Department of Veterans Affairs

JRRD Journal of Rehabilitation Research & Development
Volume 46, Number 2, 2009
Pages 277–286

Free-living physical activity in COPD: Assessment with accelerometer and activity checklist

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Abstract—To assess physical activity and disability in chronic obstructive pulmonary disease (COPD), we evaluated the use of an accelerometer and checklist to measure free-living physical activity. Seventeen males with stable COPD completed a daily activity checklist for 14 days. Ten subjects concurrently wore an Actiped accelerometer (FitSense, Southborough, Massachussetts) that records steps per day. Regression models assessed relationships between steps per day, number of daily checklist activities performed, and clinical measures of COPD status. The average steps per day ranged from 406 to 4,856. The median intrasubject coefficient of variation for steps per day was 0.52 (interquartile range [IQR] 0.41–0.58) and for number of daily checklist activities performed was 0.28 (IQR 0.22–0.32). A higher number of steps per day was associated with a greater distance walked on the 6-minute walk test and better health-related quality of life. A higher number of daily checklist activities performed was associated with a higher force expiratory volume in 1 s percent predicted and lowerbody mass index, airflow obstruction, dyspnea, exercise capacity (BODE) index. Prospectively measuring free-living physical activity in COPD using an unobtrusive accelerometer and simple activity checklist is feasible. Low intrasubject variation was found in free-living physical activity, which is significantly associated with clinical measures of COPD status.

Key words: accelerometer, ambulation, COPD, dyspnea, exercise capacity, free-living physical activity, health-related quality of life, physical activity checklist, pulmonary, wearable sensor.

INTRODUCTION

Improving exercise capacity and increasing physical activity is one of the main goals of treatment and research in chronic obstructive pulmonary disease (COPD) [1–3]. Patients with severe COPD who have low exercise capacity have a higher probability of death compared

Abbreviations: 6MWT = 6-minute walk test; BMI = body mass index; BODE = BMI, airflow obstruction, dyspnea, exercise capacity; CAD = coronary artery disease; CHF = congestive heart failure; CI = confidence interval; COPD = chronic obstructive pulmonary disease; CV = coefficient of variation; FEV_1 = force expiratory volume in 1 s; GOLD = Global Initiative for Chronic Obstructive Lung Disease; HRQL = health-related quality of life; IQR = interquartile range; MCS = Mental Component Summary; MRC = Medical Research Council; PCS = Physical Component Summary; SD = standard deviation; SF-36 = Medical Outcomes Study 36-Item Short Form; SGRQ = St. George's Respiratory Questionnaire; VA = Department of Veterans Affairs; VR-36 = Veterans RAND 36-Item Health Survey.

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DOI:10.1682/JRRD.2008.07.0083

with those with high exercise capacity [4–5]. Reduced physical activity is associated with an increased risk of hospital admissions for COPD and respiratory mortality [6]. Reduced physical activity in patients with COPD is also associated with higher levels of circulating markers of systemic inflammation, such as C-reactive protein and fibrinogen, that are associated with greater all-cause and cardiovascular mortality [7]. Methods that measure disability in COPD by prospectively assessing participation in physical activities may lead to novel applications that allow maintenance of exercise benefits following a supervised pulmonary rehabilitation program, the early detection of COPD exacerbations, assessment of response to therapeutic interventions in COPD clinical trials, and recommendations for specific changes in physical activity to improve health outcomes in COPD.

While laboratory measurements of exercise capacity are well standardized [8–10], the methods to assess free-living physical activity, defined as "the level of activity that the patients, within their physical limitations, at their own pace, and in their own environment, typically perform," have been limited [11–13]. The pedometers and accelerometers used to date to measure physical activity in COPD have been limited by low accuracy at slow walking speeds [14], substantial intra-individual fluctuations in activity [15–17], high cost per device [11], need for users to record activity counts in a diary card [12], and need to position the device precisely on the waist and leg for accurate recordings [18]. Physical activity questionnaires currently available assess recreational and occupational activities not typically performed by the relatively inactive, retired COPD population [11,19–22]. Furthermore, health-related quality of life (HRQL) questionnaires assess the impact of COPD and symptoms on physical activity rather than the amount or types of activities performed [12,23–25].

To overcome these limitations, we used the simple, inexpensive, and unobtrusive Actiped accelerometer (FitSense Technology, Inc, Southborough, Massachusetts) [26], which we have previously demonstrated to be accurate in a subgroup of subjects with COPD [27]. In addition to measuring steps per day, we developed a simple physical activity checklist to capture activities typically performed by patients with COPD. We used the Actiped accelerometer and the physical activity checklist to (1) assess the feasibility of a simple program to monitor free-living physical activity over 2 weeks, (2) quantify the typical amount of free-living physical activity in which subjects with COPD participate, and (3) examine the relationships between steps per day, number of daily checklist activities performed, and various clinical measures of COPD status.

METHODS

Subjects

Seventeen males with stable COPD were enrolled from a general pulmonary clinic between May and July 2007. COPD was defined as having forced expiratory volume in 1 s (FEV_1)/forced vital capacity <0.70 and a smoking history of >10 pack-years or computed tomographic evidence of emphysema. The protocol was approved by the Department of Veterans Affairs (VA) Boston Healthcare System Committee on Human Research. Informed consent was obtained from each subject.

Accelerometer

Steps per day were measured with the Actiped accelerometer, an unobtrusive device that attaches to the shoe. The Actiped is relatively inexpensive at US$150 per device, requires no maintenance by the user, and wirelessly transmits step counts to an Internet-based database. In the clinic, all subjects performed two walks: a level course at usual walking speed and a 6-minute walk test (6MWT) at maximal walking speed while wearing an accelerometer. We confirmed that device accuracy ([device step counts/manual step counts] × 100) was >90 percent for both walks before sending the device home with each participant. Device accuracy was <90 percent in 7 subjects with low usual walking speeds; therefore, 10 of the 17 subjects were given the accelerometer to wear at home for 14 days.

Participants were instructed to wear the accelerometer during all waking hours, except when bathing or showering. Subjects were contacted by telephone at the end of each week to assess adherence and any device problems. The devices were returned to the study site by mail. When data were downloaded, we discovered that in subjects who had high numbers of steps per day, the device did not have enough memory and overwrote stored data beginning with day 1. All subjects had data recorded for at least days 10 through 14. For the 10 subjects, a total of 86 person-days were monitored. All accelerometer data that were available were analyzed.

Physical Activity Checklist

We developed a physical activity checklist (**Appendix**, available online only) to complement the accelerometer data and assess upper-limb activities and lower-limb activities that may not be captured as ambulation. Physical activities selected for the activity checklist were related to self-care, home-management, movement, exercise, and recreation and were based in part on the Pulmonary Functional Status and Dyspnea Questionnaire Activity Assessment [23]. The checklist is self-administered and can be completed in approximately 10 minutes. Subjects indicated participation in an activity by circling "yes" or "no" and were asked to complete the one-page checklist every evening for 14 days.

Clinical Assessments

Exercise capacity was assessed with maximal distance walked on the 6MWT [8]. Pulmonary function was assessed with FEV_1 [28]. We calculated the body mass index (BMI), airflow obstruction, dyspnea, exercise capacity (BODE) index, a multidimensional 10-point grading system that assesses COPD severity [29].

Comorbidities of coronary artery disease (CAD), congestive heart failure (CHF), diabetes, and joint problems (osteoarthritis, hip or knee replacements, low back pain, or vertebral disk disease) were ascertained by interview and medical record review. Demographics and lifestyle activities that may affect level of physical activity, such as educational status, current employment status, alcohol use, current smoking status, sleep quality, and participation in regular exercise, were assessed by interview. We also assessed medication use, including prednisone use in the previous year and use of supplemental oxygen.

HRQL was assessed by the Veterans RAND 36-Item Health Survey (VR-36) [30] modified from the Medical Outcomes Study 36-Item Short Form (SF-36) [25]. We used Physical Component Summary (PCS) and Mental Component Summary (MCS) scores, with higher scores indicating better health status. The St. George's Respiratory Questionnaire (SGRQ) assessed respiratory-specific HRQL [24]. Lower SGRQ total score indicates better health status. Dyspnea was quantified with the Medical Research Council (MRC) Dyspnea Scale [31] and the modified Borg rating scale [32]. Depression was assessed with the Beck Depression Inventory [33].

Statistical Analysis

We examined summary statistics, plots of steps per day and number of daily checklist activities performed. To assess the degree of daily variation over 14 days in steps per day and number of daily checklist activities performed, we calculated the coefficient of variation (CV). We examined whether weekend days versus weekdays affected steps per day and number of daily checklist activities performed. Regression models accounting for repeated measures (PROC MIXED, Statistical Analysis Software version 9.2; SAS Institute; Cary, North Carolina) assessed the relationships between steps per day, number of daily checklist activities performed, and various measures of COPD status [34].

RESULTS

At the weekly telephone interviews, all subjects reported adherence to wearing the accelerometer and completing the activity checklist. No problems were reported with use of the accelerometer. All 238 activity checklists (17 subjects × 14 days) and 10 devices were returned by mail to the study site in a timely manner.

Subjects were white males aged 73 ± 8 years (mean ± standard deviation [SD]), with moderate airways obstruction, mean FEV_1 1.6 ± 0.68 L (57 ± 22 percent predicted); most subjects were in Global Initiatives for Chronic Obstructive Lung Disease (GOLD) stage II [1] (**Table 1**). Mean 6MWT distance was 438 ± 99 m. Six subjects had concomitant CAD and 13 had joint problems. Two subjects had a history of CHF. The group was overweight and had mild depression, with a mean Beck total score of 14 ± 12. Ten subjects reported participating in regular exercise, although only four had ever participated in a supervised pulmonary rehabilitation program. Thirteen subjects reported walking more than 10 minutes at a time on 3 or more days during a typical week. No subject experienced a COPD exacerbation during the study period. Characteristics for the group of 17 subjects as well as for the subgroups of 10 subjects who wore the accelerometer and the 7 who did not are presented in **Table 1**.

The physical activity checklist included walking a dog and playing with grandchildren. Review of the responses completed by the 17 subjects showed that 13 subjects did not have a dog and 6 did not have grandchildren. These activities were excluded from the analyses, resulting in a maximum of 15 activities performed per day. The average number of daily checklist activities performed was 7 ± 1 (range 0–13 per day). **Table 2** shows frequency of participation in physical activities; no floor or ceiling effect

Table 1.
Subject characteristics.

Variable	Total (*N* = 17)	Wore ACC (*n* = 10)	Did Not Wear ACC (*n* = 7)
Age (yr), Mean ± SD	73 ± 8	70 ± 8	78 ± 5
Usual Walking Speed (mph), Mean ± SD	2.31 ± 0.41	2.49 ± 0.31	2.05 ± 0.42
BMI (kg/m^2), Mean ± SD	28 ± 4	28 ± 4	29 ± 4
Married, *n* (%)	8 (47)	3 (30)	5 (71)
Retired, *n* (%)	12 (70)	6 (60)	6 (86)
Completed High School or More, *n* (%)	14 (82)	9 (90)	5 (71)
Current Smoker, *n* (%)	3 (18)	3 (30)	0 (0)
Regular Drinker, *n* (%)	8 (47)	4 (40)	4 (57)
Never Get a Good Night's Sleep, *n* (%)	5 (29)	5 (50)	0 (0)
Participate in Regular Exercise, *n* (%)	10 (59)	5 (50)	5 (71)
FEV_1 % Predicted, Mean ± SD	57 ± 22	60 ± 25	53 ± 18
GOLD Stage			
I	1 (5)	1 (10)	0 (0)
II	10 (59)	6 (60)	4 (57)
III	2 (12)	1 (10)	1 (14)
IV	4 (24)	2 (20)	2 (28)
Participated in Pulmonary Rehabilitation, *n* (%)	4 (24)	4 (40)	0 (0)
Current Use of Supplemental Oxygen, *n* (%)	5 (29)	3 (30)	2 (28)
Current Use of LAMA, *n* (%)	10 (59)	6 (60)	4 (57)
Current Use of LABA, *n* (%)	12 (70)	7 (70)	5 (71)
Current Use of Inhaled Corticosteroid, *n* (%)	14 (82)	8 (80)	6 (86)
Used Prednisone in Past Year, *n* (%)	6 (35)	3 (30)	3 (43)
Joint Problems, *n* (%)	13 (76)	8 (80)	5 (71)
Coronary Artery Disease, *n* (%)	6 (35)	4 (40)	2 (28)
Congestive Heart Failure, *n* (%)	2 (12)	2 (20)	0 (0)
Diabetes, *n* (%)	5 (29)	3 (30)	2 (28)
6MWT Distance (m), Mean ± SD	438 ± 99	467 ± 85	395 ± 108
Dyspnea Borg Scale, Mean ± SD	1.7 ± 1.6	1.6 ± 1.9	1.7 ± 1.4
PCS Score, Mean ± SD	36 ± 12	36 ± 14	36 ± 9
MCS Score, Mean ± SD	50 ± 12	51 ± 10	49 ± 15
SGRQ Total Score, Mean ± SD	44 ± 23	40 ± 22	49 ± 21
Beck Depression Index, Mean ± SD	14 ± 12	13 ± 9	15 ± 14
BODE Index, Mean ± SD	4.0 ± 1.7	3.8 ± 1.5	4.3 ± 2.0

6MWT = 6-minute walk test; ACC = accelerometer; BMI = body mass index; BODE = BMI, obstruction, dyspnea, exercise capacity; FEV_1 = force expiratory volume in 1 s; GOLD = Global Initiative for Chronic Obstructive Lung Disease; LABA = long-acting beta agonist; LAMA = long-acting muscarinic antagonist; MCS = Mental Component Summary; PCS = Physical Component Summary; SD = standard deviation; SGRQ = St. George's Respiratory Questionnaire.

was detected. The most common activities performed (>50% of days monitored) were preparing meals; climbing stairs; visiting friends or relatives; and traveling in a car, bus, or train. Subjects were least likely to walk in a mall or store, go to a medical appointment, dig in the yard or garden, chop wood, or exercise at a gym or at home (<29% of days). Walking in a grocery store; unloading groceries from car; performing an errand; picking up mail from mailbox; and washing and folding laundry, sweeping floors, or making the bed were performed 39 to 48 percent of the days.

For the 10 subjects who wore the accelerometer at home, average steps per day for each subject ranged from 406 to 4,856 and the overall mean steps per day was 2,026 ± 1,783. Steps per day was significantly correlated with number of daily checklist activities. For each unit increase in checklist activities, we observed an increase of 174 steps per day, $p = 0.04$. **Figures 1** and **2** show the range of steps per day and number of daily checklist activities performed within and between subjects. The median intrasubject CV for steps per day was 0.52 (interquartile range [IQR] 0.41–0.58). Greater variation was

Table 2.
Number of times (%*) each activity was performed (n = 17).

Physical Activity	Yes	No
Walk More than 5 Minutes at Time	181 (76)	37 (16)
Walk in Grocery Store	93 (39)	142 (60)
Unload Groceries from Car and Carry Them into Home	102 (43)	135 (57)
Walk in Mall or Store like Home Depot	59 (25)	171 (72)
Perform Errand (Go to Post Office, Bank, Dry Cleaner)	102 (43)	131 (55)
Go to Medical Appointment	34 (14)	196 (82)
Visit with Relatives or Friends	138 (58)	97 (41)
Prepare Your Own Meal	161 (68)	76 (32)
Climb Up Stairs	165 (69)	73 (31)
Dig in Yard or Garden, Chop Wood, or Shovel Snow	70 (29)	162 (68)
Exercise at Gym (Swim, Bike, Treadmill, Weights)	29 (12)	209 (88)
Exercise at Home (Bike, Treadmill, Weights)	51 (21)	186 (78)
Pick Up Mail from Mailbox	108 (45)	129 (54)
Wash and Fold Laundry, Sweep Floors, or Make Bed	115 (48)	122 (51)
Travel in Car, Bus, or Train	195 (82)	42 (18)

Note: Maximum number of times activity could be performed was 238 (17 subjects × 14 days).
*May not add up to 100% because question was not always answered or sometimes did not apply.

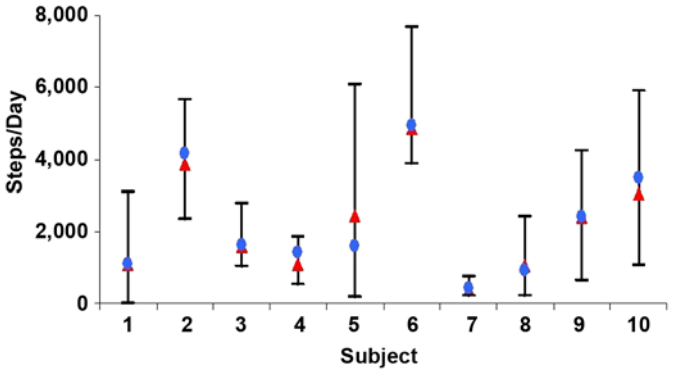

Figure 1.
Range of steps per day within and between subjects, n = 10. Red triangle = mean daily step count for all days with data. Blue circle = mean daily step count for days 10 through 14.

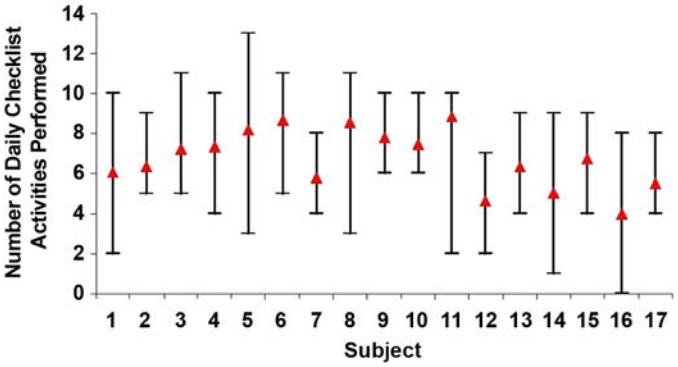

Figure 2.
Range of number of daily checklist activities within and between subjects, n = 17. Subjects 1 to 10 are same as subjects 1 to 10 in **Figure 1**. Red triangle = mean number of daily checklist activities for 14 days.

seen between subjects for steps per day, intersubject CV of 0.64. Eight of the ten subjects had an intrasubject CV (range 0.24–0.58) less than the intersubject CV, indicating that the intrasubject variation in steps per day was relatively low. The intrasubject variation in number of daily checklist activities performed was lower (median CV 0.28 [IQR 0.22–0.32]) than the intrasubject variation in steps per day. The day of the week, categorized as either weekend or weekday, was not significantly associated with either steps per day or daily number of checklist activities performed.

Steps per day were significantly associated with 6MWT distance, PCS and MCS scores, and the VR-36 Physical Function domain in regression models (**Table 3**). Number of daily checklist activities performed was significantly associated with FEV_1 percent predicted and BODE index (**Table 4**). Steps per day and number of daily checklist activities performed were significantly associated with comorbid joint problems. A history of joint problems was associated with fewer steps per day –2,742, 95% CI [–3,723, –1,761], p = 0.0002 and fewer daily activities –1.1, 95% CI [–2.2, –0.083], p = 0.04. Neither steps per day nor number of daily checklist activities was significantly associated with prior participation in pulmonary rehabilitation, report of regular exercise, prednisone use in the previous year, or supplemental oxygen use (p = 0.12–0.93). Age, BMI, Beck Depression Inventory score, and dyspnea assessed by modified Borg scale were not significantly associated with either steps per day or number of daily checklist activities performed (p = 0.08–0.90).

DISCUSSION

We demonstrate that it is feasible for subjects with COPD to complete a simple daily activity checklist to

Table 3.
Associations with steps per day (n = 10).

Independent Variable	Unadjusted Coefficient (95% CI)	*p*-Value
Checklist Activities	174 (7,341)	0.04
6MWT Distance	10 (4,17)	0.01
PCS Score	67 (35,99)	0.0003
MCS Score	–72 (–125, –19)	0.01
VR-36 Physical Function	29 (12,47)	0.002
Joint Problems	–2,742 (–3,723, –1,761)	0.0002

Note: Each univariate model has steps per day as dependent variable and one of variables listed as independent variable.
6MWT = 6-minute walk test, CI = confidence interval, MCS = Mental Component Summary, PCS = Physical Component Summary, VR-36 = Veterans RAND 36-Item Health Summary Survey.

Table 4.
Associations with number of daily checklist physical activities performed (n = 17).

Independent Variable	Unadjusted Coefficient (95% CI)	*p*-Value
FEV_1 % Predicted	0.023 (0.005, 0.041)	0.01
BODE Index	–0.34 (–0.58, –0.10)	0.008
Joint Problems	–1.1 (–2.2, –0.083)	0.04

Note: Each univariate model has number of daily checklist physical activities performed as dependent variable and one of variables listed as independent variable.
BODE = Body mass index, obstruction, dyspnea, exercise capacity; FEV_1 = force expiratory volume in 1 s.

monitor free-living physical activity for up to 2 weeks. In the subjects in whom we verified >90 percent accuracy of the accelerometer to detect step counts, we also demonstrate that it is feasible for elderly subjects with COPD and other comorbidities to wear an unobtrusive, inexpensive, easy-to-use accelerometer. Using both the checklist and the accelerometer, we show that little day-to-day variability occurs in physical activity in subjects with COPD and that free-living physical activity is significantly associated with clinical measures of COPD status. These types of methods may be used in future studies to prospectively assess participation in physical activity and measure disability in COPD.

Physical activity measured with our simple checklist was significantly associated with FEV_1 percent predicted and the BODE index, demonstrating concurrent validity with different measures of COPD severity. Similarly, Pitta et al. found that the BODE index increased significantly with each day of inactivity [35]. We found no floor or ceiling effect for the 15 activities assessed, suggesting that the checklist can be sensitive to change if subjects engage in fewer activities during a COPD exacerbation or engage in more activities after a therapeutic intervention. We minimized the potential impact of seasonal variation on participation in physical activities by conducting the study over 3 months in the spring and summer. Our results show that the types of physical activities performed do not vary much from day to day within a subject and that steps walked per day vary more day to day. We acknowledge that a greater variation in daily physical activities and step counts could possibly have been observed if our study included greater numbers of subjects across all GOLD stages, including women.

Currently, the devices most commonly used to measure physical activity in COPD are the Tritrac-R3D (RT3 is the newer version; Professional Products, Division of Reining International; Madison, Wisconsin), the Dynaport Activity Monitor (McRoberts BV; The Hague, the Netherlands), and the SenseWear Pro Armband (Body Media, Inc; Pittsburgh, Pennsylvania). Based on previous work using these devices, we know that physical activity is reduced in patients with moderate to severe COPD compared with healthy subjects [7,12,18]. We also know that physical activity is only moderately correlated with the degree of airway obstruction [12,18], indicating that physical activity captures a dimension of COPD disease status that is not assessed by current clinical measures. However, limitations of these devices have prohibited long-term monitoring and use in large-scale clinical trials. The Tritrac-R3D produces substantial intra-individual fluctuations in activity [16], the Dynaport Activity Monitor requires precise positioning on the waist and leg for accurate recordings [18], and the SenseWear Pro Armband is expensive at US$1,000 per device. In the current study, we similarly show that patients with COPD walk considerably fewer than the 10,000 steps per day recommended for health promotion [36–37] and that steps per day are significantly associated with 6MWT distance and HRQL but not with FEV_1 percent predicted. However, ours is the first study, to our knowledge, that confirms previous findings with the use of an unobtrusive, simple accelerometer.

Identifying a “gold standard” measure of actual (as opposed to reported) daily activity against which to test the accuracy of these devices is difficult. The devices used to date in COPD have different outcomes, with accuracy assessed in various ways. For example, the Tritrac-R3D has the main outcome of vector magnitude units. Content and concurrent validity were demonstrated

based on moderate to high Pearson correlation coefficients with 6MWT, FEV_1, and dyspnea during monitoring in the home environment [15]. The DynaPort Activity Monitor has its main outcome as time spent in different activities such as walking, standing, or lying. Accuracy has been assessed by comparisons with video recordings showing high agreement in protocols conducted in the clinic [38]. The SenseWear Pro Armband has the main outcome of energy expenditure [7,39]. This device has been validated against an exhaled breath metabolic system in the laboratory during slow to moderate pace walking [39].

We chose to use the Actihealth accelerometer because we were able to easily verify its accuracy against manual step counts for each subject in the clinic before home use. Although we were disappointed with its performance, given its inaccuracy at low walking speeds observed in some persons with COPD, our results highlight the importance of verifying device accuracy in each subject being studied prior to use in the field. In keeping with our previous finding that usual walking speed is the most important predictor of device accuracy [27], the main difference between the 10 subjects who had >90 percent accuracy and the 7 subjects who did not was usual walking speed, 2.49 mph versus 2.05 mph (**Table 1**). The issue of activity quantitation in COPD is still in the early stages of research and the technical issue of data accuracy in the COPD population needs to be addressed before the appropriate devices can be identified and used to assess free-living activity and promote physical activity in the COPD population. The devices will need to be inexpensive, be easy to use, provide feedback to the subjects, and have capabilities to feed data back to healthcare providers, either through the Internet or by telephone.

Furthermore, the Actihealth accelerometer had memory storage problems despite product labeling that it could store data for up to 30 days. Nevertheless, we found that average steps per day for the last 5 days of monitoring, for which all subjects had step count data, were nearly identical to average steps per day for all the days monitored for each subject, suggesting that the data available were representative of the 14-day observation period (**Figure 1**). The device does not capture upper-limb activities or energy expenditure, but we coupled its use with an activity checklist that captured daily physical activities other than ambulation relevant to persons with COPD. The purpose of this study was not to calculate the level of physical activity in absolute units such as energy expenditure. Our main objective was to test the feasibility of using an unobtrusive device and simple activity checklist under free-living conditions.

Given the number of observations obtained from repeated measurements over 2 weeks for each subject, enough statistical power was present to assess univariate correlations between steps per day, number of daily checklist activities, and other clinical variables. We found that steps per day were significantly associated with 6MWT distance, HRQL as measured by the PCS and MCS, and history of joint problems. Neither steps per day nor number of daily checklist activities performed was significantly associated with prior participation in pulmonary rehabilitation, report of regular exercise, prednisone use in the previous year, or supplemental oxygen use. Age, BMI, Beck Depression Inventory score, and dyspnea assessed by the modified Borg scale were not significantly associated with either steps per day or number of daily checklist activities performed. Similarly, walking time has been correlated with 6MWT distance, but not with use of oral corticosteroids, obesity, depression, arthritis, or back pain [18]. FEV_1 and BMI were not related to physical activity as assessed by a questionnaire, and dyspnea was not associated with physical activity in univariate models [22]. These findings support the hypothesis that free-living physical activity captures a dimension of COPD disease status that is not assessed by current clinical measures. Sandland et al. showed that activity counts in subjects with COPD who received long-term oxygen therapy were reduced by 79 percent compared with a healthy group [40]. The difference in findings may be because of a much lower average FEV_1 of 0.66 L in their cohort of nine subjects compared with 1.6 L in our cohort. To assess the main cause of low steps per day in COPD, we need a larger study to include variables that affect steps per day—such as lung function, HRQL, joint problems—in the same multivariate model.

CONCLUSIONS

In this article, we demonstrate that free-living physical activity in subjects with COPD can be assessed with a simple activity checklist and, in the subgroup of subjects in whom the device is accurate, with the use of an unobtrusive, simple accelerometer. Using the accelerometer and the activity checklist, we show that low daily intra-subject variation occurs in free-living physical activity that is significantly associated with clinical measures of COPD status. These types of methods may be used in

future studies to prospectively assess participation in physical activities and measure disability in COPD.

ACKNOWLEDGMENTS

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Statistical analysis: M.L. Moy, K. Stolzmann, E. Garshick.
Obtained funding: M.L. Moy, E. Garshick.
Administrative, technical, or material support: K. Stolzmann, K. Matthess.
Study supervision: M.L. Moy, E. Garshick.
Financial Disclosures: The authors have declared that no competing interests exist. This study was initiated by the investigators, who do not receive any financial support from FitSense, Inc. The results of the present study do not constitute endorsement of the product by the authors.
Funding/Support: This material was based on work supported in part by the VA, Veterans Health Administration, Rehabilitation Research and Development Service, and by the National Institutes of Health (NIH) through a VA Career Development Award (Dr. Moy); and by the NIH/National Institute of Child Health grant RO1 HD42141 (Dr. Garshick). The work was performed at VA Boston Healthcare System, Boston, MA.
Additional Contributions: We thank Avron Spiro III, PhD, for his thoughtful review of the manuscript.

REFERENCES

1. Rabe KF, Hurd S, Anzueto A, Barnes PJ, Buist SA, Calverley P, Fukuchi Y, Jenkins C, Rodriguez-Roisin R, Van Weel C, Zielinski J, Global Initiative for Chronic Obstructive Lung Disease. 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. [PMID: 17507545] DOI:10.1164/rccm.200703-456SO
2. Croxton TL, Weinmann GG, Senior RM, Hoidal JR. Future research directions in chronic obstructive pulmonary disease. Am J Respir Crit Care Med. 2002;165(6):838–44. [PMID: 11897653]
3. Croxton TL, Weinmann GG, Senior RM, Wise RA, Crapo JD, Buist AS. Clinical research in chronic obstructive pulmonary disease: Needs and opportunities. Am J Respir Crit Care Med. 2003;167(8):1142–49. [PMID: 12684252] DOI:10.1164/rccm.200207-756WS
4. Fishman A, Martinez F, Naunheim K, Piantodosi S, Wise R, Ries A, Weinmann G, Wood DE, National Emphysema Treatment Trial Research Group. A randomized trial comparing lung-volume-reduction surgery with medical therapy for severe emphysema. N Engl J Med. 2003;348(21):2059–73. [PMID: 12759479] DOI:10.1056/NEJMoa030287
5. Martinez FJ, Foster G, Curtis JL, Criner G, Weinmann G, Fishman A, DeCamp MM, Benditt J, Sciurba F, Make B, Mohsenifar Z, Diaz P, Hoffman E, Wise R, NETT Research Group. Predictors of mortality in patients with emphysema and severe airflow obstruction. Am J Respir Crit Care Med. 2006;173(12):1326–34. [PMID: 16543549] DOI:10.1164/rccm.200510-1677OC
6. Garcia-Aymerich J, Lange P, Benet M, Schnohr P, Anto JM. Regular physical activity reduces hospital admission and mortality in chronic obstructive pulmonary disease: A population based cohort study. Thorax. 2006;61(9):772–78. [PMID: 16738033] DOI:10.1136/thx.2006.060145
7. Watz H, Waschki B, Boehme C, Claussen M, Meyer T, Magnussen H. Extrapulmonary effects of chronic obstructive pulmonary disease on physical activity: A cross-sectional study. Am J Respir Crit Care Med. 2008;177(7):743–51. [PMID: 18048807] DOI:10.1164/rccm.200707-1011OC
8. ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement: Guidelines for the six-minute walk test. Am J Respir Crit Care Med. 2002;166(1):111–17. [PMID: 12091180]
9. Sciurba F, Criner GJ, Lee SM, Mohsenifar Z, Shade D, Slivka W, Wise RA, National Emphysema Treatment Trial Research Group. Six-minute walk distance in chronic obstructive pulmonary disease: Reproducibility and effect of walking course layout and length. Am J Respir Crit Care Med. 2003;167(11):1522–27. [PMID: 12615634] DOI:10.1164/rccm.200203-166OC
10. Ross RM. ATS/ACCP statement on cardiopulmonary exercise testing. Am J Respir Crit Care Med. 2003;167(10):1451. [PMID: 12738602] DOI:10.1164/rccm.167.2.211
11. Pitta F, Troosters T, Probst VS, Spruit MA, Decramer M, Gosselink R. Quantifying physical activity in daily life with questionnaires and motion sensors in COPD. Eur Respir J. 2006;27(5):1040–55. [PMID: 16707399]
12. Schönhofer B, Ardes P, Geibel M, Köhler D, Jones PW. Evaluation of a movement detector to measure daily activity in patients with chronic lung disease. Eur Respir J. 1997;10(12):2814–19. [PMID: 9493666] DOI:10.1183/09031936.97.10122814
13. Moy ML, Mentzer SJ, Reilly JJ. Ambulatory monitoring of cumulative free-living activity. IEEE Eng Med Biol Mag.

2003;22(3):89–95. [PMID: 12845824]
DOI:10.1109/MEMB.2003.1213631

14. Storti KL, Pettee KK, Brach JS, Talkowski JB, Richardson CR, Kriska AM. Gait speed and step-count monitor accuracy in community-dwelling older adults. Med Sci Sports Exerc. 2008;40(1):59–64. [PMID: 18091020]
15. Steele BG, Holt L, Belza B, Ferris S, Lakshminaryan S, Buchner DM. Quantitating physical activity in COPD using a triaxial accelerometer. Chest. 2000;117(5):1359–67. [PMID: 10807823]
DOI:10.1378/chest.117.5.1359
16. Nguyen HQ, Steele B, Benditt JO. Use of accelerometers to characterize physical activity patterns with COPD exacerbations. Int J Chron Obstruct Pulmon Dis. 2006;1(4):455–60. [PMID: 18044101]
DOI:10.2147/copd.2006.1.4.455
17. Steele BG, Belza B, Hunziker J, Holt L, Legro M, Coppersmith J, Buchner D, Lakshminaryan S. Monitoring daily activity during pulmonary rehabilitation using a triaxial accelerometer. J Cardiopulm Rehabil. 2003;23(2):139–42. [PMID: 12668936]
DOI:10.1097/00008483-200303000-00011
18. Pitta F, Troosters T, Spruit MA, Probst VS, Decramer M, Gosselink R. Characteristics of physical activities in daily life in chronic obstructive pulmonary disease. Am J Respir Crit Care Med. 2005;171(9):972–77. [PMID: 15665324]
DOI:10.1164/rccm.200407-855OC
19. Stewart AL, Mills KM, King AC, Haskell WL, Gillis D, Ritter PL. CHAMPS physical activity questionnaire for older adults: Outcomes for interventions. Med Sci Sports Exerc. 2001;33(7):1126–41. [PMID: 11445760]
DOI:10.1097/00005768-200107000-00010
20. Dubbert PM, Vander Weg MW, Kirchner KA, Shaw B. Evaluation of the 7-day physical activity recall in urban and rural men. Med Sci Sports Exerc. 2004;36(9):1646–54. [PMID: 15354050]
DOI:10.1249/01.MSS.0000139893.65189.F2
21. Kriska AM. A collection of physical activity questionnaires for health-related research. Med Sci Sports Exerc. 1997; 29(6 Suppl):S1–205 [PMID: 9243481]
22. Garcia-Aymerich J, Félez MA, Escarrabill J, Marrades RM, Morera J, Elosua R, Antó JM. Physical activity and its determinants in severe chronic obstructive pulmonary disease. Med Sci Sports Exerc. 2004;36(10):1667–73. [PMID: 15595285]
DOI:10.1249/01.MSS.0000142378.98039.58
23. Lareau SC, Carrieri-Kohlman V, Janson-Bjerklie S, Roos PJ. Development and testing of the Pulmonary Functional Status and Dyspnea Questionnaire (PFSDQ). Heart Lung. 1994;23(3):242–50. [PMID: 8039994]
24. Jones PW, Quirk FH, Baveystock CM, Littlejohns P. A self-complete measure of health status for chronic airflow limitation. The St. George's Respiratory Questionnaire. Am Rev Respir Dis. 1992;145(6):1321–27. [PMID: 1595997]
25. Ware JE. The SF-36 health survey. In: Spilker B, editor. Quality of life and pharmacoeconomics in clinical trials. 2nd ed. Philadelphia (PA): Lippincott-Raven; 1996.
26. Weyand PG, Kelly M, Blackadar T, Darley JC, Oliver SR, Ohlenbusch NE, Joffe SW, Hoyt RW. Ambulatory estimates of maximal aerobic power from foot-ground contact times and heart rates in running humans. J Appl Physiol. 2001;91(1):451–58. [PMID: 11408463]
27. Moy ML, Garshick E, Matthess K, Lew R, Reilly JJ. Accuracy of a uniaxial accelerometer in chronic obstructive pulmonary disease. J Rehabil Res Dev. 2008;45(4):611–17. [PMID: 18712646]
DOI:10.1682/JRRD.2007.09.0147
28. Lung function testing: Selection of reference values and interpretative strategies. Am Rev Respir Dis. 1991;144(5): 1202–18. [PMID: 1952453]
29. Celli BR, Cote CG, Marin JM, Casanova C, Montes de Oca M, Mendez RA, Pinto Plata V, Cabral HJ. 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. [PMID: 14999112]
DOI:10.1056/NEJMoa021322
30. Kazis LE, Miller DR, Clark JA, Skinner KM, Lee A, Ren XS, Spiro A 3rd, Rogers WH, Ware JE Jr. Improving the response choices on the veterans SF-36 health survey role functioning scales: Results from the Veterans Health Study. J Ambul Care Manage. 2004;27(3):263–80. [PMID: 15287216]
31. Mahler DA, Wells CK. Evaluation of clinical methods for rating dyspnea. Chest. 1988;93(3):580–86. [PMID: 3342669]
DOI:10.1378/chest.93.3.580
32. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc. 1982;14(5):377–81. [PMID: 7154893]
DOI:10.1249/00005768-198205000-00012
33. Beck AT, Ward CH, Mendelson M, Mock J, Erbaugh J. An inventory for measuring depression. Arch Gen Psychiatry. 1961;4:561–71. [PMID: 13688369]
34. Kleinbaum D, Kupper L, Muller K, Nizam A. Applied regression analysis and other multivariable methods. 3rd ed. Boston (MA): Duxbury Press; 1998.
35. Pitta F, Troosters T, Probst VS, Lucas S, Decramer M, Gosselink R. 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. [PMID: 17268729]
36. Tudor-Locke C, Bassett DR Jr. How many steps/day are enough? Preliminary pedometer indices for public health. Sports Med. 2004;34(1):1–8. [PMID: 14715035]
DOI:10.2165/00007256-200434010-00001

37. Bravata DM, Smith-Spangler C, Sundaram V, Gienger AL, Lin N, Lewis R, Stave CD, Olkin I, Sirard JR. Using pedometers to increase physical activity and improve health: A systematic review. JAMA. 2007;298(19):2296–2304. [PMID: 18029834] DOI:10.1001/jama.298.19.2296
38. Pitta F, Troosters T, Spruit MA, Decramer M, Gosselink R. Activity monitoring for assessment of physical activities in daily life in patients with chronic obstructive pulmonary disease. Arch Phys Med Rehabil. 2005;86(10):1979–85. [PMID: 16213242] DOI:10.1016/j.apmr.2005.04.016
39. 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. [PMID: 17530503] DOI:10.1080/15412550701246658
40. Sandland CJ, Singh SJ, Curcio A, Jones PM, Morgan MD. A profile of daily activity in chronic obstructive pulmonary disease. J Cardiopulm Rehabil. 2005;25(3):181–83. [PMID: 15931024] DOI:10.1097/00008483-200505000-00011

Submitted for publication July 9, 2008. Accepted in revised form September 22, 2008.