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Energy expenditure during daily activities as measured by two motion sensors in patients with COPD

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Summary
Background: In patients with chronic obstructive pulmonary disease (COPD), energy expenditure (EE) assessment during the performance of daily activities is not yet studied in depth. The aim of this study was to determine which daily activities are more demanding to patients with COPD and to compare the accuracy of EE estimation given by the pedometer Digiwalker SW701 (DW) and the multisensor SenseWear Armband (SAB).
Methods: Thirty-six patients with COPD (20 men; FEV_1 48 ± 15%predicted; BMI 25.7 ± 8 kg/m^2) were submitted to a modified version of the Glittre ADL-test, which included five activities performed for 1 min each: walking on the level, walking on the level carrying a backpack, walking up/downstairs, rising/sitting in chairs and moving objects in and out of a shelf. During the protocol subjects wore both devices concomitantly, and indirect calorimetry (IC) was simultaneously performed as the criterion method to assess EE.
Results: The most demanding daily activity for individuals with COPD was walking up/downstairs (4.9 ± 1.7 kcal *versus* 3.7 ± 1.4 to 4.2 ± 1.8 kcal for the other tasks; $p < 0.05$). EE estimation by the SAB did not show difference in comparison to IC for the sum of the five activities (SAB = 22.7±7 kcal *versus* IC = 21±8 kcal; $p > 0.05$), although overestimation was found in activities involving walking. DW showed significant EE underestimation in the sum of the activities (9.6 ± 4.3kcal; $p < 0.05$ *versus* IC) and for each activity.

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Conclusion: Walking up/downstairs was the most energy-demanding daily activity for patients with COPD. Furthermore, during daily activities, the multisensor showed adequate overall estimation of energy expenditure, as opposed to the pedometer.

Introduction

One of the most important aspects regarding the limitations imposed by the chronic obstructive pulmonary disease (COPD) is the limitation of the patients to perform their daily activities.[1] This functional limitation, which features physical inactivity in daily life[2,3] and high energy expenditure (EE) for simple activities,[4] has an important role in the morbid-mortality of this population.[5,6] However, there is still limited information concerning what kind of daily activity is more energy-demanding to patients with COPD.

Detailed and objective measurement of physical activities in daily life is now considered an essential outcome of the overall evaluation of patients with COPD, and assessment of EE and step counting (SC) are common methods when assessing this outcome. For EE assessment, literature usually recommends the doubly-labeled water method or indirect calorimetry.[7–9] For SC, direct observation and videotaping have been considered as reference methods.[10] However, these techniques are not easily available in everyday life because of their methodological complexity, limited practicality, and/or high cost. Instead, a variety of motion sensors have been recently used. Simple "step counters" or pedometers (*e.g.*, DigiWalker SW701, or DW) and advanced multisensors (*e.g.*, SenseWear Armband, or SAB) are among the most used motion sensors. Despite their technological differences, both of them quantify steps and estimate total EE, providing information from free living conditions and not just information derived from laboratory tests.

The SAB multisensor was validated in order to assess walking in patients with COPD.[11] Furthermore, Watz et al.[3] showed a comprehensive description of daily physical activity in patients with COPD by using EE assessment provided by the SAB, classifying patients as active, predominantly sedentary and very inactive. Recently, two studies confirmed that the SAB is useful to estimate walking EE of patients with COPD.[12,13] Moreover, Furlanetto et al[12] showed that, in patients with COPD, the DW pedometer was accurate for estimation of EE and SC only at a high walking speed (4.8 $\pm$ 0.8 km/h) during a treadmill protocol. However, there are no studies comparing SAB and DW during real life daily activities in patients with COPD.

Therefore, the aims of this study were: (1) to determine which daily activities are more energy-demanding to patients with COPD; and (2) to compare the accuracy of EE and SC estimation by SAB and DW during the performance of different daily activities.

Methods

Study design and subjects

In this cross-sectional observational study, 36 individuals (20 men) with clinically stable COPD (ratio of postbronchodilator forced expiratory volume in 1 s (FEV_1) to forced vital capacity <0.7)[1] were recruited from the outpatient Respiratory Physiotherapy clinic from Hospital Universitário Londrina (Brazil). No patient was long-term oxygen user. Individuals were excluded if they showed a co-morbid condition thought to compromise their mobility (*e.g.*, musculoskeletal problems) or had problems with adaptation to the devices used for assessment. The study was approved by the institution's Ethics and Research Committee, and all subjects signed a formal informed consent term.

Protocol

All subjects were submitted to an initial assessment of lung function (spirometry and maximal inspiratory and expiratory pressures [MIP and MEP, respectively]), functional exercise capacity (6-min walking test [6MWT]) and sensation of dyspnea (modified Medical Research Council scale [MRC]) as screening measures, or the most recent measurements were retrieved from the hospital records (less than 6 months). All patients were classified by two indexes: BODE[14] (body mass, obstruction, dyspnea and exercise capacity) and ADO[15] (age, dyspnea and obstruction).

On a second day, subjects were instructed to walk 10 steps in a straight line as in their daily walking for step size determination. Total distance was measured and divided by 10. Afterward, patients were submitted to a modified version of the Glittre ADL-test[16] (Fig. 1), which included five activities performed during 1 min each: walking on the level, walking on the level carrying a backpack (5 kg for men and 2.5 Kg for women), rising from a chair and sitting in another chair positioned 1 m apart, walking up/downstairs (stair with 9 steps, 15 cm high and 30 cm deep) and moving an object weighting 1 kg in and out of two shelves (it was moved from the top shelf [positioned at shoulder height] to the bottom shelf [positioned at waist height], down to the floor, back to the bottom shelf, to the top shelf again and so on). Activities were performed in random order, and time between activities was determined by the return of heart rate (HR) and oxygen consumption (VO_2) to resting values. During the protocol subjects wore both devices (DW and SAB) concomitantly, and indirect calorimetry (VO_{2000} AeroGraph, AeroSport) was simultaneously performed as the criterion method to assess EE. The indirect calorimetry equipment was calibrated before each test in accordance with manufacturer instructions. EE (in Kilocalories for standardization of units) was derived from VO_2 assessment (mL kg^{-1} min^{-1}). The exact beginning and ending of each activity were synchronized in all devices since there were at least 3 investigators during each test. Concomitantly, the protocol was videotaped by a digital camera (Sony CyberShot DSC-W120) as criterion method for SC. EE and SC estimated by both motion sensors were compared with the criteria

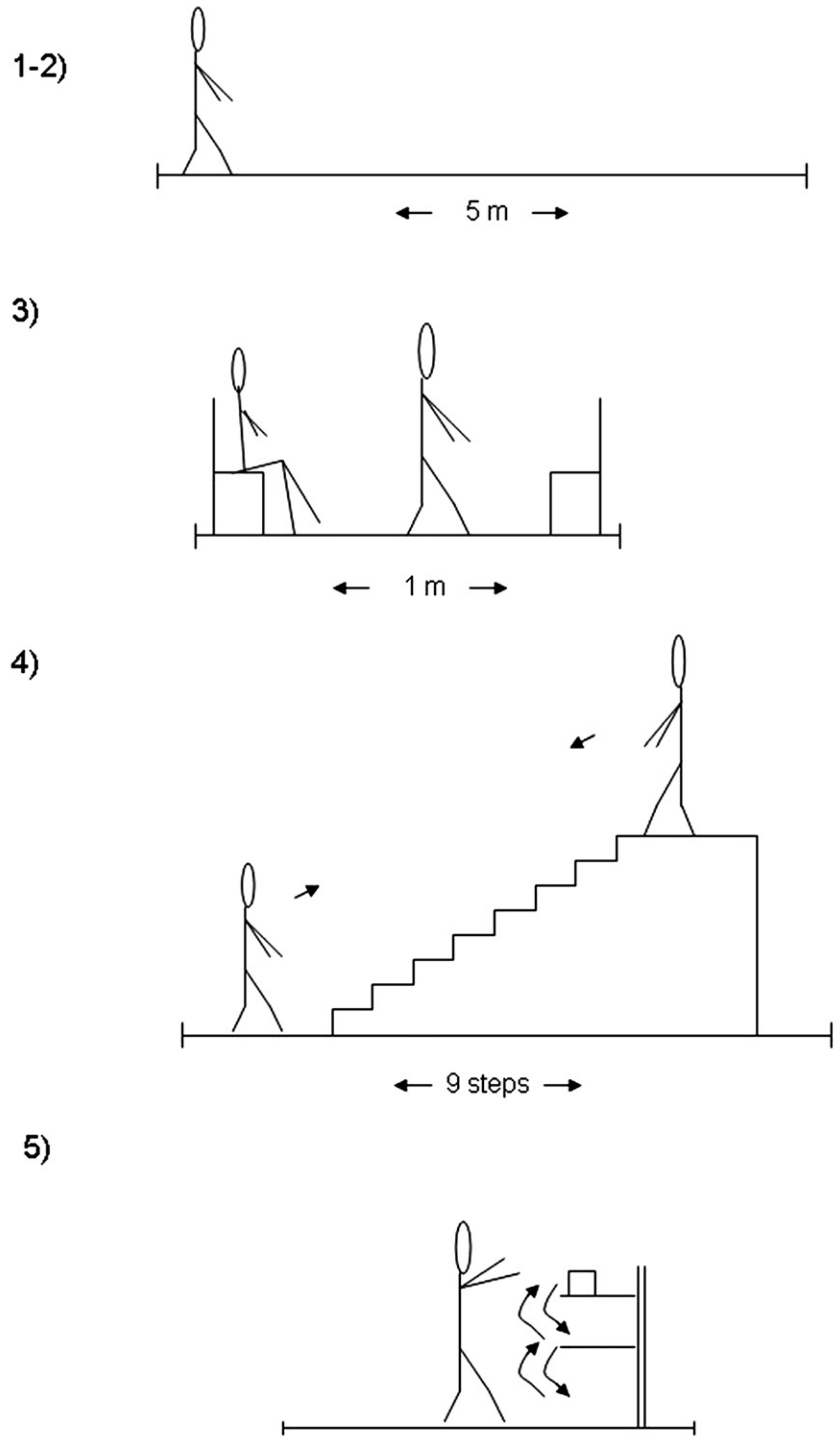

Figure 1 Protocol of activities based on the Glittre ADL-test which included five activities performed during 1 min each: 1) walking on the level (5 m corridor), 2) walking on the level (5 m corridor) carrying a backpack (5 kg for men and 2,5 Kg for women), 3) rising from a chair and sitting in another chair positioned 1 m apart, 4) walking up/downstairs (9 steps) and 5) moving objects in and out of a shelf.

methods (indirect calorimetry and videotape, respectively). Borg scores (0—10) for dyspnea and fatigue were taken at the beginning of the protocol and at the end of each activity. Peripheral oxygen saturation (SpO_2) and HR were measured at the beginning and the end of each activity.

Lung function assessment and 6MWT

Spirometry (Pony, Cosmed, Italy) and 6MWT were performed in accordance with international standards.[17,18]Reference values were those by Pereira et al[19] and Troosters et al,[20] respectively. For the 6MWT, two tests were performed with each subject, and the longest distance was used. MIP and MEP were performed with an analogical manovacuometer (Makil, Brazil) according to the technique described by Black and Hyatt[21] and using Brazilian reference values.[22]

Multisensor SenseWear Armband (SAB)

The SAB (BodyMedia, USA) is a small (8.8 × 5.6 × 2.1 cm) and light (82g) monitor that is worn on the triceps brachii bulk of the right arm. Information regarding various parameters including accelerometry, multiple physiological sensors, step counting and demographic characteristics such as gender, age, weight and height are used to estimate EE through manufacturer algorithms. A final report is obtained through analysis of the data by a specific software (SenseWear Professional 6.1).

Pedometer Digiwalker SW701 (DW)

The DW (Yamax, Japan) is a simple and relatively inexpensive device, worn attached to the waist, providing the number of steps performed, distance, and EE estimation for a given period. For this, the device requires a few characteristics of the wearer such as weight and step length. Its mechanism consists of an internal spring-levered system that is sensitive to vertical hip movements. This spring lever is connected to an electric circuit that detects each deflection as a step.

Portable gas analyzer

The portable metabolic system VO2000 AeroGraph is a previously tested and validated[8] transducer for metabolic analysis of pulmonary gas exchange, projected to operate connected to a computer. Field data can be collected by its telemetric component. The system provides EE estimation by indirect calorimetry executing continuous gas and ventilation analysis.

Data management and statistical analysis

Analysis were performed using GraphPad Prism 3 (GraphPad software, Inc., USA). Normality in the distribution of data was checked by the Kolmogorov–Smirnov test. Parametric statistics were used as variables were normally distributed and results were expressed as mean ± SD. Repeated measures analysis of variance (ANOVA) followed by Newman–Keuls *pos-hoc* testing were used to compare indirect calorimetry's EE of the 5 activities. For each task and for the sum of all the daily activities performed, ANOVA + Newman–Keuls were also used to compare the EE given by indirect calorimetry, SAB and DW, as well as SC given by video, SAB and DW. Correlations among tasks' variables and subjects' characteristics were verified by Pearson's correlation coefficient. In addition, agreement between measures was studied by the Bland and Altman graphic method.[23] A p value of less than 0.05 was considered as statistically significant.

Sample size calculation

EE values during the 6MWT showed by Patel et al[11] in patients with COPD were used for sample calculation. A total of 36 patients was necessary to detect a difference of 4.6 kcal among methods, assuming a standard deviation of ±4.7 kcal, to reach a power of 80% by adopting a significance of 0.05.

Results

Thirty-eight subjects entered the study, however two could not finish the protocol. One did not return on the second day of testing due to an acute exacerbation and the other one had problems in the adaptation with the mouthpiece required for the gas analysis. The characteristics of the 36 COPD patients who consented to participate and finished the protocol are summarized in Table 1.

Comparison of daily activities

Walking up/downstairs was the activity in which patients with COPD had the highest EE showed by indirect calorimetry (4.9 ± 1.7 kcal *versus* 4.2 ± 1.7 kcal [walking], 4.2 ± 1.8 kcal [walking carrying a backpack], 4.1 ± 1.7 kcal [rising/sitting in chairs] and 3.7 ± 1.4 kcal [moving objects in a shelf]; $p < 0.05$ for all). Moving objects in a shelf was the activity with the lowest EE ($p < 0.05$ in comparison to all the others). There was no difference in EE among walking, walking carrying a backpack and rising/sitting in chairs ($p > 0.05$). Furthermore, Table 2 shows that walking up/downstairs was the activity which promoted the highest increase in HR ($p < 0.05$ against all others) and the highest values of dyspnea and fatigue sensation ($p < 0.05$ against all others). There was no difference among activities concerning changes in SpO_2 ($p > 0.05$).

Performance

Patients' performance in daily activities were: walking (48 ± 9 m), walking carrying a backpack (47 ± 9 m), rising/sitting in chairs (13 ± 3 rises/seats), walking up/downstairs

Table 1 Subject characteristics ($n = 36$,20 males).

Variable	Mean ± SD
Age (years)	67 ± 9
Height (m)	1.62 ± 0.09
Weight (Kg)	67 ± 16
BMI ($Kg.m^{-2}$)	25.7 ± 7.8
FEV_1 (litres)	1.18 ± 0.45
FEV_1 (% predicted)	48 ± 15
BODE index (0–10 points)	3.1 ± 1.9
ADO index (0–10 points)	4.4 ± 1.7
MRC scale (1–5)	3.1 ± 1.0
MIP(% predicted)	71 ± 25
MEP (% predicted)	110 ± 34
6MWT(m)	455 ± 77
6MWT (% predicted)	77 ± 15

BMI = body mass index; FEV_1 = forced expiratory volume in the first second; BODE = body mass, obstruction, dyspnea and exercise capacity index; ADO = age, dyspnea and obstruction index; MRC = Medical research council scale; MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure; 6MWT = 6-min walking test.

Table 2 Comparison of changes in peripheral oxygen saturation and heart rate during the 5 daily activities and the BORG (dyspnea and fatigue) at the end of the activities.

	ΔSp0$_2$ (%)	ΔHR (bpm)	BORG$_{dys}$	BORG$_{tat}$
Walking	-2.4 ± 3.3	11.9 ± 7.1[a,c]	2.3 ± 2.1[d]	2.7 ± 2.3[b]
Walking carrying a backpack	-3.4 ± 3.6	13.8 ± 8.4[a,c]	2.6 ± 2.1[d]	2.7 ± 2.2[b]
Rising/sitting in chairs	-3.3 ± 4.6	17.6 ± 11.4[a]	2.6 ± 2.3[d]	2.6 ± 2.4[b]
Walking up/downstairs	-3.7 ± 3.9	24.3 ± 13.8	3.9 ± 2.7	3.3 ± 2.6
Moving objects in a shelf	-2.4 ± 2.4	14.1 ± 10.6[a,c]	2.7 ± 2.4[d]	2.4 ± 2.6[b]

ΔSpO$_2$ = difference between final and initial peripheral oxygen saturation; ΔHR = difference between final and initial heart rate; BORGdys = sensation of dyspnea at the end of the activity; BORGfat = sensation of fatigue at the end of the activity.
Values are expressed as mean $\pm$ SD.
[a] $p < 0.05$ *vs.* ΔHR walking up/downstairs.
[b] $p < 0.05$ *vs.* BORGfat walking up/downstairs.
[c] $p < 0.05$ *vs.* ΔHR rising/sitting in chairs.
[d] $p < 0.05$ *vs.* BORGdys walking up/downstairs.

(63 $\pm$ 18 steps) and moving objects in a shelf (14 $\pm$ 3 moves). The average walking and walking carrying a backpack speed were 2.90 $\pm$ 0.6 and 2.84 $\pm$ 0.6 km/h, respectively ($p > 0.05$).

There were high correlations among the performances in the different daily activities as shown on Table 3 ($0.62 < r < 0.95$; $p < 0.0001$).

Correlations among patients' characteristics and EE

Height and body weight correlated with the sum of EE during all the activities ($r = 0.41$ and $r = 0.39$; respectively; $p < 0.02$ for both). There was no correlation between the sum of EE during all the activities and age, BMI, FEV$_1$, MIP, MEP, BODE, ADO, MRC and 6MWT.

Comparison of energy expenditure assessment between methods

Table 4 shows the comparison of EE given by indirect calorimetry and estimated by DW and SAB.

DW underestimated EE for all tasks and for the sum of the five activities ($p < 0.05$). SAB overestimated EE for the 2 walking "on the level" activities ($p < 0.05$); however, it showed similar EE estimation to indirect calorimetry on the other 3 activities. Moreover, total EE estimation provided by the SAB during the whole protocol (sum of all tasks) did not show statistical difference to indirect calorimetry ($p > 0.05$). A Bland and Altman plot depicting this agreement is shown on Fig. 2.

The overestimation of the SAB for the two walking activities was correlated to the subjects' body weight and BMI (walking: $r = 0.48$ with body weight and $r = 0.41$ with BMI; $p < 0.02$ for both; walking carrying a backpack: $r = 0.37$ with body weight and $r = 0.38$ with BMI; $p < 0.03$ for both).

Comparison of step counting between methods

Table 5 shows the comparison of SC given by videotape and estimated by DW and SAB. Both devices underestimated SC for each activity and for the sum of the five activities ($p < 0.05$). There was no difference between SAB and DW for SC during the whole protocol ($p > 0.05$).

Discussion

The present study showed that, for patients with COPD, walking up/downstairs was the most demanding daily activity among those included in the protocol, since it promoted the highest EE, the highest increase in HR and the highest values of dyspnea and fatigue sensation. The study also showed that moving objects in and out of a shelf was the least demanding activity, and that performances in different daily activities relate well to each other. Furthermore, this was the first study to test the accuracy of a multisensor and a pedometer in patients with COPD when performing "real life" activities. Results demonstrate that an activity monitor incorporating multiple physiologic sensors and accelerometry (SAB) provided accurate estimates of EE during a set of daily activities in this population, although a few activities (especially involving walking) are prone to overestimation. On the other hand, the spring-levered pedometer (DW) underestimated EE for each task and for the whole protocol. We have also reported that both devices equally underestimated SC for the whole set of activities.

Table 3 Correlations (r values) between the performances of patients in the 5 different daily activities.

	A	B	C	D	E
A-Walking	—	0.95	0.73	0.89	0.70
B-Walking carrying a backpack	—	—	0.69	0.89	0.62
C-Rising/sitting in chairs	—	—	—	0.67	0.65
D-Walking up/downstairs	—	—	—	—	0.70
E-Moving objects in a shelf	—	—	—	—	—

$p < 0.0001$ for all r values.

Table 4 Comparison of energy expenditure (kcal) registered by three methods for each activity and during the entire protocol (sum of all activities).

Energy Expenditure (kcal)	DW	SAB	IC
Walking	3.4 ± 1.5[a]	5.5 ± 2.2[a]	4.2 ± 1.7
Walking carrying a backpack	3.3 ± 1.6[a]	5.1 ± 1.9[a]	4.2 ± 1.8
Rising/sitting in chairs	0.8 ± 0.6[a]	3.9 ± 1.1	4.1 ± 1.7
Walking up/downstairs	2.2 ± 1.1[a]	4.9 ± 1.9	4.9 ± 1.7
Moving objects in a shelf	0 ± 0[a]	3.3 ± 1.2	3.7 ± 1.4
Sum of all activities	9.6 ± 4.3[a]	22.7 ± 7.0	21 ± 7.9

DW = DigiWalker pedometer; SAB = Multisensor SenseWear ArmBand; IC = indirect calorimetry.
Values are expressed as mean ± SD.
[a] $p<0.05$ *vs*. indirect calorimetry.

An interesting information demonstrated by the present study is that walking up/downstairs was the most energy-demanding activity. Using a COPD Self-Efficacy Scale,[24] it has been reported that climbing stairs was the major factor related to breathing difficulty in this population. Sensation of dyspnea (Borg scale) reported by our patients is in line with this result and we have added new information to this matter by finding that perception of fatigue was also higher when walking up/downstairs. Probably these findings occurred due to the higher EE and HR achieved during this task in comparison to the other activities.

Porto et al[25] showed that, at the same metabolic demand, exercise with the upper limbs causes more dynamic hyperinflation and dyspnea than exercise with the lower limbs. Our activities did not have the same metabolic demand and the only upper limb activity performed in the present study (moving objects in a shelf) was the task in which patients achieved the lowest EE. This might help explaining the fact that, in the present protocol, dyspnea sensation was not higher during this upper limb activity in comparison to the lower limb activities. Furthermore, the lower EE during an upper limb activity could be due to the lower VO_2 imposed by arm exercises when compared to leg exercises observed specifically in patients with COPD, regardless of the HR.[26]

Concerning the SAB, it was previously validated to estimate EE in patients with COPD, showing fair estimation of EE during a 6MWT[11] and a treadmill protocol with different walking speeds.[12] We are now adding to these previous data the fact that, in this population, the SAB can also estimate EE in daily activities such as rising/sitting in chairs, walking up/downstairs and moving objects in a shelf. Regarding this last activity, it was possible to hypothesize that the SAB can accurately estimate EE of upper limb activities in patients with COPD, what was not yet previously tested.

This study showed that the SAB overestimated EE for walking activities (walking "unloaded" and walking carrying a backpack, both on the level). This is in contrast with previous studies[11,12] and with a recently published paper[13] which demonstrated a fair agreement between the SAB and the IC EE. Probable explanations for these facts are: (1) Patel et al[11] used a different SAB software (*i.e.*, a previous version) to analyze the data (InnerView 2.2); (2) differently than the present study's "field" walking tasks, Furlanetto et al.[12] evaluated treadmill walking; it has been shown that walking on a treadmill is more demanding than a corridor walking for a comparable submaximal walking speed[27]; and (3) Hill et al.[13] used metabolic equivalents (METs) as the SAB outcome for EE. The SAB software provides an estimation of the total EE for a selected activity in kilocalories (kcal) and a different estimation for the average METs, which reflects the mean movement intensity for the selected activity. Similarly to other researchers,[7,9,12,12,28–30] we opted for using EE in kcal, which is a unit mainly used to express energy. Although there was EE overestimation for walking activities by the SAB, it was associated with body weight and BMI, which is an important information for the development of adequate algorithms by the manufacturer. Furthermore, when summing up the whole set of activities, the SAB produced an accurate EE estimation, what provides promising preliminary evidence that the device may be accurate for full-day real life EE assessments.

The SAB and the DW spring-levered pedometer used in this study underestimated SC when compared to the criterion method. These results corroborate previous findings.[12,31] A probable explanation for this finding is that the SAB is worn around the upper part of the arm, which is not an ideal placement site for step detection, although the mechanism of step detection in the SAB is not clearly described by the device's manufacturer. In terms of step detection in healthy subjects, the DW was previously suggested as superior to

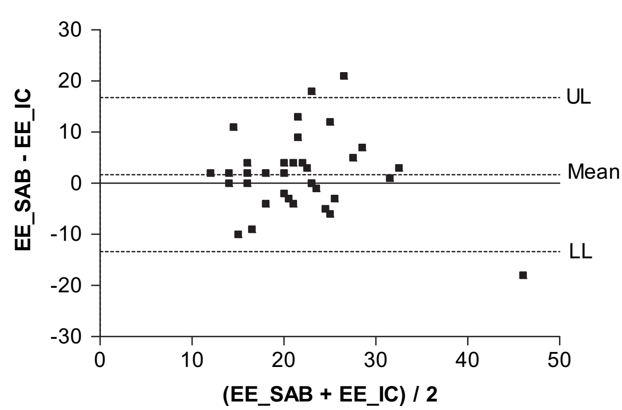

Figure 2 Bland & Altman plots comparing the results of energy expenditure (EE, in kcal) registered by the SenseWear Armband (SAB) *versus* the criterion method (indirect calorimetry [IC]) in patients with COPD during the entire protocol (summing the 5 daily activities). The central dotted line corresponds to the mean difference between the respective methods, whereas the upper and lower dotted lines correspond to the upper and lower limits of agreement (UL and LL, respectively).

Table 5 Comparison of step counting (number of steps) registered by three methods for each activity and during the entire protocol (sum of all activities).

Step Counting (number of steps)	DW	SAB	Video
Walking	90 ± 24[a]	82 ± 25[a]	103 ± 11
Walking carrying a backpack	88 ± 26[a]	84 ± 22[a]	102 ± 11
Rising/sitting in chairs	24 ± 17[a]	18 ± 11[a]	30 ± 5
Walking up/downstairs	62 ± 23[a]	58 ± 27[a]	79 ± 18
Moving objects in a shelf	1 ± 3[a]	3 ± 8[a]	0 ± 0
Sum of all activities	260 ± 84[a]	244 ± 83[a]	314 ± 37

DW = DigiWalker pedometer; SAB = Multisensor SenseWear ArmBand.
Values are expressed as mean ± SD.
[a] $p < 0.05$ *vs.* video.

other similar devices in different treadmill speeds[32] and predetermined distances.[33] However, SC by the DW in the present protocol was inaccurate compared to the criterion method. This result may have occurred because of the slow walking speed of patients with COPD (2.90 ± 0.6 km/h for walking and 2.84 ± 0.6 km/h for walking carrying a backpack). This corroborates previous literature data showing that pedometers adequately detected steps at higher speeds, but underestimated steps at slow walking.[12] Pitta et al.[2] showed that patients with COPD walk 25% less briskly than healthy elderly. Taking these facts into consideration, important concerns are raised about the use of pedometers to count steps during daily life in patients with COPD. In this study, DW also underestimated EE. Crouter et al[34] reported that pedometers are inaccurate both for the estimation of distance walked and EE. This might be due to pedometers' mechanism to estimate EE: it is based on the subject's step counting, which is equally inaccurate at slow speeds.

Study limitations

Temperature and humidity were not controlled for the assessments. However, as we aimed to study EE estimation during "real life" activities, we preferred to perform the tests outside the laboratory in non-controlled weather conditions. Moreover, there were no extreme conditions of warm and cold weather over the data collection period.

The inclusion of other upper limb activities to the present protocol could have provided more information on the comparison of EE during different upper and lower limb activities. However, the Glittre ADL protocol was used as basis for this study, and differing too much from the original Glittre protocol would likely cause its "mischaracterization", what was not intended.

Indirect calorimetry EE was not analyzed at the steady state (3 min after the beginning of the task). However, in our perception, it is uncommon for patients with COPD to spend long periods of time in single activities such as walking up/downstairs, rising/sitting in chairs and moving objects in and out of a shelf. Therefore, in order to get closer to real life behavior, we used shorter periods of time in which patients performed these activities. One minute of task was adopted because it is the minimum period of time which can be analyzed by the SAB software.

In summary, the present study showed that, in patients with COPD, the most demanding daily activity in terms of EE was walking up/downstairs. In addition, it was shown that the multisensor SenseWear Armband is an useful tool in order to provide an overall estimation of EE during daily activities, and the pedometer cannot be used for this purpose.

Conflict of interest statement

The authors have no conflicts of interest to declare.

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References

1. Rabe KF, Hurd S, Anzueto A, et al. Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease: GOLD executive summary. *Am J Respir Crit Care Med* 2007;**176**(6):532—55.
2. Pitta F, Troosters T, Spruit MA, et al. Characteristics of physical activities in daily life in chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2005;**171**(9):972—7.
3. Watz H, Waschki B, Meyer T, et al. Physical activity in patients with COPD. *Eur Respir J* 2009;**33**(2):262—72.
4. Velloso M, Stella SG, Cendon S, et al. Metabolic and ventilatory parameters of four activities of daily living accomplished with arms in COPD patients. *Chest* 2003;**123**(4):1047—53.
5. Garcia-Aymerich J, Lange P, Benet M, et al. Regular physical activity reduces hospital admission and mortality in chronic obstructive pulmonary disease: a population based cohort study. *Thorax* 2006;**61**(9):772—8.
6. Pitta F, Troosters T, Probst VS, et al. Potential consequences for stable chronic obstructive pulmonary disease patients who do not get the recommended minimum daily amount of physical activity. *J Bras Pneumol* 2006;**32**(4):301—8.
7. 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.

8. Wahrlich V, Anjos LA, Going SB, et al. Validation of the VO2000 calorimeter for measuring resting metabolic rate. *Clin Nutr* 2006;**25**(4):687—92.
9. 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.
10. Pitta F, Troosters T, Probst VS, et al. Quantifying physical activity in daily life with questionnaires and motion sensors in COPD. *Eur Respir J* 2006;**27**(5):1040—55.
11. Patel SA, Benzo RP, Slivka WA, et al. Activity monitoring and energy expenditure in COPD patients: a validation study. *COPD* 2007;**4**(2):107—12.
12. Furlanetto KC, Bisca GW, Oldemberg N, et al. Step counting and energy expenditure estimation in patients with chronic obstructive pulmonary disease and healthy elderly: accuracy of 2 motion sensors. *Arch Phys Med Rehabil* 2010;**91**(2): 261—7.
13. Hill K, Dolmage TE, Woon L, et al. Measurement properties of the SenseWear Armband in adults with chronic obstructive pulmonary disease. *Thorax* 2010;**65**(6):486—91.
14. Celli BR, Cote CG, Marin JM, et al. The body-mass index, airflow obstruction, dyspnea, and exercise capacity index in chronic obstructive pulmonary disease. *N Engl J Med* 2004;**350** (10):1005—12.
15. Puhan MA, Garcia-Aymerich J, Frey M, et al. Expansion of the prognostic assessment of patients with chronic obstructive pulmonary disease: the updated BODE index and the ADO index. *Lancet* 2009;**374**(9691):704—11.
16. Skumlien S, Hagelund T, Bjortuft O, et al. A field test of functional status as performance of activities of daily living in COPD patients. *Respir Med* 2006;**100**(2):316—23.
17. ATS statement: guidelines for the six-minute walk test. *Am J Respir Crit Care Med* 2002;**166**(1):111—7.
18. Miller MR, Hankinson J, Brusasco V, et al. Standardisation of spirometry. *Eur Respir J* 2005;**26**(2):319—38.
19. Pereira CAC, Barreto SP, Simöes JG, et al. Valores de referência para a espirometria em uma amostra da populaçäo brasileira adulta/Reference values for spirometry in Brazilian adults. *J Bras Pneumol* 1992;**18**(1):10—22.
20. Troosters T, Gosselink R, Decramer M. Six minute walking distance in healthy elderly subjects. *Eur Respir J* 1999;**14**(2): 270—4.
21. Black LF, Hyatt RE. Maximal respiratory pressures: normal values and relationship to age and sex. *Am Rev Respir Dis* 1969; **99**(5):696—702.
22. Neder JA, Andreoni S, Lerario MC, et al. Reference values for lung function tests. II. Maximal respiratory pressures and voluntary ventilation. *Braz J Med Biol Res* 1999;**32**(6):719—27.
23. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;**1**(8476):307—10.
24. Wigal JK, Creer TL, Kotses H. The COPD Self-Efficacy scale. *Chest* 1991;**99**(5):1193—6.
25. Porto EF, Castro AA, Velloso M, et al. Exercises using the upper limbs hyperinflate COPD patients more than exercises using the lower limbs at the same metabolic demand. *Monaldi Arch Chest Dis* 2009;**71**(1):21—6.
26. Probst VS, Troosters T, Pitta F, et al. Cardiopulmonary stress during exercise training in patients with COPD. *Eur Respir J* 2006;**27**(6):1110—8.
27. Singh SJ, Morgan MD, Hardman AE, et al. Comparison of oxygen uptake during a conventional treadmill test and the shuttle walking test in chronic airflow limitation. *Eur Respir J* 1994;**7**(11):2016—20.
28. King GA, Torres N, Potter C, et al. Comparison of activity monitors to estimate energy cost of treadmill exercise. *Med Sci Sports Exerc* 2004;**36**(7):1244—51.
29. Camillo CA, Pitta F, Possani HV, et al. Heart rate variability and disease characteristics in patients with COPD. *Lung* 2008;**186** (6):393—401.
30. Dwyer TJ, Alison JA, McKeough ZJ, et al. Evaluation of the SenseWear activity monitor during exercise in cystic fibrosis and in health. *Respir Med* 2009;**103**(10):1511—7.
31. Melanson EL, Knoll JR, Bell ML, et al. Commercially available pedometers: considerations for accurate step counting. *Prev Med* 2004;**39**(2):361—8.
32. Bassett Jr DR, Ainsworth BE, Leggett SR, et al. Accuracy of five electronic pedometers for measuring distance walked. *Med Sci Sports Exerc* 1996;**28**(8):1071—7.
33. Schneider PL, Crouter SE, Lukajic O, et al. Accuracy and reliability of 10 pedometers for measuring steps over a 400-m walk. *Med Sci Sports Exerc* 2003;**35**(10):1779—84.
34. Crouter SE, Schneider PL, Karabulut M, et al. Validity of 10 electronic pedometers for measuring steps, distance, and energy cost. *Med Sci Sports Exerc* 2003;**35**(8):1455—60.