

Performance of a pedometer to measure physical activity in a U.S. cohort with chronic obstructive pulmonary disease

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Abstract—Objective assessment of physical activity (PA) in chronic obstructive pulmonary disease (COPD) is important. We examined the performance of the Omron HJ-720ITC pedometer. A sample of 176 persons with stable COPD wore the Omron and the StepWatch Activity Monitor (SAM) in the clinic and the community. A 4 s step filter in the Omron screens out erroneous intermittent steps; it captures continuous walking that lasts >4 s. The SAM captures all intermittent and continuous steps walked. Omron-steps were compared with manually counted steps in the clinic and with SAM-steps in the community. We calculated the intraclass correlation coefficient for the first 2 d, the first 3 d, etc., up to 14 d. The Omron registered $>= 90\%$ of the manually counted steps from the in-clinic walk in 155 of 176 subjects (88%). In the community, 47 \pm 16% of SAM-steps were continuous ones that were captured by the Omron. For the Omron and the SAM, at least 7 d of monitoring should be used to capture decreases in PA on weekend days and obtain optimum reliability for all Global Initiative for Chronic Obstructive Lung Disease stages. The Omron accurately and reliably measures continuous walking in COPD. The Omron may be ideal for use in PA interventions that promote continuous walking as exercise.

Key words: continuous walking, COPD, exercise, functional capacity, intermittent steps, Omron, pedometer, physical activity, pulmonary disease, StepWatch Activity Monitor.

INTRODUCTION

Persons with chronic obstructive pulmonary disease (COPD) are significantly less active than healthy persons [1], even at the earliest stages of disease [2–3]. Decreased physical activity (PA), defined as any bodily movement produced by skeletal muscles that results in energy expenditure [4], is associated with increased levels of systemic inflammation and increased risk of hospital admissions, acute exacerbations, and death independent of lung function in persons with COPD [5–10]. Physical inactivity is a major contributor to skeletal muscle dysfunction in COPD [11]. Objective assessment of PA can potentially play a role in risk stratification and development of PA

Abbreviations: COPD = chronic obstructive pulmonary disease, FEV₁ = forced expiratory volume in 1 s, GOLD = Global Initiative for Chronic Obstructive Lung Disease, ICC = intraclass correlation coefficient, PA = physical activity, SAM = StepWatch Activity Monitor, VA = Department of Veterans Affairs, VMU = vector magnitude unit.

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interventions [6–7,12]. Promoting PA could alter the disease course and improve outcomes in persons with COPD [13].

To date, sophisticated and expensive accelerometers have been used to measure PA in the COPD research setting. They include the Actigraph (Pensacola, Florida); DynaPort (McRoberts; Den Haag, the Netherlands); StepWatch Activity Monitor (SAM) (Orthocare Innovations; Mountlake Terrace, Washington); RT3 (Stay-healthy Inc; Monrovia, California); and SenseWear Armband (BodyMedia Inc; Pittsburgh, Pennsylvania), a multisensor monitor [1,3,5,7,14–18]. They have been shown to be accurate and are able to measure various characteristics of PA such as intensity [19]. However, a limitation of these monitors is that they report different characteristics of PA that are not easily understood by patients if used in the clinical setting. The Actigraph reports activity time and vector magnitude units (VMUs); the Dynaport reports movement intensity and time spent walking, standing, sitting, or lying; the SAM reports step counts; the RT3 reports activity counts and VMUs; and the SenseWear armband reports activity intensity level [5,7,14–18].

There is a need to simplify the devices and the PA characteristic of primary interest if research is to be translated widely to the clinical setting. Commercially available pedometers have gained popularity and may be a simple alternative to accelerometers [20]. Walking, measured by daily step count, is a PA that is relevant to patients, is easy to understand, and potentially can be modified [12,21–23]. Daily step count reflects overall daily PA [24], can be a surrogate for PA level [25], and relates to COPD outcomes of exacerbations and hospitalizations regardless of intensity [7–10]. Of various PA units, steps per day is one of the most sensitive outcomes [26].

Pedometers like the Omron HJ-720ITC (Omron Healthcare Inc; Bannockburn, Illinois) are accurate and user-friendly in the general population and are significantly less expensive than accelerometers [27–30]. A 4 s step filter is an intrinsic property of the Omron that screens out erroneous steps that might result from shuffling, standing up, sitting down, and vibrations from a moving vehicle [29–30]. Thus, the Omron captures steps from continuous walking that lasts >4 s [27–30]. Our pilot work in persons with COPD has shown the Omron pedometer to be accurate in the clinic and feasible for use in an Internet-mediated PA intervention [12,31]. In this study, we extended our work by examining the monitor-

ing capabilities of the Omron in COPD. Our aims were to assess (1) the Omron's accuracy in detecting continuous steps in the clinic, (2) the percentage of steps walked in the community that are continuous, (3) the ability of the Omron to detect differences in daily step count observed between weekdays and weekend days [15], and (4) the number of monitoring days needed for optimum reliability.

METHODS

Study Population

We studied participants with COPD recruited from the general pulmonary clinics at the Department of Veterans Affairs (VA) Boston Healthcare System from January 2009 through September 2011 and enrolled in an observational research study to characterize daily step count [5–7,21–22]. Eligible participants were over 40 yr of age and had a clinical diagnosis of COPD. Persons who could not ambulate (with or without a walking aid) were excluded. All assessments were conducted with subjects in stable clinical condition when at least 1 mo had elapsed from the time of any treatment for a COPD exacerbation. The protocol was approved by the Institutional Committee on Human Research at the VA Boston Healthcare System, and written informed consent was obtained from all subjects.

Clinical Assessments

At the in-clinic visit, we assessed demographic characteristics, medical history, and comorbidities. Forced expiratory volume in 1 s (FEV_1), measured with an Eaglet spirometer (nSpire Health Inc; Longmont, Colorado), and the 6 min walk test distance were assessed following American Thoracic Society guidelines [32–33]. COPD severity was categorized by Global Initiative for Chronic Obstructive Lung Disease (GOLD) stage, I (mild) to IV (most severe) [34]. Dyspnea at rest was assessed using the modified Medical Research Council scale (responses 0–4, with 4 being the most dyspneic) [35]. Subjects completed the St. George's Respiratory Questionnaire, with lower total score indicating better health-related quality of life [36].

Physical Activity Monitoring Devices

The Omron uses a piezoelectric strain gauge to measure acceleration and count steps [29–30]. A 4 s step filter is an intrinsic property of the Omron that screens out

erroneous steps that might result from shuffling, standing up, sitting down, and vibrations from a moving vehicle [29–30]. Thus, the Omron captures continuous steps that last >4 s [27–30]. The Omron is inexpensive (\$32 U.S.), is lightweight (35 g), clips at the waist, and provides feedback with on-instrument digital display of step counts. It interfaces with the Internet via an embedded USB connection, allowing upload of date- and time-stamped step counts [27–30].

The SAM, a research-grade device, has no filter and captures all step counts from intermittent lifestyle activities and continuous walking [37–38]. The SAM is a lightweight (38 g) microprocessor-controlled accelerometer designed for persons with mobility limitations [21,37–38]. Attached to the ankle with a Velcro strap, the SAM responds to time, acceleration, and position to detect walking motion [21,37–38]. The SAM is highly accurate in persons with chronic diseases, including COPD, but is expensive (\$525 U.S. for device plus \$1,500 U.S. for docking station and software) and has no on-instrument display [21,37–38]. For this study, the SAM was set at the normal default settings for “walking speed,” “range of speeds,” and “leg motion,” as recommended by the manufacturer [21,37–38].

Step-Count Assessment

In the clinic, participants walked a predetermined level course of 244 m at their usual speed while wearing the Omron. Study staff manually counted steps with a tally counter. Omron accuracy was assessed by comparing the Omron-steps with manual steps. Participants were then sent home to wear the Omron and SAM for 14 consecutive days, during all awake hours. Participants were asked to perform their usual PAs, including daily activities and exercise. We covered the digital display on the Omron with a sticker so participants would not receive feedback of step counts. Subjects returned the Omron and SAM by mail, and staff downloaded the date- and time-stamped step counts. The percentage of steps walked in the community that represent continuous walking lasting >4 s was assessed by comparing Omron-steps (continuous) with SAM-steps (intermittent plus continuous).

Statistical Analysis

One-hundred seventy-six participants completed the clinic visit and 170 participants completed the home monitoring. Bland-Altman plots compared Omron-steps with manual steps in the clinic and compared Omron-

steps to SAM-steps in the community [39]. Valid wear days were defined as ones with ≥200 steps recorded and ≥8 h of wear time [21,26,31,40]. For the remaining analyses, we restricted the study population to 128 participants with valid Omron step-count measurements or 136 participants with valid SAM step-count measurements for all 14 d of monitoring. Changes in step counts, measured by the Omron and SAM, between the first and second week of monitoring and between weekdays and weekend days, overall and stratified by GOLD stage, were assessed using paired *t*-tests. To estimate the reliability of the number of consecutive days monitored, we calculated the intraclass correlation coefficient (ICC) for the first 2 d, the first 3 d, etc., up to and including all 14 d of step-count monitoring. The ICC was calculated for the cohort and by GOLD stage using the formula: $B/\{B+(W/D)\}$, where B = between subject variance, W = within subject variance, and D = number of days [41].

RESULTS

Of the subjects, 99 percent were males, with mean ± standard deviation age 72 ± 8 yr and $\text{FEV}_1 1.55 \pm 0.58$ L ($55 \pm 20\%$ predicted) [42] (**Table 1**). Forty-five (26%) subjects reported regular use of oxygen and 21 (12%) reported prior participation in pulmonary rehabilitation (**Table 1**). Twenty-three (13%) participants reported using a walking aid more than half the time. Eighteen used a cane, one used a walker, two used a cane and a walker, and two used a cane and at times a scooter.

When participants walked the 244 m course in the clinic, the Omron registered ≥90 percent of the manually counted steps in 155 of the 176 subjects (88%). It took an average of 4.5 ± 3.8 min to perform the step count assessment, with an average stride length of 55.1 ± 9.2 cm and walking speed of 3.5 ± 0.8 km/h. The Bland-Altman plot displayed a mean difference in step counts (manual minus Omron-steps) of 34 ± 112 , 95 percent confidence interval –186 to 253 (**Figure 1(a)**). Of 2,464 d (176 subjects × 14 d) monitored in the community, 94 percent had valid Omron step-counts. During the 14 d monitoring period, on average, 47 ± 16 percent of all SAM steps walked by participants were continuous ones that were captured by the Omron. The Bland-Altman plot reveals the presence of a proportional error such that higher daily step counts are associated with increases in the difference in daily step counts (SAM minus Omron-steps) (**Figure 1(b)**).

Table 1.Subject characteristics, $N = 176$.

Characteristic	Mean \pm SD or Frequency (%)
Age (yr)	72 \pm 8
Stride Length (cm)	55.1 \pm 9.2
Walking Speed (km/h)	3.5 \pm 0.8
Use of Walking Aid	23 (13)
Pack Years	67 \pm 36
Prior Participation in Pulmonary Rehabilitation	21 (12)
Self-Report of Regular Exercise	60 (34)
Regular Oxygen Use	45 (26)
Joint Problems	89 (51)
Medical Problems Affecting Walking	94 (53)
Diabetes Mellitus	46 (26)
Hypertension	110 (62)
Coronary Artery Disease	56 (32)
FEV ₁ (L) [*]	1.55 \pm 0.58
FEV ₁ % Predicted [*]	55 \pm 20
GOLD Stage	
I	17 (10)
II	80 (46)
III	58 (33)
IV	20 (11)
6MWT distance (m)	369 \pm 102
mMRC Score	
0	8 (5)
1	61 (35)
2	32 (18)
3	47 (27)
4	28 (16)
SGRQ Total Score [†]	45 \pm 19

^{*} $n = 175$.[†] $n = 174$.

6MWT = 6 min walk test, FEV₁ = forced expiratory volume in 1 s, GOLD = Global Initiative for Chronic Obstructive Lung Disease, mMRC = modified Medical Research Council, SD = standard deviation, SGRQ = St. George's Respiratory Questionnaire.

We examined in greater detail the 23 persons who used a walking aid. In the clinic, the 23 persons who used a walking aid had an average Omron accuracy compared with manual counts of 83 percent versus 95 percent for the 153 persons who did not use a walking aid. In the clinic, 8 of the 23 (35%) who used a walking aid had less than 90 percent Omron accuracy versus 14 of the 153 (9%) who did not use a walking aid. In the community, in the 20 persons who used a walking aid, the Omron detected 40 percent of the steps captured by the SAM

versus 47 percent in the 150 persons who did not use a walking aid. Similarly, we more closely characterized the seven persons who had the greatest difference in step counts between manual and Omron-steps (**Figure 1(a)**). They were generally older, had shorter stride length and lower walking speed, were more likely to use a walking aid, used supplemental oxygen, and self-reported medical problems that affected walking.

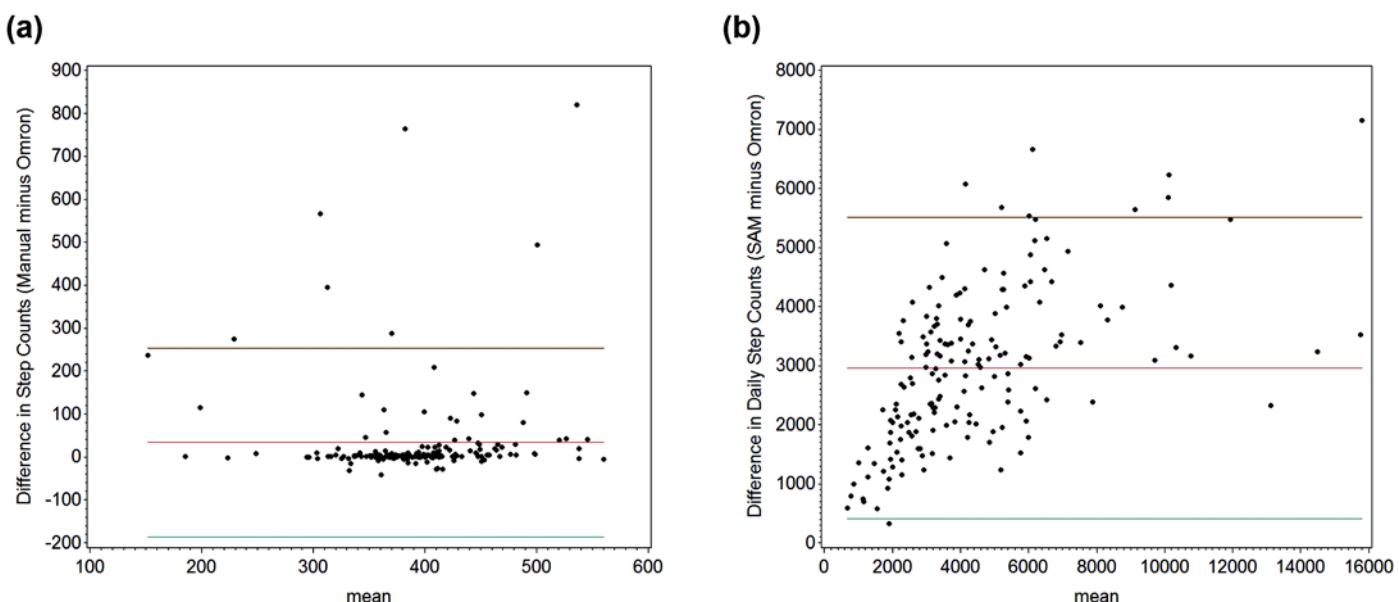
Overall, there was no significant difference between daily step counts during the first versus the second week of monitoring by either device (**Tables 2** and **3**). Participants walked on average 374 more Omron-recorded steps per day on weekdays than weekend days, $p < 0.001$. Similarly, persons walked 490 more SAM-recorded steps per day on weekdays than weekend days, $p < 0.001$.

Four days of monitoring were needed to achieve an ICC of at least 0.90 for the Omron (**Figure 2(a)**) and the SAM (**Figure 2(b)**). Overall, increasing the number of monitoring days from 4 to 9 increased the ICC from 0.90 to 0.95 for the Omron and SAM. The number of monitoring days for optimum reliability differed by GOLD stage, with differences in ICCs between GOLD stages most prominent for the Omron (**Figure 2(a)**). For the Omron and SAM, participants in GOLD stage I had the highest ICCs and required 3 to 4 d of monitoring to achieve an ICC ≥ 0.90 . In contrast, participants in GOLD stage IV had the lowest ICCs and required 6 to 7 d of monitoring to achieve an ICC ≥ 0.90 .

DISCUSSION

The Omron pedometer can be a simple and inexpensive alternative to accelerometers to monitor PA in persons with COPD. The Omron pedometer is accurate in the majority of persons with COPD when measuring continuous walking in the clinic. Furthermore, 47 percent of all steps taken by persons with COPD in the community are continuous ones that are detected by the Omron. The Omron is reliable, able to capture day-to-day variability in PA level, and able to detect the lower levels of PA during weekend days characteristic of COPD patients [15]. At least seven monitoring days are needed to capture the decreases in PA on weekend days and obtain optimum reliability for all GOLD stages under study.

Understanding the complex interaction between device properties and user characteristics is critical for choosing a device for study. The Omron accurately

**Figure 1.**

(a) Bland-Altman plot of manually counted and Omron-measured steps in clinic, $N = 176$. **(b)** Bland-Altman plot of Omron- and Step-Watch Activity Monitor (SAM)-measured daily step counts in community, $N = 170$.

counts continuous walking that lasts >4 s. If a person were to walk <4 s and stop, the Omron would not record any steps. Yet human beings commonly walk 4 to 6 steps in a row [43], so the Omron does not capture these intermittent steps. Silcott et al. has similarly shown in normal adults that the Omron records only 52 to 64 percent of SAM step counts in the community and proposed that this is due to the Omron's 4 s filter [30]. Furthermore, we have shown that the Omron has a greater chance of being inaccurate in persons using a walking aid, and the Omron may be less accurate in those who are older, have shorter

stride length and lower walking speed, use supplemental oxygen, or have medical problems that affect walking. The choice of monitoring device (accelerometer, pedometer) and PA characteristic (steps, bouts, intensity, moderate-vigorous activity) should ultimately depend on the question asked, characteristics of the COPD population under study, and cost. Based on detailed knowledge about the performance of the Omron, we propose that it can be used as part of interventions to increase PA when the focus is on promoting walking for exercise.

Table 2.

Average daily Omron step count by week and day type, $N = 128$.

	<i>n</i>	Week 1 (Days 1–7)	Week 2 (Days 8–14)	<i>p</i> -Value	Week Days	Weekend Days	<i>p</i> -Value
All	128	3,296	3,160	0.06	3,335	2,961	<0.001
I	13	4,040	3,527	0.006	3,897	3,500	0.06
II	61	3,585	3,343	0.04	3,576	3,184	0.047
III	40	2,909	2,947	0.71	2,996	2,758	0.09
IV	13	2,210	2,230	0.87	2,348	1,900	0.05

Note: One participant could not perform spirometry and does not have GOLD stage.
GOLD = Global Initiative for Chronic Obstructive Lung Disease.

Table 3.Average daily StepWatch Activity Monitor step count by week and day type, $N = 136$.

	n	Week 1 (Days 1–7)	Week 2 (Days 8–14)	p-Value	Week Days	Weekend Days	p-Value
All	136	5,914	5,773	0.11	5,984	5,494	<0.001
I	14	6,794	6,347	0.03	6,726	6,181	0.17
II	61	6,713	6,455	0.09	6,703	6,286	0.07
III	45	5,380	5,386	0.96	5,521	5,040	0.02
IV	15	3,355	3,286	0.64	3,453	2,990	0.04

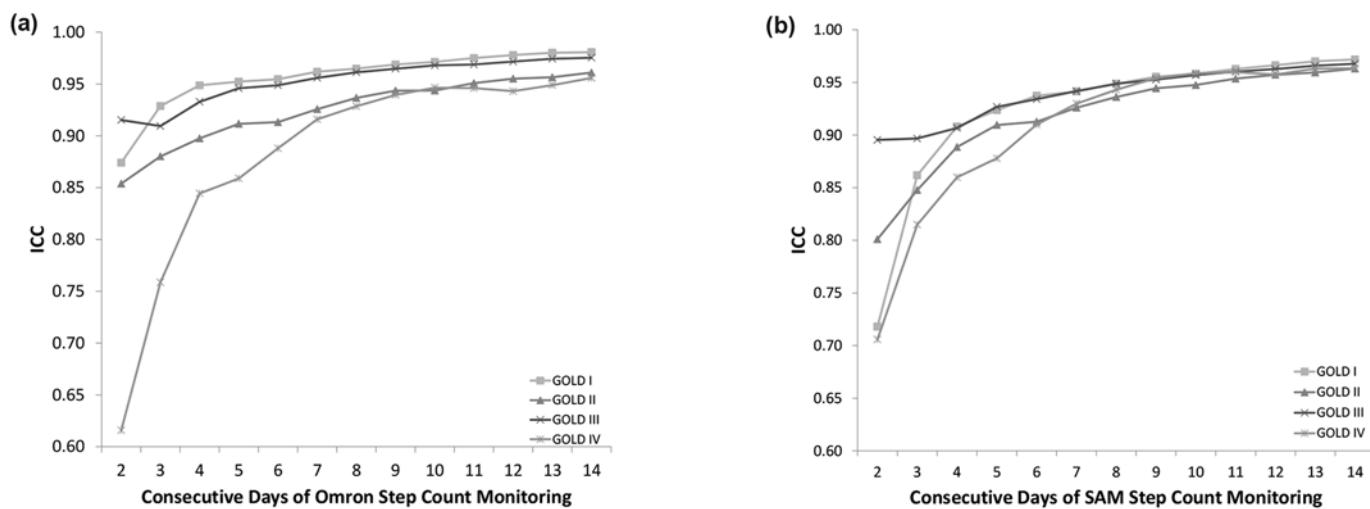
Note: One participant could not perform spirometry and does not have GOLD stage.

GOLD = Global Initiative for Chronic Obstructive Lung Disease.

The percentage of steps walked in the community that represent continuous walking is reflected by the fraction of SAM counts captured by the Omron. We concluded that if the Omron accurately captured steps during continuous walking in the clinic, then it would accurately capture these types of steps in the community. In addition, **Figure 1(b)** shows that higher total daily step counts are associated with increases in the difference between SAM and Omron steps. The most likely reason for this proportional error is that increases predominantly in the number of intermittent steps (detected by the SAM but not the Omron), not continuous steps, contribute to increases in total daily steps.

Overall, persons with COPD have little variability in step counts from day to day regardless of weekend days versus weekdays. The Omron is able to detect the lower

step counts observed on weekend days versus weekdays and is reliable. A 4 d monitoring period can provide reliable measurements of daily step count, but 7 d are ideal to capture differences seen on weekend days and between GOLD stages. A previous study examined 17 persons with COPD who had completed pulmonary rehabilitation [37]. Although there was no comparison of weekdays with weekend days, it similarly found that more monitoring days were associated with greater measurement precision. Watz et al. showed that 2 to 3 d were sufficient for reliable measurement of daily step counts in patients with GOLD stage IV, whereas up to 5 d of measurement were required in patients with GOLD stage I [41]. The different findings in the two studies may be explained by the facts that the Watz et al. study monitored subjects for 5 d, did not always include weekend days, and used the

**Figure 2.**

Intraclass correlation coefficients (ICCs) of (a) Omron counts, $N = 128$, and (b) StepWatch Activity Monitor (SAM) counts, $N = 136$, calculated for the first 2 through 14 d of monitoring, by Global Initiative for Chronic Obstructive Lung Disease (GOLD) stage.

SenseWear ProArmband, which underestimates step counts [44].

We significantly extend the literature by fully characterizing the performance of a pedometer in COPD that can be used on a large scale. A PA monitor should be acceptable and user-friendly to the patient [14–15]. Ninety-four percent of days monitored in the community had valid Omron step-counts, demonstrating a high adherence rate for pedometer use. This is in contrast to the 79 to 91 percent compliance previously reported for six PA monitors [16]. The most common problem reported was the Omron falling out of its holder clipped at the waist. To the best of our knowledge, our current study provides the most detailed information about the performance of a pedometer in COPD. Interventions are needed to promote PA in persons with COPD, in whom PA is reduced even at the earliest stages of the disease. Our study in persons with little dyspnea shows that they have reduced daily step counts despite minimal symptoms.

Our study has many strengths, including a large well-characterized cohort, a 14 d monitoring period, and high study adherence. Some limitations deserve discussion. The Omron offers no information on the pattern or intensity of PA, upper-limb activities, or energy expenditure. Studying these characteristics of PA in future studies will be important. Nevertheless, daily step count is a valid surrogate for total PA and does not depend on equations that can be inaccurate for estimation of energy expenditure in COPD [14–16]. There is no gold standard for monitoring step counts in the community; it is not feasible to continuously manually count or videotape steps while participants go about their daily activities. It was reasonable to use the highly accurate SAM to capture all steps in the community. Finally, our study was composed predominantly of male Veterans. Nevertheless, our results provide the rationale to study the use of pedometers in both men and women with COPD.

CONCLUSIONS

The Omron accurately measures continuous walking in the majority of persons with COPD. Only 47 percent of steps taken by persons with COPD in the community are continuous ones that are detected by the Omron. The Omron is user-friendly, able to detect the lower step counts observed on weekend days versus weekdays, and reliable. At least 7 d of monitoring should be used to cap-

ture decreases in PA on weekend days and obtain optimum reliability for all GOLD stages under study. The Omron may be ideal for use in PA interventions that promote continuous walking as exercise.

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Participant Follow-Up: The authors plan to notify the study subjects of the publication of this article via a COPD newsletter distributed annually.

Disclaimer: This study was initiated by the investigators. The results of the present study do not constitute endorsement of the Omron or SAM by the authors. Omron Healthcare and Orthocare Innovations had no involvement in the study design; the collection, analysis, and interpretation of data; the writing of the report; or the decision to submit the manuscript for publication.

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