWMA were processed using the SenseWear Professional Software (version 7.0, Pittsburgh, USA). Total EE from SWMA was computed at 1-minute intervals using the generalized proprietary algorithm developed by the manufacturer. Minute-by-minute oxygen consumption and carbon dioxide production EE from MC were converted to energy equivalents (kcal/min) using Weir's equation (Weir, 1949). The SWMA-derived total EE values were synchronized minute-by-minute with total EE from MC and compared for individual sedentary behaviors (writing, watching TV, playing computer games, reading, and sleeping), RMR^{2hr}, RMR^{4hr}, BMR, and total 16-hour EE.

A *t*-test was used to test differences in body height, body weight, resting heart rate, BMI, and percentage of body fat between boys and girls. A paired *t*-test was used to test the differences between EE measured by MC and SWMA, including the differences in the EEs of sedentary behaviors, RMR^{2hr}, RMR^{4hr}, BMR, and total 16-hour EE. The absolute error rate was defined as:

Absolute error rate = $[|(EE_{SWMA}–EE_{MC})|/EE_{MC}]×100\%$.

A regression analysis was finally used to create a correction equation using SWMA as the predictor and MC as the estimated outcome.

These analyses were completed using Microsoft Excel 2010 and SPSS Version 18.0 statistical software.

Table 1. Anthropometric characteristics of the participants (M±SD)

	Boys (n=16)	Girls (n=10)	Total (n=26)
Body height (cm)	161.86±8.69	155.74±4.16[a]	159.51±7.80
Body weight (kg)	53.31±10.45	46.23±6.65	50.59±9.68
Resting heart rate (beats/min)	80.33±10.20	68.89±7.32[b]	76.04±10.68
Body mass index (kg/m²)	18.77±8.71	22.02±8.67	20.02±8.67
Percentage of body fat (%)	20.56±9.03	23.98±7.65	21.87±8.54

Note. [a] $p<.05$, [b] $p<.01$, there were statistically significant differences between boys and girls in body height and resting heart rate.

Table 2. Schedule of activities during an 16-hour stay in the Metabolic Chamber

Times	Activity	Contents
17:00-17:30	Anthropometric examination	Measuring height, weight, heart rate, percentage of body fat, etc.
17:30-18:00	Taking shower and changing clothes	
18:00-18:30	Lunch	
18:40	Enter the room and start protocol	Familiarizing self with the room environment (prohibited from playing computer games and strenuous PA)
19:00	**Start recording the data**	
19:00-19:20	Preparing	Learning the procedures, taking shower
19:20-19:50	Sedentary behavior	Writing
19:50-20:20	Sedentary behavior	Watching TV
20:20-21:00	Lying in bed	Staying awake, being quiet, no PA
21:00-21:30	Sedentary behavior	Playing computer games
21:30-22:00	Sedentary behavior	Reading
22:00-22:10	Washing face, hands, and having a snack	
22:10-22:50	Lying in bed	Staying awake, be quiet, no PA
22:50-23:00	Pre-sleep	Preparing for sleeping
23:00-07:00	Sleep	Sleeping (8 hours)
07:00-07:40	Lying in bed	Staying awake, being quiet, no PA
07:40-08:00	Breakfast	
08:00-08:40	Random behavior	Writing, watching TV, or reading, prohibited from playing computer games and strenuous PA
08:40-09:10	Sedentary behavior	Writing
09:10-09:40	Sedentary behavior	Watching TV
09:40-10:10	Sedentary behavior	Playing computer games
10:10-10:40	Sedentary behavior	Reading
10:40	**End recording data**	Leaving the room and completing the study

Table 3. Energy expenditure (M±SD; kcal/min) of adolescents (N=26) during various activities and during a 16-hour stay in the whole-room indirect calorimeter measured by the Metabolic Chamber (MC) and estimated from the SenseWear Mini Armband (SWMA), corrected SenseWear Mini Armband (SWMA) calculated by the equation (Corrected MC=0.233+0.990SWMA)

Activity	Metabolic Chamber (kcal/min)	SenseWear Mini Armband (kcal/min)		*t*-test Effect size		*p*-value		Absolute error rate (%)		r		p-value	
		Actual	Corrected	Actual	Corrected	Actual	Corrected	Actual	Corrected	Actual	Corrected	Actual	Corrected
Writing	1.40±0.26	1.15±0.27	1.37±0.27	1.540	0.197	<.05	>.05	19.61±8.52	9.51±7.25	0.806	0.806	<.05	<.05
Watching TV	1.32±0.26	1.02±0.21	1.24±0.21	2.202	0.612	<.05	<.05	23.76±7.80	10.25±8.28	0.840	0.840	<.05	<.05
Playing computer games	1.31±0.26	1.00±0.19	1.23±0.19	1.997	0.530	<.05	<.05	23.64±7.93	10.61±8.17	0.811	0.811	<.05	<.05
Reading	1.34±0.27	1.12±0.24	1.35±0.24	1.262	-0.020	<.05	>.05	19.80±8.15	10.63±13.69	0.776	0.776	<.05	<.05
Sleeping	0.95±0.20	0.88±0.15	1.10±0.15	0.482	-1.055	<.05	<.05	14.85±14.71	19.94±24.51	0.684	0.684	<.05	<.05
Resting metabolic rate (RMR^{2hr})	1.33±0.26	0.94±0.16	1.16±0.16	2.645	1.124	<.05	<.05	28.65±7.25	12.86±7.37	0.870	0.870	<.05	<.05
Resting metabolic rate (RMR^{4hr})	1.20±0.27[c]	0.93±0.17[d]	1.16±0.16	1.575	0.270	<.05	>.05	21.31±9.84	10.25±7.62	0.802	0.802	<.05	<.05
Basal metabolic rate (BMR)	1.16±0.26[c]	0.92±0.15[d]	1.15±0.15	1.346	0.081	<.05	>.05	21.26±8.58	11.61±11.18	0.737	0.737	<.05	<.05
Total 16-h energy expenditure	1.30±0.26	1.08±0.22		1.650		<.05		18.02±7.65		0.856		<.05	

Note. [c] $p<.01$, there were statistically significant differences between two of RMR^{2hr}, RMR^{4hr} and BMR in which EE measured using MC. [d] $p<.01$, there were statistically significant differences between two of RMR^{2hr}, RMR^{4hr} and BMR in which EE measured using SWMA. Effect size = M/SD. A regression analysis was used to create a correction equation using SWMA as the predictor and MC as the estimated outcome, and the correction equation was created: Corrected MC=0.233+0.990SWMA.

Results

The EE for all participants obtained from MC and SWMA is presented in Table 3. The results of the paired *t*-tests indicated that there were statistically significant differences between MC and SWMA in the EE of all sedentary behaviors, RMR^{2hr}, RMR^{4hr}, and BMR, with effect sizes ranging from 0.482 to 2.645. The correlations between SWMA and MC were from moderately high (0.684) to high (0.870). The absolute error rates ranged from 14.85% to 28.65%, with the lowest rate in sleeping (14.85%±14.71%) and the highest one in RMR^{2hr} (28.65%±7.25%).

A regression analysis was conducted to correct the results of SWMA, which are also presented in Table 3. A correction equation was created:

Corrected MC=0.233+0.990(SWMA) (1).

As expected, the correlations between MC and corrected SWMA are still the same, but the average absolute error rate was reduced from 19.94% to 9.51%.

Discussion and conclusions

This study examined the validity of the SWMA in estimating total EE of healthy Chinese adolescents using MC as the criterion measure. The results revealed moderate high to high correlations between EE estimated by MC and SWMA. However, the SWMA significantly underestimated EE when comparing with EE measured by MC.

The results from this study are consistent with findings from previous studies that investigated the validity of SWMA EE estimates in adults. Johannsen et al. (2012) reported that the SenseWear Pro3 Armband and the SWMA tended to underestimate total energy expenditure (TEE) and physical activity energy expenditure (PAEE). They reported that the absolute error rate was 28% compared with DLW measures, whereas we found a lower absolute error rate at about 20%. Martien, Seghers, Boen, and Delecluse (2015) also found SWMA underestimated EE in older adults during resting and three activity tasks using a portable gas analyzer as the criterion measure, with an overall absolute percent error of 14.1%. The current study is the first one to report the validity of SWMA in estimating EE in adolescents.

The underestimations of EE by SWMA may have been caused by several factors. The different internal algorithms may lead to different estimation between MC and SWMA measures. Even using the same devices, Calabró, Stewart, and Welk (2013) found that SWMA-Algorithm version 2.2 and SenseWear Pro Armband-Algorithm version 2.2 underestimated TEE and activity energy expenditure (AEE) compared with DLW, and SWMA-Algorithm version 5.0 and SenseWear Pro Armband-Algorithm version 5.0 overestimated the TEE and the AEE. The SWMA wearing location could also have an impact. As recommended by the BodyMedia® SenseWear Armband display manual, the adolescents in the current study wore SWMA on the back of the upper non-dominant arm (the triceps). SWMA might not be able to capture activity performed by the non-dominant hands only. Therefore, the SWMA was more likely to underestimate EE.

The use of MC allowed us to compare BMR with RMR. BMR measurement requires a complete rest condition without stimulation of a person's sympathetic nervous system. RMR, the minimum energy required to sustain vital body functions in a resting state during fasting conditions, is considered as the major component of total EE (Speakman & Selman, 2003). In our study, we measured RMR at two times, two hours and four hours after the lunch (RMR^{2hr} and RMR^{4hr}). The results showed that BMR < RMR^{4hr} < RMR^{2hr} in both the SWMA and MC. There were statistically significant differences between any two of RMR^{2hr}, RMR^{4hr}, and BMR estimated by MC and SWMA. In the periods of RMR^{2hr}, RMR^{4hr}, BMR, and sleeping, participants lying prone quietly on the bed, and there was no PA involved. There was the lowest absolute error rate in sleeping (14.85%±14.71%). This may be because the adolescents were not in a completely resting state during BMR, RMR^{4hr}, and RMR^{2hr}, so sleeping might be the only real static state in this study.

When there is a systematic error in the existing prediction algorithm, a linear regression can be applied as a correction. As an example, by creating the correction formula in this study, the mean of the absolute error rate was reduced from 19.94% to 9.51%.

A few limitations of the current study should be acknowledged. Only a small sample of 12-year-old normal weight Chinese adolescents was studied. The findings may not be generalizable to other populations such as overweight or obese adolescents, children and adolescents of different ages, or adolescents of other ethnicities. In addition, only a few sedentary behaviors were examined in the study. Other activities, such as free play and sporting activities, should be included in future studies. This study used the MC as the criteria method to measure EE, and experimentally demonstrated that SWMA is a convenient valid method, and it can be applied in practice.

In conclusion, we tried to verify the validity of SWMA in adolescents' EE of sedentary behavior, and finally concluded that SWMA significantly underestimated EE compared with MC in Chinese adolescents. However, the amount of error rate can be reduced by applying the study-derived correction equation proposed in this study.

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