Respiratory Medicine (2009) **103**, 1511—1517

available at www.sciencedirect.com
ScienceDirect
journal homepage: www.elsevier.com/locate/rmed

Evaluation of the SenseWear activity monitor during exercise in cystic fibrosis and in health☆

Tiffany Jane Dwyer[a,b,*], Jennifer Ailsey Alison[a,b], Zoe Jane McKeough[a], Mark Russell Elkins[b], Peter Thomas Patrick Bye[b]

[a] *Discipline of Physiotherapy, University of Sydney, Sydney, Australia*
[b] *Department of Respiratory Medicine, Royal Prince Alfred Hospital, Sydney, Australia*

Received 19 March 2009; accepted 15 April 2009
Available online 23 May 2009

KEYWORDS
Energy expenditure;
Motion sensor;
Physical activity;
Respiratory disease;
Step count

Summary
Objective: Determine the SenseWear Pro3 Armband (SWA) accuracy for estimating energy expenditure (EE) and step count during treadmill walking in cystic fibrosis (CF) compared to healthy adults.
Hypothesis: SWA estimation of EE would be less accurate for CF, than for healthy subjects, due to interference with the SWA skin sensors caused by the high salt concentration in the sweat of CF subjects.
Methods: 17 CF (mean age 26 yr; FEV_1 54% predicted) and 17 age-matched control subjects walked slightly faster than their comfortable pace on a treadmill for 20 min, whilst simultaneously wearing the SWA and breathing through an open-circuit indirect calorimetry (IC) system. Subjects' steps were manually counted.
Results: Combined EE data from all subjects showed no significant difference in EE measured by IC (6.0 ± 3.4 kcal min^{-1}) compared to the SWA estimate (6.3 ± 2.5 kcal min^{-1}), however the SWA significantly overestimated EE at low exercise intensities and underestimated EE at high exercise intensities. Correlations between EE values, estimated by the SWA and measured by IC, were greater than 0.85 ($p < 0.001$) for both the CF and control group. Standard multiple regression showed that diagnosis of CF independently predicted less than 0.1% of the difference between the IC measure of EE and the SWA estimate. The SWA recorded slightly but significantly fewer steps (113 ± 12 steps min^{-1}) than the manual count (119 ± 9 steps min^{-1}).
Conclusion: Diagnosis of CF had no significant negative impact on the accuracy of the SWA estimate of EE. The SWA provided a reasonably accurate estimate of EE and step count during treadmill walking.

☆ Prior publication: part of this study was presented in poster format at the 22nd Annual North American Cystic Fibrosis Conference in Orlando, Florida, USA on October 23—25, 2008. The abstract was published in Pediatric Pulmonology 2008, Supplement 31: A514, p. 386.
* Correspondence to: Tiffany Jane Dwyer, Department of Respiratory Medicine, Level 11 West, Royal Prince Alfred Hospital, Missenden Road, Camperdown NSW 2050, Australia. Tel.: +61 2 9515 5234; fax: +61 2 9515 8196.
E-mail address: tdwyer@med.usyd.edu.au (T.J. Dwyer).

0954-6111/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rmed.2009.04.013

Introduction

Exercise is recommended in consensus documents regarding health care management of people with cystic fibrosis (CF).[1–3] Higher levels of exercise capacity amongst people with CF are associated with longer survival,[4] improved sense of well-being[5] and greater employment capability.[6] As well, amongst CF individuals, higher levels of habitual physical activity are associated with a significantly slower rate of decline in lung function[7] and bone mineral density[8] and a greater exercise capacity in adults[9] and children.[10] Therefore, physical activity and its accurate evaluation are very important for people with CF.

A variety of methods have been used to quantify habitual physical activity. Subjective measures, such as interviews, questionnaires and self-report diaries are cheap and easy to administer but can often be flawed by memory recall errors and inaccurate perception of activity behavior.[11,12] Stable isotopes, such as doubly labelled water, are the gold standard measurement of daily energy expenditure in the free-living environment, however this technique is costly and does not provide information on patterns or intensity of physical activity.[12] Indirect calorimetry is the gold standard measurement of physical activity in the laboratory but is too cumbersome for measurement in the free-living environment.[13] Motion sensors, such as accelerometers and pedometers, are ideal for the free-living environment and are good at estimating walking and jogging on flat ground,[14] but are poor at estimating upper limb activity[15] or walking and running on an incline.[14,16] The addition of heart rate monitors aids estimation of intensity of physical activity[17] but can be influenced by fitness level, ambient temperature and emotional stress.[12] The measurement of physical activity in the free-living environment therefore remains problematic and has stimulated ongoing development of new technologies.

A recently developed portable physical activity monitor, the SenseWear Pro3 Armband (SWA, BodyMedia, Pittsburgh, USA), has been designed to improve the measurement of physical activity. This activity monitor integrates, through proprietary non-linear algorithms, subject characteristics (age, gender, height, weight, handedness and smoking history), a bi-axial accelerometer, galvanic skin resistance, heat flux, skin and near body temperature, to estimate energy expenditure (EE) and step count. Early research with this device has shown that it can accurately estimate: resting EE in healthy[13,18,19] and obese[19] subjects; active EE in healthy,[13,20,21] chronic obstructive pulmonary disease[22] and cardiac disease[23] subjects; and daily EE in healthy[24] and diabetic[25] subjects. The only published report on the accuracy of the SWA's step count is a pilot study, which showed the SWA to record 3–4% less steps than the manual count.[26] This pilot study included only eight participants and did not report the methods employed.

For the estimation of EE, the SWA uses data from physiological sensors placed on the skin. It is unknown if the high concentration of salt in the sweat of individuals with CF[27] would interfere with the estimation of EE. Hence, the primary aim of this study was to evaluate the accuracy of the SWA estimation of EE during treadmill walking in a group of CF compared to age-matched, healthy control subjects. We hypothesised that the SWA would be less accurate in the estimation of EE for the group of CF subjects than for the group of healthy control subjects. The secondary aim of this study was to evaluate the accuracy of the SWA measurement of step count during treadmill walking in the same group of CF and age-matched, healthy control subjects.

Materials and methods

Subjects

Seventeen adults with CF were recruited from the CF Clinic at Royal Prince Alfred Hospital, Sydney, Australia and 17 age-matched healthy control participants were recruited from staff and colleagues of the same hospital (Table 1). Potential CF subjects were excluded if they had received a lung transplant, were colonised with *Burkholderia cepacia*, were not clinically stable or were unable to exercise for 20 min without stopping. Research procedures were approved by the Ethics Committee of the Sydney South West Area Health Service and all subjects provided written informed consent prior to participating in this study.

Measurement of demographic data

Age, height, weight, gender, handedness, smoking history and lung function were recorded prior to exercising. Spirometry was performed according to ATS guidelines,[28] using the Vmax229 system (SensorMedics, Yorba Linda, USA) and reported as a percentage of predicted values.[29] Lung function was tested to assess the clinical status of CF subjects and to confirm normal respiratory function for the control subjects.

Exercise protocols

Subjects walked on a motorised treadmill (LE200 CE, h/p/cosmos sports and medical gmbh, Nussdorf-Traunstein, Germany) for 20 min without slowing down or stopping, whilst simultaneously wearing the SWA and breathing through an open-circuit indirect calorimetry system. Subjects were asked to walk at a speed that was slightly faster than their comfortable walking pace, which was intended to elicit moderate intensity exercise. For the first 10 min, the treadmill was set at 0% incline for all subjects (flat walking) and for the second 10 min, the treadmill was set at 5% incline for CF subjects and 10% incline for control subjects (incline walking). The incline percentage was based on pilot data of 15 subjects with CF, which showed that the average treadmill incline to achieve 60% VO_2 peak was 5%. It was assumed that the control subjects would need to walk at a higher incline to achieve similar exercise intensity. At the end of each 10-min period, the subject's reported dyspnea, using the modified Borg dyspnea scale,[30] and rate of perceived exertion, using the modified 0–10-point scale,[31] were recorded as markers of exercise intensity.

Open-circuit indirect calorimetry

The criterion method for assessing EE during treadmill walking was breath-by-breath open-circuit indirect

Table 1 Subject characteristics.

	CF subjects ($n = 17$)		Control subjects ($n = 17$)	
	Mean ± SD	Range	Mean ± SD	Range
Age (yr)	26 ± 6	18–38	29 ± 7	20–49
Gender	6F : 11M		8F : 9M	
BMI (kg m^{-2})	21.4 ± 4.6	15.1–34.6	23.3 ± 3.8	17.1–33.3
FEV_1 (predicted %)	54 ± 25	18–90	103 ± 13	82–124
FVC (predicted %)	75 ± 22	39–115	100 ± 18	76–133

Forced expiratory volume in 1 s (FEV_1) and forced vital capacity (FVC) measured as percent of predicted normal lung volume.[29]

calorimetry (IC), using the Vmax229 system. This system uses Weir's equation to calculate EE ($EE = 3.94 * VO_2 + 1.11 * VCO_2$),[32] where EE is measured in kilocalories per minute (kcal min^{-1}) and VO_2 and VCO_2 are measured in litres per minute (L min^{-1}). A pulse oximeter (Masimo Corporation, Irvine, USA), worn on the subject's forehead and connected to the Vmax229 system, provided heart rate data. After completing the 20-min exercise protocol, the IC and heart rate data were saved to a computer file, which was randomly coded, to ensure de-identification at later analysis.

Manual step count

The criterion method for assessing step count during treadmill walking was manual counting. During both the 10-min flat and incline walking periods, a research assistant counted the subject's steps every third minute.

SenseWear Pro3 Armband

The comparison method for assessing EE and step count during treadmill walking was the SenseWear Pro3 armband. Before each exercise trial, the subject's details (age, height, weight, gender, handedness and smoking history) were entered into the SWA software program (InnerView Research Software v6.1, BodyMedia). As recommended by the manufacturer, the SWA was worn on the posterior upper right arm. Once the SWA had acclimatised to the subject (between 1 and 10 min), the subject was connected to the IC circuit, and the exercise trial commenced. The SWA ''timestamp'' button was used to delineate the start of exercise, the end of the flat walking period and the end of the incline walking period. After completing the 20-min exercise protocol, the SWA data was downloaded to the software program. This program uses proprietary non-linear algorithms to compute EE from the accelerometry, physiologic sensors and demographic data. This data was then saved to a computer file, which was randomly coded, to ensure de-identification at later analysis.

Data analysis

Once all subjects had completed the trial, the exercise data sheets (including subject details, walking speed, manual step count, dyspnea and perceived exertion scores), the IC computer files and the SWA computer files were analysed by a blinded assessor. From the data sheets, the assessor calculated the criterion measure of manual step count for flat and incline walking as the average of the data collected for 3 min in each 10-min period. From the IC computer files, the assessor calculated the criterion measure of EE and heart rate for flat and incline walking as the average of the data collected from the IC breath-by-breath analysis throughout each 10-min period. From the SWA computer files, the assessor calculated the comparison estimate of EE and step count for flat and incline walking as the average of the data collected from the SWA minute-by-minute analysis throughout each 10-min period. The blinded assessor completed all calculations before unblinding was performed.

Statistical analysis

Statistical analyses were performed using SPSS software (version 14.0 for Windows, SPSS Inc., Chicago, USA). Sample size calculations showed that 17 subjects in each group would give 80% power to detect a correlation of $r > 0.7$ between the criterion and comparison values of EE and step count at a significance level of $p < 0.05$. Paired t-tests were calculated for comparison of IC measures of EE and SWA estimates of EE and for comparison of measures of step count between manual counting and the SWA. Pearson correlation coefficients (r) and Bland–Altman[33] analyses were performed to determine agreement and to assess for any bias between IC measures of EE and the SWA estimates of EE, and between manual counting and the SWA measures of step count. Standard multiple regression was conducted to determine which variables affected accuracy of the EE estimated by the SWA compared to the EE measured by IC.

Results

All 34 subjects completed the study and there were no missing data.

Exercise intensity

Subjects walked at an average speed of 5.4 ± 1.0 km h^{-1} (4.7 ± 0.9 km h^{-1} and 6.1 ± 0.7 km h^{-1} for CF and control subjects respectively). The dyspnea, rate of perceived exertion and heart rate data during flat and incline walking for the CF and control group are presented in Table 2.

Energy expenditure

When the EE data from the 34 subjects was combined for flat and incline walking (for a total of 68 exercise periods), there was no significant difference in EE measured by IC compared to that estimated by the SWA (6.0 ± 3.4 kcal min^{-1} and 6.3 ± 2.5 kcal min^{-1} respectively; mean difference 0.3 kcal min^{-1}, 95%CI −0.2 to 0.8). However, when exercise periods were divided into flat and incline walking (Table 3), the SWA significantly overestimated EE compared to IC during flat walking for both the CF and control group. During incline walking, the SWA non-significantly overestimated EE compared to IC for the CF group and significantly underestimated EE compared to IC for the control group.

There were significant strong correlations between EE values measured by IC and estimated by the SWA during flat walking for both the CF and control group ($r = 0.89$, $p < 0.001$; $r = 0.85$, $p < 0.001$ respectively) and during incline walking for both the CF and control group ($r = 0.87$, $p < 0.001$; $r = 0.92$, $p < 0.001$ respectively). The Bland–Altman plot for EE during flat and incline walking for all subjects is shown in Fig. 1. Ninety percent (61 of 68 exercise periods) were within two standard deviations of the difference between the IC measure of EE and the SWA estimate of EE (± 4.0 kcal min^{-1}). The analysis also highlighted that the SWA tended to underestimate EE at high exercise intensities (greater than 8 kcal min^{-1}).

Although the mean difference in EE, between flat and incline walking, detected by the SWA was less than that measured by IC, the SWA did significantly detect the change in exercise intensity from flat to incline walking in both the CF and control group. The mean difference in EE between flat and incline walking for the CF group was 1.6 kcal min^{-1} (95%CI 1.1 to 2.0) for IC measurement and 0.7 kcal min^{-1} (95%CI 0.3 to 1.1) for SWA estimation. The mean difference in EE between flat and incline walking for the control group was 5.1 kcal min^{-1} (95%CI 4.1 to 6.0) for IC measurement and 1.2 kcal min^{-1} (95%CI 0.9 to 1.6) for SWA estimation.

Standard multiple regression was performed with all 68 exercise periods combined to determine which variables affected the SWA estimation of EE. Of particular interest was to evaluate if CF subjects, compared to control subjects, had less accurate SWA estimates of EE compared to the IC measures of EE. The dependent variable was the absolute difference in EE between the IC measurement and the SWA estimate (i.e. the difference between the criterion and comparison method for EE values). The independent variables entered into the regression analysis were: group (CF or control); gender; body mass index (BMI); and exercise intensity (VO_2 in L min^{-1}). The independent variables that significantly reduced the accuracy of the SWA estimate were having a higher BMI and exercising at a higher intensity. Both of these variables independently predicted 8% ($p < 0.001$) of the difference between the IC measure of EE and the SWA estimate of EE. Diagnosis of CF independently predicted less than 0.1% of the difference between the IC measure of EE and the SWA estimate of EE.

Step count

There was no change in walking speed between flat and incline walking, so the 68 exercise periods were combined for analysis of step count between manual counting and SWA measurement. The SWA recorded slightly but significantly fewer steps than those recorded by manual counting (113 ± 12 steps min^{-1} and 119 ± 9 steps min^{-1} respectively; mean difference 7 steps min^{-1}, 95%CI 5 to 9). The SWA step count over-recorded the manual step count in only one exercise period and this was by 3 steps min^{-1}. There was a significant strong correlation between step count measured by manual counting and the SWA ($r = 0.66$, $p < 0.001$). A Bland–Altman analysis (Fig. 2), determined that 94% (64 of the 68 exercise periods) were within two standard deviations of the difference between the two values of step count (± 18 steps min^{-1}), and the greatest under-scoring of step count occurred at slower cadences (less than 116 steps min^{-1}).

Discussion

The primary purpose of this study was to evaluate the accuracy of the SWA estimation of EE during treadmill walking in a group of adults with CF compared to a group of age-matched, healthy control subjects. The validity of the SWA estimate of EE was assessed by comparing its results with the simultaneous measurement of EE by IC. To our knowledge, this is the first study investigating the accuracy of the SWA in CF patients.

Contrary to our hypothesis, diagnosis of CF had no significant negative impact on the accuracy of the SWA estimation of EE. Calculation by multiple regression showed that diagnosis of CF independently predicted less than 0.1% of the difference in EE estimated by the SWA compared to IC measurement. Although we did not formally measure the amount of sweat or salt content in the sweat produced

Table 2 Exercise intensity during treadmill walking.

	Flat walking			Incline walking		
	Dyspnea	RPE	HR (bpm)	Dyspnea	RPE	HR (bpm)
CF ($n = 17$)	1.2 ± 1.0	1.1 ± 1.0	111 ± 10	2.9 ± 1.6	2.4 ± 1.7	128 ± 11
Control ($n = 17$)	0.7 ± 0.9	0.7 ± 0.6	108 ± 9	3.7 ± 1.9	4.3 ± 2.3	149 ± 15
CF vs Control	0.5 (−0.1 to 1.2)	0.4 (−0.2 to 1.0)	3 (−4 to 9)	−0.8 (−2.0 to 0.5)	−1.9† (−3.3 to −0.4)	−20* (−29 to −11)

Group values for mean ± standard deviation of Borg dyspnea,[30] rate of perceived exertion (RPE)[31] and heart rate (HR) in beats min^{-1} (bpm) for CF and control subjects during flat and incline walking, as reported by the subject and measured by pulse oximetry. Comparisons between the CF and control group are shown as group mean differences and (95%CI).
*$p < 0.001$.
†$p = 0.01$.

Table 3 Energy expenditure during treadmill walking.

	Flat walking EE (kcal min^{-1})			Incline walking EE (kcal min^{-1})			Incline vs flat
	IC	SWA	SWA vs IC	IC	SWA	SWA vs IC	SWA
CF ($n = 17$)	3.6 ± 1.7	5.1 ± 2.4	1.5* (0.9 to 2.1)	5.1 ± 2.5	5.8 ± 2.7	0.6 (−0.1 to 1.3)	0.7† (0.3 to 1.1)
Control ($n = 17$)	5.2 ± 1.6	6.7 ± 2.0	1.5* (0.9 to 2.0)	10.3 ± 3.3	7.9 ± 2.1	−2.4* (−3.2 to −1.6)	1.2* (0.9 to 1.6)

Group values for mean ± standard deviation of energy expenditure (EE) in kcal min^{-1}, as measured by indirect calorimetry (IC) and estimated by the SenseWear Pro3 Armband (SWA), for CF and control subjects during flat and incline walking. Comparisons between the EE values, measured by IC and estimated by the SWA, are shown as group mean differences and (95%CI). Comparisons between the EE values estimated by the SWA during incline walking and flat walking are shown as group mean differences and (95%CI).
*$p < 0.001$.
†$p = 0.002$.

during the exercise testing, all CF and control subjects were documented to have sweated. It can therefore be assumed that the high concentration of salt in the sweat of CF individuals does not interfere with the physiological skin sensors and data collection for the estimation of EE with the SWA.

While diagnosis of CF did not impact the ability of the SWA to accurately estimate EE, the multiple regression analysis in this study indicated that exercise intensity significantly affected the accuracy of the EE estimate. Our results showed that the SWA underestimated EE at higher exercise intensities. Previous investigations of the SWA estimation of EE during walking in young, healthy subjects,[13,20] patients with chronic obstructive pulmonary disease[22] and cardiac disease[23] all reported this same observation for the SWA to increasingly underestimate EE with increasing exercise intensity.

Further analysis combining flat and incline walking for all CF and control subjects showed that the SWA provided an accurate estimate of EE, as evidenced by a mean difference of only 0.3 kcal min^{-1} compared to measurement of EE by IC. In addition, individual results, comparing the SWA estimate of EE to IC measurement of EE by correlation and Bland–Altman analyses, showed strong agreement between the two measurement techniques. Correlations between the two techniques were greater than 0.85 for both the CF and control group at each level of incline. These results are markedly higher than for previously published work, which used older SWA models and InnerView software, when comparing SWA estimates of EE to IC measurement during treadmill walking at similar speeds and incline, with correlations ranging from 0.47 to 0.76.[13,20]

Another important finding from this study was that the SWA, using the latest commercially available InnerView software (v6.1), was able to detect the change in exercise intensity, as measured by EE, elicited by a change in

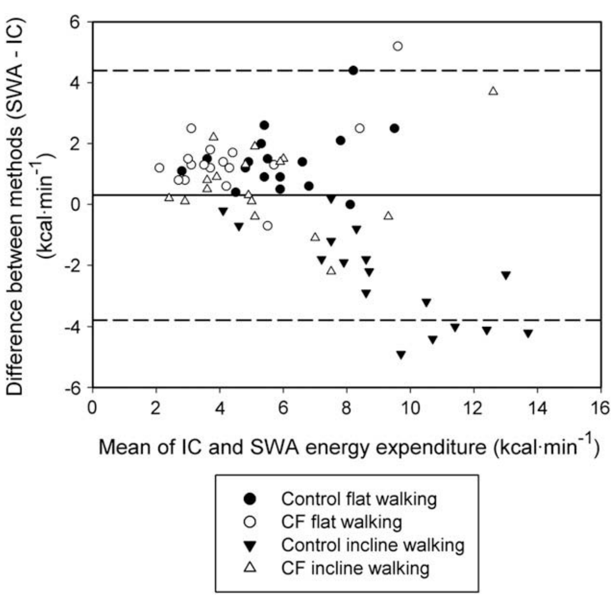

Figure 1 Bland–Altman plot between the IC measurement and SWA estimate of EE during flat and incline treadmill walking for all subjects ($n = 34$, two exercise periods). The solid horizontal line represents the mean difference between the IC measure of EE and the SWA estimate of EE (+0.3 kcal min^{-1}). The broken horizontal lines represent the limits of agreement corresponding to ±2 SD of the difference between the IC measure of EE and the SWA estimate of EE (±4.0 kcal min^{-1}).

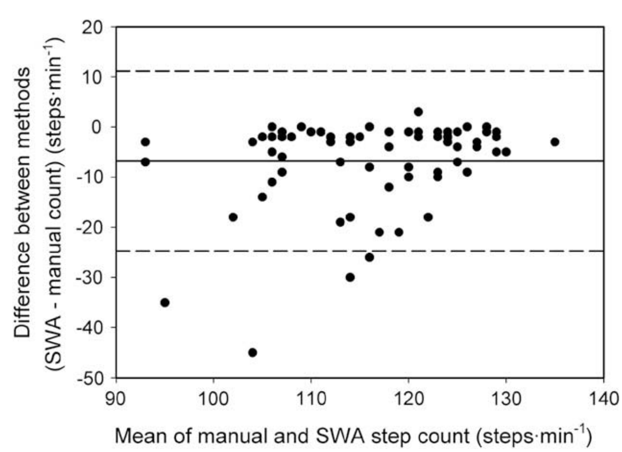

Figure 2 Bland–Altman plot between the manual count and SWA measurement of step count during treadmill walking for all subjects ($n = 34$, two exercise periods). The solid horizontal line represents the mean difference between the manual count and the SWA measurement of step count (−7 steps min^{-1}). The broken horizontal lines represent the limits of agreement corresponding to ±2 SD of the difference between the manual count and the SWA measurement of step count (±18 steps min^{-1}).

treadmill incline. This finding was significant for both the CF group, with a change from 0% to 5% incline, and the control group, with a change from 0% to 10% incline. Earlier research, using older versions of the software (v1.0 and v3.2), showed only a detection in the change in exercise intensity from a change in speed,[13,21] but not from a change in incline.[13,20] Our results would suggest that the SWA, with the newer software, may perform better when measuring physical activity in the free-living environment than standard motion sensors, which often failed to detect changes in incline.[14,16]

The secondary purpose of this study was to evaluate the accuracy of the SWA measurement of step count during treadmill walking. The validity of the SWA measure of step count was assessed by comparing the results with a simultaneous manual count. To our knowledge, this is the first detailed study to evaluate the accuracy of the SWA measure of step count.

The SWA provided a reasonably accurate measure of step count compared to manual counting during treadmill walking. The average SWA step count was 5% less than the average manual count. This result is similar to a pilot study, which showed the SWA step count to be 3–4% less than the manual count.[26] Our result is comparable to other studies investigating motion sensors and pedometers, which are worn on the trunk or lower limb and specifically designed to measure step count.[34–36] Monitors of step count are considered "extremely accurate" if within $\pm$3% of the manual count and "acceptable" if within $\pm$10% of the manual count.[35]

In summary, the diagnosis of CF did not affect the accuracy of the SWA estimation of EE. The SWA provided a reasonably accurate estimate of physical activity, in terms of EE and step count, during treadmill walking for both CF and young, healthy control subjects. Although the SWA significantly underestimated EE at higher exercise intensities, the algorithms in the latest commercially available software provided better agreement with measurement of EE by IC than previously reported in studies using older software[13,20] and were able to detect changes in exercise intensity with changing treadmill incline. The SWA would therefore be a useful tool when measuring physical activity in CF when IC is too cumbersome or difficult.

Acknowledgements

The authors would like to thank Dr. Roger Adams, from the Discipline of Physiotherapy, Faculty of Health Sciences, University of Sydney, for his invaluable help with statistical analysis.

Disclosure of funding

Ms Tiffany Jane Dwyer is supported by an Australian Postgraduate Award scholarship from the University of Sydney. Ascencia Limited (BodyMedia distributor in Australia) provided a SenseWear Pro3 Armband, the InnerView Research software v6.1 and interface cable for this study, all of which were returned to the company at the end of the study.

Conflict of interest statement

None of the authors has a professional relationship with Ascencia Limited or BodyMedia.

References

1. Kerem E, Conway S, Elborn S, Heijerman H. Standards of care for patients with cystic fibrosis: a European consensus. *J Cyst Fibros* 2005;**4**(1):7–26.
2. Cystic Fibrosis Australia. Cystic fibrosis standards of care, Australia. http://www.thoracic.org.au/cysticfibrosis01.pdf; date last updated: November 2007 [accessed 17.03.09.].
3. Yankaskas JR, Marshall BC, Sufian B, Simon RH, Rodman D. Cystic fibrosis adult care: consensus conference report. *Chest* 2004;**125**(Suppl. 1):1–39.
4. Nixon PA, Orenstein DM, Kelsey SF, Doershuk CF. The prognostic value of exercise testing in patients with cystic fibrosis. *N Engl J Med* 1992;**327**(25):1785–8.
5. Orenstein DM, Nixon PA, Ross EA, Kaplan RM. The quality of well-being in cystic fibrosis. *Chest* 1989;**95**(2):344–7.
6. Frangolias DD, Holloway CL, Vedal S, Wilcox PG. Role of exercise and lung function in predicting work status in cystic fibrosis. *Am J Respir Crit Care Med* 2003;**167**(2):150–7.
7. Wilkes DL, Schneiderman-Walker J, Corey M, et al. Longterm effect of habitual physical activity on lung health in patients with cystic fibrosis. *Pediatr Pulmonol* 2007;**42**(Suppl. 30):358–9. A440.
8. Wilkes DL, Schneiderman-Walker J, Atenafu E, et al. Bone mineral density and habitual physical activity levels in cystic fibrosis. *Pediatr Pulmonol* 2008;**43**(Suppl. 31):436. A647.
9. Hebestreit H, Kieser S, Rudiger S, et al. Physical activity is independently related to aerobic capacity in cystic fibrosis. *Eur Respir J* 2006;**28**(4):734–9.
10. Selvadurai HC, Blimkie CJ, Cooper PJ, Mellis CM, Van Asperen PP. Gender differences in habitual activity in children with cystic fibrosis. *Arch Dis Child* 2004;**89**(10):928–33.
11. Freedson PS, Miller K. Objective monitoring of physical activity using motion sensors and heart rate. *Res Q Exerc Sport* 2000;**71**(Suppl. 2):21–9.
12. Melanson Jr EL, Freedson PS. Physical activity assessment: a review of methods. *Crit Rev Food Sci Nutr* 1996;**36**(5):385–96.
13. Fruin ML, Rankin JW. Validity of a multi-sensor armband in estimating rest and exercise energy expenditure. *Med Sci Sports Exerc* 2004;**36**(6):1063–9.
14. Jakicic JM, Winters C, Lagally K, Ho J, Robertson RJ, Wing RR. The accuracy of the TriTrac-R3D accelerometer to estimate energy expenditure. *Med Sci Sports Exerc* 1999;**31**(5):747–54.
15. Campbell KL, Crocker PRE, McKenzie DC. Field evaluation of energy expenditure in women using Tritrac accelerometers. *Med Sci Sports Exerc* 2002;**34**(10):1667–74.
16. Montoye HJ, Washburn R, Servais S, Ertl A, Webster JG, Nagle FJ. Estimation of energy expenditure by a portable accelerometer. *Med Sci Sports Exerc* 1983;**15**(5):403–7.
17. Strath SJ, Bassett Jr DR, Swartz AM, Thompson DL. Simultaneous heart rate-motion sensor technique to estimate energy expenditure. *Med Sci Sports Exerc* 2001;**33**(12):2118–23.
18. Malavolti M, Pietrobelli A, Dugoni M, et al. A new device for measuring resting energy expenditure (REE) in healthy subjects. *Nutr Metab Cardiovasc Dis* 2007;**17**(5):338–43.
19. Papazoglou D, Augello G, Tagliaferri M, et al. Evaluation of a multisensor armband in estimating energy expenditure in obese individuals. *Obesity* 2006;**14**(12):2217–23.
20. Jakicic JM, Marcus M, Gallagher KI, et al. Evaluation of the SenseWear Pro Armband to assess energy expenditure during exercise. *Med Sci Sports Exerc* 2004;**36**(5):897–904.

21. King GA, Torres N, Potter C, Brooks TJ, Coleman KJ. Comparison of activity monitors to estimate energy cost of treadmill exercise. *Med Sci Sports Exerc* 2004;**36**(7):1244—51.
22. Patel SA, Benzo RP, Slivka WA, Sciurba FC. Activity monitoring and energy expenditure in COPD patients: a validation study. *COPD* 2007;**4**(2):107—12.
23. Cole PJ, LeMura LM, Klinger TA, Strohecker K, McConnell TR. Measuring energy expenditure in cardiac patients using the Body Media Armband versus indirect calorimetry. A validation study. *J Sports Med Phys Fitness* 2004;**44**(3):262—71.
24. St-Onge M, Mignault D, Allison DB, Rabasa-Lhoret R. Evaluation of a portable device to measure daily energy expenditure in free-living adults. *Am J Clin Nutr* 2007;**85**(3):742—9.
25. Mignault D, St-Onge M, Karelis AD, Allison DB, Rabasa-Lhoret R. Evaluation of the Portable HealthWear Armband: a device to measure total daily energy expenditure in free-living type 2 diabetic individuals. *Diabetes Care* 2005;**28**(1):225—7.
26. Troosters T, Langer D, Vrijsen B, et al. Skeletal muscle weakness, exercise tolerance and physical activity in adults with cystic fibrosis. *Eur Respir J* 2009;**33**(1):99—106.
27. Rosenstein BJ, Cutting GR. The diagnosis of cystic fibrosis: a consensus statement. Cystic Fibrosis Foundation Consensus Panel. *J Pediatr* 1998;**132**(4):589—95.
28. Miller MR, Hankinson J, Brusasco V, et al. Standardisation of spirometry. *Eur Respir J* 2005;**26**(2):319—38.
29. Morris JF, Koski A, Johnson LC. Spirometric standards for healthy nonsmoking adults. *Am Rev Respir Dis* 1971;**103**(1):57—67.
30. Mahler DA, Mejia-Alfaro R, Ward J, Baird JC. Continuous measurement of breathlessness during exercise: validity, reliability, and responsiveness. *J Appl Physiol* 2001;**90**(6):2188—96.
31. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc* 1982;**14**(5):377—81.
32. Weir JB. New methods for calculating metabolic rate with special reference to protein metabolism. *Nutrition* 1949;**6**(3):213—21.
33. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;**1**(8476):307—10.
34. Schneider PL, Crouter SE, Lukajic O, Bassett Jr DR. Accuracy and reliability of 10 pedometers for measuring steps over a 400-m walk. *Med Sci Sports Exerc* 2003;**35**(10):1779—84.
35. Schneider PL, Crouter SE, Bassett DR. Pedometer measures of free-living physical activity: comparison of 13 models. *Med Sci Sports Exerc* 2004;**36**(2):331—5.
36. Crouter SE, Schneider PL, Karabulut M, Bassett Jr DR. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. *Med Sci Sports Exerc* 2003;**35**(8):1455—60.