Brief Report

Validation of an Armband to Measure Daily Energy Expenditure in Older Adults

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Background. Objective methods to measure daily energy expenditure in studies of aging are needed. We sought to determine the accuracy of total energy expenditure (TEE) and activity energy expenditure (AEE) estimates from the SenseWear Pro armband (SWA) using software versions 6.1 (SWA 6.1) and 5.1 (SWA 5.1) relative to criterion methods in free-living older adults.

Methods. Participants ($n = 19$, mean age 82.0 years) wore a SWA for a mean $\pm$ *SD* 12.5 $\pm$ 1.1 days, including while sleeping. During this same period, criterion values for TEE were assessed with doubly labeled water and for resting metabolic rate (RMR) with indirect calorimetry. AEE was calculated as 0.9 TEE – RMR.

Results. For TEE, there was no difference in mean $\pm$ *SD* values from doubly labeled water (2,040 $\pm$ 472 kcal/day) versus SWA 6.1 (2,012 $\pm$ 497 kcal/day, $p = .593$) or SWA 5.1 (2,066 $\pm$ 474 kcal/day, $p = .606$); individual values were highly correlated between methods (SWA 6.1 $r = .893$, $p < .001$; SWA 5.1 $r = .901$, $p < .001$) and demonstrated strong agreement (SWA 6.1 intraclass correlation coefficient = .896; SWA 5.1 intraclass correlation coefficient = .904). For AEE, mean values from SWA 6.1 (427 $\pm$ 304 kcal/day) were lower by 26.8% than criterion values (583 $\pm$ 242 kcal/day, $p = .003$), and mean values from SWA 5.1 (475 $\pm$ 299 kcal/day) were lower by 18.5% than criterion values ($p = .021$); however, individual values were highly correlated between methods (SWA 6.1 $r = .760$, $p < .001$; SWA 5.1 $r = .786$, $p < .001$) and demonstrated moderate agreement (SWA 6.1 intraclass correlation coefficient = .645; SWA 5.1 intraclass correlation coefficient = .720). Bland–Altman plots identified no systematic bias for TEE or AEE.

Conclusions. Acceptable levels of agreement were observed between SWA and criterion measurements of TEE and AEE in older adults.

Key Words: Accelerometer—Activity monitor—Physical activity—Aged—DLW.

LOW daily activity energy expenditure (AEE) is associated with increased risk of mortality in older adults (1) and is postulated to be an important contributing factor to many age-related health conditions, including cognitive impairment (2), fatigue (3), frailty (4), and mobility limitation (5). However, objective measurement of free-living daily energy expenditure via the criterion method of doubly labeled water (DLW) poses substantial challenges in large, epidemiologic studies. The labeled water is expensive, and

the method currently requires a high degree of technical expertise for implementation. To better understand the role of energy expenditure in aging, less expensive and more practical methods to objectively measure daily energy expenditure need to be validated.

The SenseWear Pro armband (SWA; BodyMedia Inc., Pittsburgh, PA) is a portable multisensor device that measures energy expenditure. Previous research assessed the validity of the SWA in young adults against indirect

calorimetry during laboratory exercise protocols involving treadmill walking and running, cycling, stepping, and arm ergometry (6–8) and against DLW under free-living conditions (9,10). However, there remains no evaluation of the validity of the SWA in older adults in free-living conditions. Given the growing interest in energy expenditure and aging, this study sought to determine the accuracy of total energy expenditure (TEE) and AEE estimates from the SWA relative to criterion methods in free-living older adults.

METHODS

Study Participants

In 1997–1998, investigators from the University of Pittsburgh and University of Tennessee, Memphis recruited 3,075 community-dwelling black and white men and women aged 70–79 years to participate in the Health, Aging, and Body Composition Study. In 2006–2007 (study year 10), 134 participants completed an energy expenditure substudy involving DLW. Between April and May 2007, a convenience sample of $n = 27$ wore an SWA during their energy expenditure substudy. Participants were subsequently excluded from analysis if their DLW isotope data ($n = 4$) or SWA data ($n = 4$) failed to meet a priori quality-control criteria, leaving an analytic sample of $n = 19$ (11 men, 8 women). Participants provided written informed consent, and the institutional review boards at both study sites and the coordinating site in San Francisco approved all protocols.

Doubly Labeled Water

TEE was measured using the criterion technique of DLW, described in detail previously (11). Specimens were obtained at two visits separated by approximately 2 weeks. At the first visit, participants provided a baseline urine specimen and then ingested a dose of DLW, composed of 1.9 g/kg estimated total body water of 10% $H_2^{18}O$ and 0.12 g/kg estimated total body water of 99.9% ^2H_2O. After dosing, three urine samples were obtained at approximately 2, 3, and 4 hours at which time the $^2H_2^{18}O$ dose had initially equilibrated in the body. Two consecutive urine voids were taken during the second visit. Plasma from a 5-mL blood sample was also obtained from everyone, but used in calculations only for those who had evidence of delayed isotopic equilibration, likely caused from urine retention in the bladder, or those who were missing a urine sample ($n = 6$, 11). Urine and plasma samples were stored at –20°C until analysis by isotope ratio mass spectrometry, which was completed at the University of Wisconsin, Madison, by a single technician.

Dilution spaces for ^2H and ^{18}O were calculated according to Coward (12). Total body water was calculated as the average of the dilution spaces of ^2H and ^{18}O after correction for isotopic exchange (1.041 for ^2H and 1.007 for ^{18}O). Carbon dioxide production was calculated using the two-point

DLW method outlined by Schoeller and colleagues (13), and TEE was derived in kilocalories per day using Weir's equation with a respiratory quotient of 0.86. The within-subject repeatability of TEE based on blinded, repeat, urine isotopic analysis was previously reported to be excellent in this cohort (1).

Resting Metabolic Rate

Resting metabolic rate (RMR) was measured using the criterion method of indirect calorimetry on a Deltatrac II respiratory gas analyzer (Datex Ohmeda Inc., Helsinki, Finland) as described previously (14). While in a fasting state and after 30 minutes of rest, a respiratory gas exchange hood was placed over the participant's head and RMR was measured minute-by-minute for 40 minutes. To avoid measurement of gas exchange created by the initial placement of the hood, only the final 30 minutes were used in subsequent calculations. Movement or sleeping during the test was noted, and those time periods were excluded from the RMR calculation. Test–retest reliability for the Deltatrac II has been shown to be excellent (15).

Activity Energy Expenditure

Criterion values for AEE were calculated as 0.9 TEE – RMR, which removed the energy expenditure due to the thermic effect of meals (assumed to be 10% of TEE) and energy expenditure devoted to resting metabolism (1). Thus, AEE was defined as the calories an individual expended in any and all movements per day. TEE in this equation was measured by DLW, and RMR was measured by indirect calorimetry, as described previously.

SenseWear Pro Armband

Participants received an SWA at the time of their first visit. They were instructed to wear the armband at all times, including while sleeping, until their second visit and to remove it only for brief periods for bathing or water activities. The armband was worn over the right triceps muscle, and data were sampled in 1-minute epochs from a heat flux sensor, a galvanic skin response sensor, a skin temperature sensor, a near body temperature sensor, and a bi-axial accelerometer. These data were used in combination with participant characteristics including gender, age, height, weight, smoking status, and handedness to estimate TEE from proprietary software developed by the manufacturer (InnerView Professional Research Software). At the time of data collection, InnerView Professional Version 5.1 was available. Since data collection, InnerView Professional Version 6.1 was released. SWA data were analyzed using both software versions, which we refer to subsequently as SWA 5.1 and SWA 6.1.

SWA estimates of AEE were calculated as 0.9 TEE – RMR, using SWA estimates of TEE. RMR was not assessed

Table 1. Energy Expenditure (kcal/day) Estimates From the SWA and Criterion Methods ($n = 19$)

	Mean (*SD*)	Range	Difference (SWA – Criterion)				Agreement	
			Mean (*SD*)	Range	95% CI	*p*	ICC	95% CI
TEE								
Criterion (DLW)	2,040 (472)	1,472, 2,889						
SWA 6.1	2,012 (497)	1,396, 3,187	–28 (225)	–456, 482	–137, 80	.593	.896	0.752, 0.958
SWA 5.1	2,066 (474)	1,501, 3,048	25 (211)	–378, 343	–76, 127	.606	.904	0.770, 0.962
AEE								
Criterion (DLW and IC)	583 (242)	255, 1,073						
SWA 6.1	427 (304)	96, 1,291	–156 (198)	–495, 403	–251, –60	.003	.645	0.146, 0.862
SWA 5.1	475 (299)	186, 1,166	–108 (185)	–478, 278	–197, –19	.021	.720	0.356, 0.887

Notes: AEE = activity energy expenditure; DLW = doubly labeled water; IC = indirect calorimetry; ICC = intraclass correlation coefficient; SWA = SenseWear Pro armband; and TEE = total energy expenditure. Criterion values for TEE were from DLW. Criterion values for AEE were calculated from TEE, as measured by DLW, and resting metabolic rate, as measured by IC. Day = 24-h period.

directly by the SWA, so RMR was estimated using the Harris–Benedict equations: RMR (men) = (13.75 × weight in kg) + (5 × height in cm) – (6.76 × age in years) + 66 and RMR (women) = (9.6 × weight in kg) + (1.8 × height in cm) – (4.7 × age in years) + 655. A priori, we decided a participant's SWA data were acceptable for analysis if overall wear time was ≥85% of the total time they had the SWA in their possession.

Other Measurements

At the first visit, body weight was measured by a calibrated balance–beam scale, and height was measured with a Harpenden stadiometer. Race was self-reported at the baseline Health, Aging, and Body Composition Study visit in 1997–1998. Daily steps taken between the first and second energy expenditure visits were calculated from the SWA software algorithms.

Statistical Analysis

To assess differences in mean TEE and AEE estimates from the SWA and criterion methods, we used paired *t* tests. To examine strength of the linear relation between SWA and criterion estimates of TEE and AEE, we calculated Pearson correlation coefficients. To examine the degree of agreement between SWA and criterion estimates of TEE and AEE, we calculated the intraclass correlation coefficients and assumed a two-way (instrument × subject) analysis of variance; the closer the correlation is to 1.0, the less within-subject variance and the stronger concordance between estimates. To examine the degree of systematic bias in SWA estimates of TEE and AEE (i.e., whether the differences between SWA and criterion estimates were correlated with the magnitude of energy expenditure), we constructed Bland and Altman plots and calculated the limits of agreement between the SWA and criterion methods, defined as the mean difference between the two methods ± 2 *SD* of the difference. We also regressed the residual values (SWA – criterion) against the values obtained from the criterion method; a lack of association was interpreted to indicate no systematic over- or under-

estimation. Because investigators may be interested in categorizing SWA estimates of energy expenditure, we also calculated tertiles of TEE and AEE and determined the proportion of participants whose TEE and AEE estimates from the SWA were classified correctly. Statistical analyses were performed in SAS v 9.1 (SAS Institute, Cary, NC) and R v 2.5.1 (R Foundation for Statistical Computing, http://www.r-project.org).

RESULTS

Participant Characteristics

Participants ranged in age from 78 to 89 years, with mean (*SD*) age of 82.0 (3.3) years. More than half of participants were men ($n = 11$, 58%), white ($n = 13$, 68%), and from the Pittsburgh clinical site ($n = 13$, 68%). As a group, they were overweight with mean body mass index 28.1 (3.8) kg/m^2 (range 22.3–34.9 kg/m^2), took an average of 3,676 (2,366) steps per day, and had mean RMR measured by indirect calorimetry of 1,253 (236) kcal/day. Percent wear time for the armband averaged 95.9% (3.7), and the mean duration between visit 1 and visit 2 was 12.5 (1.1) days.

Total Energy Expenditure

Mean (*SD*) values and ranges of TEE from DLW and the SWA are shown in Table 1. Paired *t*-test analysis revealed no significant difference in TEE from DLW versus the SWA. TEE values from DLW and the SWA were strongly correlated (Figure 1). Individual TEE values from DLW and the SWA also showed strong agreement (Table 1) with intraclass correlation coefficients that indicated approximately 90% of the total variance was explained by differences between participants, whereas only 10% was due to within-subject variation between methods. In the Bland–Altman plots for TEE (Figure 2), all but one of the values were within the limits of agreement for SWA 6.1 (450 kcal/day), and 100% of the values were within the limits of agreement for SWA 5.1 (422 kcal/day). Regression of the residual values for TEE (SWA – DLW) against the
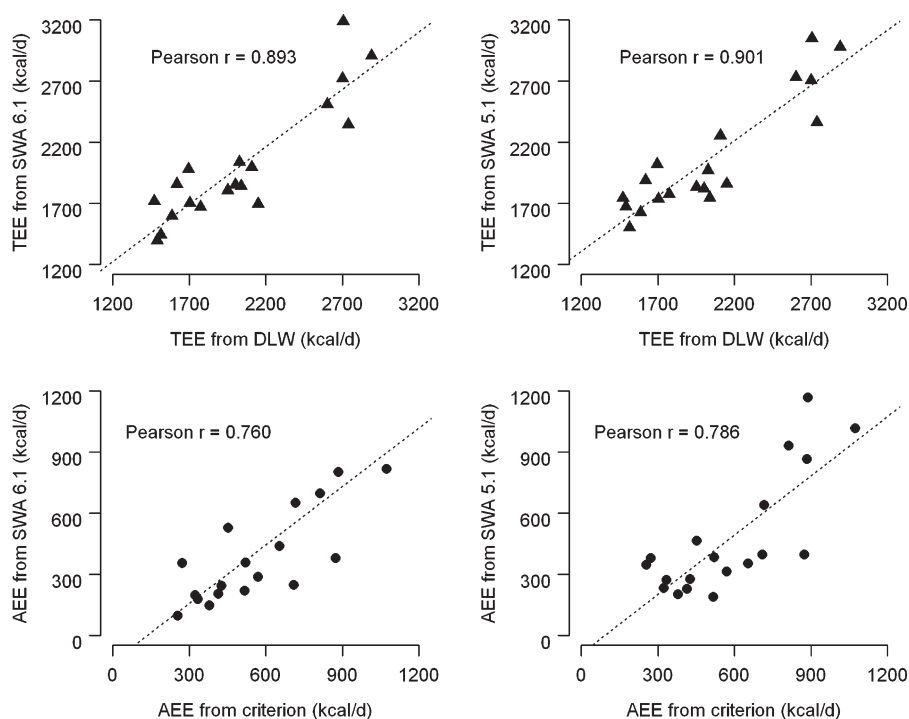
Figure 1. Measurements of total energy expenditure (TEE, top row) and activity energy expenditure (AEE, bottom row) from the criterion method on the x-axis and the SenseWear Pro armband (SWA) on the y-axis (SWA 6.1, left column; SWA 5.1, right column). Criterion values for TEE were from doubly labeled water (DLW). Criterion values for AEE were calculated from TEE, as measured by DLW, and resting metabolic rate, as measured by indirect calorimetry. Dotted line is from linear regression. $p < .001$ for all correlations.

values obtained from DLW identified no systematic over- or underestimation of TEE values across the magnitude of values observed for either SWA 6.1 ($r = -.127$, $p = .606$) or SWA 5.1 ($r = -.215$, $p = .376$). Overall, 63.2% (12/19) of participants were classified in the same tertile of TEE by DLW and the SWA 6.1 and 73.7% (14/19) were classified in the same tertile of TEE by DLW and the SWA 5.1.

Activity Energy Expenditure

Mean (*SD*) values and ranges of AEE from the criterion method and the SWA are shown in Table 1. Paired *t*-test analysis revealed that AEE values calculated from SWA 6.1 were significantly lower by 26.8% (156 kcal/day) than criterion values and that AEE values calculated from SWA 5.1 were significantly lower by 18.5% (108 kcal/day) than criterion values. AEE values from the criterion method and the SWA were strongly correlated (Figure 1). Individual AEE values from the criterion method and the SWA showed moderate agreement (Table 1). In the Bland–Altman plots for AEE (Figure 2), all but one of the values were within the limits of agreement for SWA 6.1 (396 kcal/day), and all but two of the values were within the limits of agreement for SWA 5.1 (370 kcal/day). Regression of the residual values for AEE (SWA – criterion) against the values obtained from the criterion method identified no systematic over- or underestimation of AEE values across the magnitude of AEE values observed for either SWA 6.1 ($r = -.054$, $p = .826$) or

SWA 5.1 ($r = -.039$, $p = .875$). Overall, 68.4% (13/19) of participants were classified in the same tertile of AEE by the criterion method and the SWA 6.1 and by the criterion method and the SWA 5.1.

Discussion

The results of this validation study show that the SWA accurately estimated free-living energy expenditure of older adults who performed a variety of physical and lifestyle activities over an extended period of time. There were no significant differences in mean TEE from the SWA versus DLW. Measures of TEE from DLW and the SWA were strongly correlated and demonstrated strong agreement, and the Bland–Altman analysis revealed no systematic bias for SWA measurements of TEE. Categorizing participants into tertiles of TEE based on SWA 6.1 and SWA 5.1 estimates misclassified 36.8% and 26.3% of participants, respectively.

On average, the SWA underestimated AEE. Despite these between-group differences, measures of AEE from the criterion method and the SWA were strongly correlated and demonstrated moderate agreement, and the Bland–Altman analysis revealed no systematic bias for SWA measurements of AEE. Categorizing participants into tertiles of AEE based on SWA 6.1 and SWA 5.1 estimates misclassified 31.6% of participants. The SWA software did not provide direct estimates of AEE as defined in this study (0.9 TEE – RMR), so we calculated AEE using SWA
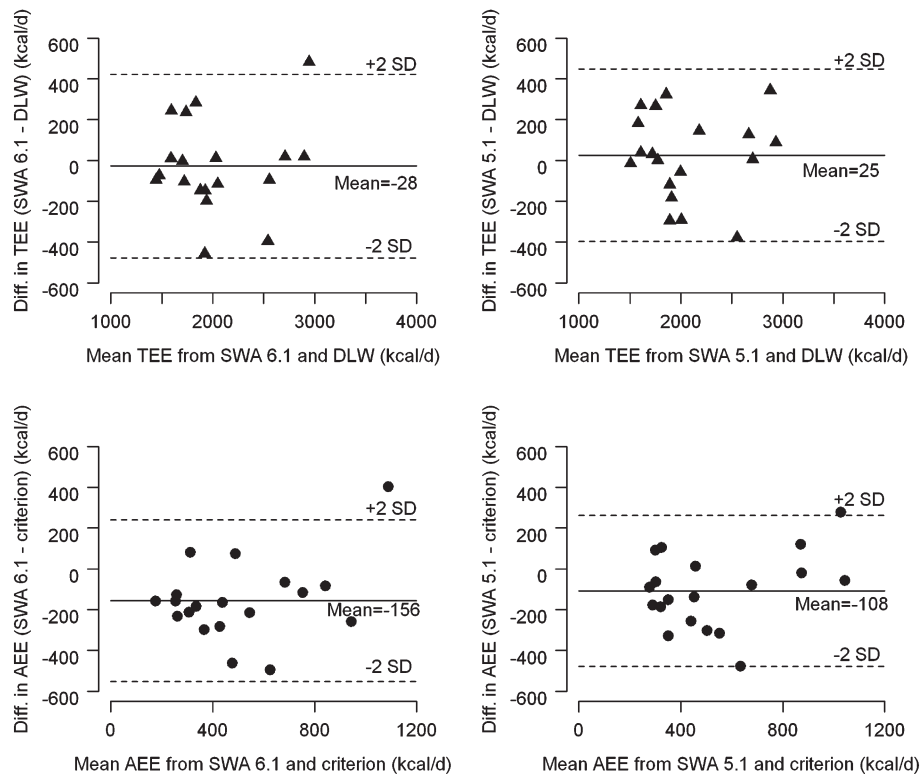
Figure 2. Bland–Altman plots for total energy expenditure (TEE, top panel) and activity energy expenditure (AEE, bottom panel). Results for SenseWear Pro Armband with version 6.1 software (SWA 6.1) are shown in the left column, and from SWA 5.1 are shown in the right column. Criterion values for TEE were from doubly labeled water (DLW). Criterion values for AEE were calculated from TEE, as measured by DLW, and resting metabolic rate, as measured by indirect calorimetry. Solid lines show the mean difference between methods, and dotted lines show the limits of agreement (±2 *SD* of the mean difference).

estimates of TEE and Harris–Benedict estimates of RMR. Any errors in estimating TEE and RMR would have translated into errors measuring AEE, which explains why AEE was measured by the SWA with more error than TEE.

To our knowledge, no previous study has validated the SWA against criterion methods in free-living older adults. The results of the current study are generally consistent with the results from studies of younger free-living adult populations done by Johannsen and colleagues (9; 14 days, mean age 38 years, software version 6.1) and St-Onge and colleagues (10; 10 days, mean age 35 years, software version 4.02), which both demonstrated strong agreement between TEE measurements from the SWA and DLW. As in the current study, both of these previous studies found that the SWA underestimated AEE (Johannsen: 123 kcal/day; St-Onge: 218 kcal/day).

A strength of the SWA is that it integrates motion data from an accelerometer with data from a variety of heat-related sensors, which assess the energy cost of nonambulatory and low-intensity activities that are common among older adults but that are difficult to sense with an accelerometer. The SWA prediction algorithms, which incorporate data from all five physiologic sensors to estimate energy expenditure, are not shared by the manufacturer, so the exact manner in which the data are integrated is not known. Our results suggest that version 5.1 algorithms are

somewhat more accurate than version 6.1 algorithms for older adults.

Participants tolerated the SWA well over the study period (range 11–14 days). We did not receive any reports of safety issues related to the armband or of minor discomforts, such as skin irritation or discomfort during sleeping, as have been noted in other studies (10). Adherence to the SWA prescription was good. Of the 27 participants who received an armband, four participants were excluded from analysis because their DLW data were not acceptable, but the SWA mean percent wear time for these participants was excellent at 98.0%. Four other participants wore the SWA most of the time (range 56.3–73.8%) but not for ≥85% of the time and thus were excluded from analysis. We could not determine whether these participants simply forgot to put their SWA back on after removing it or whether they decided not to wear it on certain days. Future studies may observe even greater adherence than in the current study if they require a shorter duration of wear.

This study has certain limitations. The results do not provide information on whether the SWA yields accurate estimates of energy expenditure over a single day or over a shorter period of days than was studied. The current study involved a relatively small sample, so it was not possible to quantify the accuracy of the SWA in subgroups of interest. Future work on larger samples is warranted to examine the

accuracy of energy expenditure estimates separately for men and women, in different race groups, and across a diverse range of body mass index.

In summary, the results of this study demonstrate acceptable levels of agreement between the SWA and criterion measurements of TEE and AEE in older adults under free-living conditions. Agreement was greater for estimates of TEE than AEE. Future studies that are sufficiently powered for separate assessments in men and women, in different race groups, and across a wider range of body mass index will add to the evidence base for the SWA.

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