Daily step counts in a US cohort with COPD

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KEYWORDS
Accelerometer; Exercise; Outcomes; Pulmonary disease

Summary
Background: Baseline values for daily step counts in US adults with COPD and knowledge of its accurate measurement, natural change over time, and independent relationships with measures of COPD severity are limited.
Methods: 127 persons with stable COPD wore the StepWatch Activity Monitor (SAM) for 14 days, and 102 of them wore it a median 3.9 months later. SAM counts were compared to manual counts in the clinic. We assessed change over time, the effect of season, and relationships with forced expiratory volume in 1 s (FEV1) % predicted, 6-min walk test (6MWT) distance, the modified Medical Research Council (MMRC) dyspnea score, and the St. George’s Respiratory Questionnaire Total Score (SGRQ-TS).
Results: 98% of subjects were males, with mean age 71.78 years and FEV1 1.48 ± 0.54 L (52±19% predicted). All 4 GOLD stages were represented, with the most subjects in GOLD II (44%) and GOLD III (37%). The SAM had >90% accuracy in 99% of subjects. Average step count was 5680 steps/day, which decreased with increasing GOLD stage (p = 0.0046). Subjects walked 645 fewer steps/day at follow-up, which was partly explained by season of monitoring (p = 0.013). In a multivariate model, FEV1 % predicted, 6MWT distance and MMRC score were weakly associated with daily step counts, while SGRQ-TS was not.
Conclusions: These findings will aid the design of future studies using daily step counts in COPD. Accurately measured, daily step counts decline over time partly due to season and capture unique information about COPD status.
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Introduction

COPD is the fourth most common cause of death in the US, affects 5% of US adults, and accounts for a large number of hospitalizations and unscheduled physician visits. A growing body of knowledge has identified physical activity as a modifiable factor that may impact morbidity and mortality in COPD. Higher levels of physical activity are associated with better functional status, fewer hospital admissions, and lower mortality.8,9

Walking is a form of physical activity that most people can do; it is generally a safe, convenient, and inexpensive way to increase physical activity. Steps per day is a simple metric for assessment of physical activity that is meaningful to persons trying to increase their activity.2 Many studies have examined steps per day in healthy older adults, but limited data exist for special populations such as those with chronic illness. In COPD, a higher daily step count, when directly measured, has been associated with lower mortality in COPD, independent of pulmonary function. Interventions to increase daily step counts in persons with COPD are under development, and one clinical trial studying a long-acting bronchodilator in COPD will use daily step counts as an outcome measure.10

Although directly measured step count is an emerging measure of health status and a target for intervention in COPD, several methodological issues remain. First, in US adults with COPD, baseline values for daily step counts are limited to a few studies with a small number of participants, with no reported values by GOLD stage.5,9 To date, daily step counts have been reported in 10 persons with COPD in Boston, MA,7 17 persons in Seattle, WA,18 and 21 persons in Pittsburgh, PA.11 Second, accurate measurement of daily step counts in persons with COPD has not been achieved.12 The majority of published reports on daily step counts have used the SenseWear armband (SenseWear, BodyMedia, Pittsburgh, USA) activity monitor, which significantly underestimates step counts when compared directly with manual step counts.16 Third, the magnitude of the variability in step count over time and the impact of season on change in daily step counts in persons with COPD are unclear. To date, change in physical activity over time has been studied in COPD only in the setting of an intervention, such as pulmonary rehabilitation.17–19 Finally, the independent relationships between daily step count and commonly used clinical measures of COPD severity, namely, forced expiratory volume in 1 s (FEV1) % predicted, 6-min walk test (6MWT) distance, dyspnea, and health-related quality of life (HRQL) are unknown. Previous studies used simple correlations to examine these relationships.10,11,14,15,20

In this report, we address previous limitations by (1) accurately characterizing daily step counts in a US cohort of persons representing all GOLD stages, (2) quantifying the variability in step count over time and season, and (3) assessing the independent relationships between daily step count and FEV1 % predicted, 6MWT distance, dyspnea, and HRQL.

Methods

Study population

From January 2009 through February 2011, we studied 134 persons with stable COPD defined as age over 40 years, FEV1/forced vital capacity (FVC) < 0.70 or evidence of emphysema on chest computed tomography, and a smoking history of >10 pack years from the pulmonary clinic at VA Boston Healthcare System. Subjects were excluded if they were unable to ambulate. All subjects participated when at least 4 weeks had elapsed since the most recent COPD exacerbation. The protocol was approved by the Committee on Human Research and informed consent was obtained from each subject.

Clinical assessments

At the initial study visit, we assessed demographics, smoking history, current oxygen use, prednisone use in the previous year, and prior participation in pulmonary rehabilitation. Medical records were reviewed for comorbidities. At initial and follow-up study visits, spirometry, measured with an Eaglet spirometer (nSpire Health, Inc.), and the 6MWT were performed following ATS guidelines.21,22 COPD severity was categorized by GOLD stage.9 Dyspnea at rest was assessed using the modified Medical Research Council (MMRC) scale (responses 0–4 with 4 being the most dyspneic). Subjects completed the St. George’s Respiratory Questionnaire (SGRQ),24 with lower SGRQ Total Score (SGRQ-TS) indicating better HRQL.

Step count assessments

We used the StepWatch Activity Monitor (SAM) (Orthocare Innovations, Seattle, WA, USA), a lightweight (38 g) ankle-worn accelerometer that accurately detects steps in subjects with a range of physical activity levels and mobility limitations.25 At the initial study visit, we assessed the accuracy of the SAM by manually counting steps while participants walked a predetermined level course of 244 m at their usual speed.12 Bland Altman plot compared SAM counts to manual counts in the clinic.26 We defined acceptable device accuracy as capturing >90% of manual counts and excluded subjects from analyses if SAM accuracy was <90%.12

Daily step counts in the field were assessed at 2 time points, a median of 3.9 months apart. Subjects collected baseline step counts by wearing the SAM during waking hours for a 14-day monitoring period, excluding periods of bathing or other water activities. They were instructed to perform their usual physical activities. We repeated clinical assessments at the follow-up study visit and collected follow-up step counts by having subjects wear the SAM for an additional 14 days.

We defined no-use days as ones on which <200 steps were recorded and excluded them from analyses.7 The season during which most of the step count monitoring occurred was recorded. The months of December, January, February were defined as winter; March, April, May as spring; June, July, August as summer; and September, October, November as fall.19 We characterized the variability in baseline daily step counts with the intra-subject and inter-subject coefficients of variation (CV).27 The CV, a dimensionless number, is the ratio of the standard deviation to the mean. The inter-subject CV reflects true differences between participants and the intra-subject CVs.
reflect day-to-day variations within each participant. Within subject variability of daily step counts over the baseline 14-day monitoring period was also described by the range (difference between the highest and lowest daily step counts) and peak daily step count (highest daily step count).

Statistical analysis

Of the 134 participants, there were 7 who did not complete the initial clinic visit or baseline step count assessment as one could not perform spirometry, one had SAM accuracy <90%, three were unable to complete step count monitoring during an exacerbation-free period, and two lost the SAM. Among the 127 participants who completed the baseline step count assessment, 19 did not return for the follow-up clinic visit. Two died, nine did not return due to medical reasons, six did not return due to non-medical reasons, and two were deemed by study staff unable to complete another visit. Of the 108 subjects who returned for follow-up, three were unable to complete follow-up step count assessment during an exacerbation-free period, two lost the SAM, and one wore the SAM upside down resulting in no recorded step counts. Therefore, data from 127 participants at baseline and 102 participants at follow-up were analyzed.

Analyses were performed with the SAS statistical software package (9.2, SAS Institute; Cary, NC). Fisher’s Exact Test for categorical variables and ANOVA (PROC GLM) for continuous variables determined if characteristics differed across GOLD stages. Average daily step count was used in the analyses. T-tests assessed change in daily step count at follow-up compared to baseline. The effect of season on the change in daily step count, adjusting for baseline daily step count, was examined (PROC GLM). The relationship between daily step count and FEV1 % predicted, 6MWT distance, MMRC dyspnea score, and SGRQ-TS were examined individually in univariate models and together in a multivariate model (PROC REG and PROC GLM).

Results

Subject characteristics

Ninety-eight percent of subjects were males, with mean age 71 ± 8 years and FEV1 1.48 ± 0.54 L (52 ± 19% predicted). All 4 GOLD stages were represented, with the most subjects in GOLD II (44%) and GOLD III (37%). With increasing GOLD stage, there was a significant trend for more subjects to report regular use of oxygen, use of prednisone in the previous year, increasing dyspnea, and worse SGRQ-TS (Table 1). Of 1778 total monitored days at baseline and 1428 days at follow-up, 93 (5%) and 48 (3%), respectively, met the definition of a no-use day.

SAM accuracy and daily step counts

In 133 of the 134 subjects (99%) who completed the initial clinic visit, the SAM registered > 90% of the manual step counts walked on the 244-m course. Bland Altman plot of these data obtained in the clinic showed that the SAM, on average, over counted by 3 steps compared to manual counts (Fig. 1). From the baseline step count assessments in the field, average daily step count was 5680, with significant trends toward lower daily step counts with increasing GOLD stage, p = 0.0046 (Table 2). Subjects in GOLD IV had an average daily step count of 3707 versus 6600 in subjects in GOLD II.

Baseline variability and short-term change in daily step counts

117 of 127 subjects (92%) who completed the baseline step count assessment had an intra-subject CV that was less than the inter-subject CV of 55. There was also less within subject variability in daily step counts, as described by the range and peak, with increasing GOLD stage (Table 2). The median time between the initial and follow-up clinic visits was 3.9 months (range 3.5–8.7 months). There were no differences in baseline average daily step count, FEV1 % predicted, 6MWT distance, MMRC dyspnea score, or SGRQ-TS among the 25 subjects who did not return for follow-up compared to the 102 who returned. For the 102 participants analyzed at follow-up, there were no significant changes in FEV1 % predicted, 6MWT distance, MMRC dyspnea score, or SGRQ-TS compared to baseline (Table 3). Daily step count was significantly lower at follow-up, with a mean 645 fewer steps taken per day compared to baseline. The range and peak steps per day were also significantly lower at follow-up by 713 and 1096 steps, respectively, compared to baseline.

Effect of season on change in daily step counts

At baseline, 14 subjects (11%) had step count monitoring in the winter, 37 (29%) in the spring, 37 (29%) in the summer, and 39 (31%) in the fall. Average daily step counts were 6004 (winter), 5128 (spring), 5808 (summer), and 5967 (fall). At follow-up, 35 subjects (34%) had step count monitoring in the winter, 17 (17%) in the spring, 27 (26%) in the summer, and 23 (23%) in the fall. Average daily step counts were 5632 (winter), 4970 (spring), 5188 (summer), and 4872 (fall). Although there were no significant differences in daily step counts by season at baseline or at follow-up, there was a significant linear trend in the magnitude of change in step count according to the season of baseline step count monitoring, after controlling for baseline step count (p = 0.013). Those who had their baseline visit in the winter and follow-up predominantly in the spring experienced an average increase of 153 steps per day, baseline visit in the spring and follow-up predominantly in the summer had a decline of 365 steps per day, baseline visit in the summer and follow-up predominantly in the fall had a decline of 770 steps per day, and baseline visit in the fall and follow-up predominantly in the winter had a decline of 972 steps per day.

Relationship of step counts with measures of COPD severity

In univariate models, a higher daily step count was significantly associated with a higher FEV1 % predicted, higher
Although statistically significant, FEV$_1$ % predicted ($R^2 = 0.078$) and SGRQ-TS ($R^2 = 0.078$) explained little of the variance in step count. Although 6MWT distance, a measure of functional capacity like daily step count, explained more of the variance ($R^2 = 0.32$), there was a wide range of daily step counts for a given 6MWT distance (Fig. 2). In a multivariate model, FEV$_1$ % predicted, 6MWT distance and MMRC score were significantly associated with daily step counts, but SGRQ-TS was not (Table 4).

Discussion

Using a monitoring device whose accuracy was verified, our study provides baseline values for daily step counts from a cohort of US persons representing all GOLD stages. We
show that short-term variability in daily step counts was influenced by change in season. In a multivariate model, FEV1 % predicted, 6MWT distance and MMRC score were weakly associated with daily step counts, while SGRQ-TS was not.

We previously reported that low walking speed and presence of lower-limb problems predict low device accuracy and recommended that accuracy of devices be confirmed in the COPD population under study. Other studies have not uniformly confirmed the accuracy of monitoring devices. To date, step counts in COPD have been predominantly measured with the SenseWear armband, which undercounted by an average of 486 steps when compared directly to manual counts when persons with COPD walked a 30-m corridor. In contrast, we demonstrate that step counts can be accurately measured with the SAM, which over counted by only 3 steps. We also propose that since walking is a common physical activity and steps per day is a simple metric that is relevant to persons with COPD, steps per day should be the focus of physical activity studies in COPD. Previously, devices have reported activity units which are difficult to understand and do not allow comparison between studies. The RT3 accelerometer detects physical activity movements reported in vector magnitude units (VMUs), the Dynaport activity monitor reports time spent in walking, cycling, standing, sitting, or lying, and the SenseWear armband reports total daily energy expenditure which is then converted to a "physical activity level".

We demonstrate that our cohort with COPD walks significantly less than 7000–10,000 steps per day, which is equivalent to the minimum exercise recommendation of 30 min per day of moderate-vigorous physical activity. In addition, our results suggest that the distribution of daily step counts among persons with mild to moderate COPD is more heterogeneous compared to those with severe COPD. Similarly, Watz et al. studied a cohort in Germany and reported that variability in physical activity is higher in less severe COPD. These findings may have implications for strategies to increase daily step counts in persons with COPD. The lack of variability in daily step counts among persons with severe COPD suggests they are limited by their disease and are unable to walk more even if they wanted to. Treatment of their disease and symptoms are needed, in addition to behavioral modifications, to further increase their walking. In contrast, the variability seen in daily step counts among persons with mild to moderate COPD suggests they are capable of walking more and behavioral strategies can be employed to maintain high levels of walking every day.

In the absence of intervention, we found a decline in step counts of 645 steps per day on average over the short-term that was partly explained by season. This change was observed in stable COPD with no change in FEV1 % predicted, 6MWT distance, MMRC dyspnea score, and SGRQ-TS at follow-up compared to baseline. Changes in physical activity over time have been previously studied in the setting of an intervention. A study examining the effects of pulmonary rehabilitation showed no change in VMUs, and a study looking at the effects of a long-acting bronchodilator showed no change in energy expenditure. Sewell et al. previously showed that patients who started a pulmonary rehabilitation program in the winter had greater improvements in physical activity compared to those who started the program in the summer. Our results provide further evidence that studies of directly measured step counts should account for expected variability and for changes in season. Our results provide estimates for change in step count stratified by season of baseline visit. Future intervention studies would have control arms that can assess seasonal changes in step counts specific to each study.

We considered that the decrease in step count at follow-up compared to baseline could be due to lower compliance with wearing the SAM. We conducted a sensitivity analysis of our compliance measure using the SAM software which displays step counts by hour of day. We defined noncompliance as a day when there were <200 steps per day AND

![Figure 1](image-url) Bland–Altman plot of SAM and manual counts, n = 127. Mean difference is 3.29 with SD of 8.58. Lower 95% confidence limit is –13.53 and upper 95% confidence limit is 20.11.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Baseline step count characteristics (mean [standard deviation]). P values for ANOVA.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
</tbody>
</table>
<8 h of wear time. For the 102 subjects, there were no differences at baseline and follow-up in the number of noncompliant days. Out of 1428 days of monitoring, the total number of noncompliant days at baseline was 51 (3.6%) compared to 48 (3.4%) at follow-up. 76% of subjects at baseline had no noncompliant days compared to 74% at follow-up. Therefore, it is highly unlikely that the decline in daily step counts at the second measurement time was due to lower compliance with wearing the SAM.

Our results provide additional evidence that daily step counts capture information not assessed by current markers of COPD severity such as FEV1 % predicted, 6MWT distance, dyspnea, and HRQL. Previous studies have found similar weak to moderate relationships between walking time, physical activity level, or daily step counts with FEV1 % predicted, 6MWT distance, and HRQL.6,10,11,14,15,20,30 Correlation coefficients (Pearson r values) between total steps and HRQL domains have ranged from 0.07 to 0.49.11 Waschki et al. showed correlation coefficients between physical activity level and FEV1 % predicted and 6MWD to be 0.40 and 0.45, respectively.6 Watz et al. showed correlation coefficients between steps per day and FEV1 % predicted and 6MWD to be 0.46 and 0.63, respectively.14 We hypothesized that daily step counts and HRQL would be highly associated since they reflect both the physiological and psychosocial status of patients. However, using a multivariate model, we show that after adjusting for FEV1 % predicted, 6MWT distance, and MMRC score, daily step counts and HRQL are not related. These results suggest that daily step counts and HRQL evaluate unique constructs related to health status in COPD.

Several limitations deserve discussion. It has been proposed that at least 2 weeks of monitoring is needed to capture the daily and weekly variations of physical activities.25 The intra-class correlation coefficient (ICC), the proportion of total variance accounted for by inter-subject sources, reflects the reliability of measurements over multiple days.27 An ICC ≥ 0.8 is the generally accepted value in accelerometer studies.27 We calculated a very high ICC of 0.96 using 14 days of monitoring, and acknowledge that 14 days may not be feasible for all studies. Since intra-subject variation is less than inter-subject variation, our results indicate that true differences in daily step counts between individuals can be detected. Our cohort is a convenience sample of predominantly men representing a single center in the New England region of the US. The results presented may not be generalizable to women or persons with COPD in other regions of the US. There may also have been selection bias of subjects who are less sick and interested in a research study.

We did not include a control group as our primary aim was not to compare walking in COPD to a healthy elderly cohort. Nevertheless, the decrease in average daily step counts with increasing GOLD stage supports a relationship with COPD and suggests that our observations are related to COPD and not to "normal" sedentary behavior in the Boston area. Furthermore, the similarity between our average daily step count of 5680 and those from smaller samples of

### Table 3
Clinical and step count characteristics at baseline and follow-up (N = 102) (mean [standard deviation]).

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Follow-up</th>
<th>P value for paired t-test for difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV1 % predicted</td>
<td>51.3 [18.1]</td>
<td>52.4 [20.6]</td>
<td>0.23</td>
</tr>
<tr>
<td>6MWT distance (meters)</td>
<td>369 [104]</td>
<td>366 [108]</td>
<td>0.60</td>
</tr>
<tr>
<td>MMRC score</td>
<td>2.21 [1.19]</td>
<td>2.18 [1.37]</td>
<td>0.78</td>
</tr>
<tr>
<td>SGRQ total score</td>
<td>46 [19]</td>
<td>44 [17]</td>
<td>0.053</td>
</tr>
<tr>
<td>Average daily step</td>
<td>5878 [3267]</td>
<td>5233 [2822]</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>count (steps/day)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD of daily step count</td>
<td>1958 [1147]</td>
<td>1705 [1017]</td>
<td>0.0035</td>
</tr>
<tr>
<td>Range of daily count</td>
<td>6526 [3651]</td>
<td>5813 [3315]</td>
<td>0.0072</td>
</tr>
<tr>
<td>Peak daily step count</td>
<td>9379 [4961]</td>
<td>8283 [4331]</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

a N = 101.

### Table 4
Relationship between average daily step count and measures of COPD severity.

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted β estimate</th>
<th>95% CI</th>
<th>P value</th>
<th>Model R²</th>
<th>Adjusted β estimate</th>
<th>95% CI</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEV1 % predicted</td>
<td>45</td>
<td>17; 73</td>
<td>0.0015</td>
<td>0.078</td>
<td>29</td>
<td>6; 53</td>
<td>0.016</td>
</tr>
<tr>
<td>6 MW distance</td>
<td>17</td>
<td>13; 22</td>
<td>&lt;0.0001</td>
<td>0.32</td>
<td>13</td>
<td>8; 18</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>MMRC score (ref = 0 or 1)</td>
<td>-2719</td>
<td>-3757; -1681</td>
<td>&lt;0.0001</td>
<td>0.18</td>
<td>-1358</td>
<td>-2474; -241</td>
<td>0.018</td>
</tr>
<tr>
<td>SGRQ total score</td>
<td>-45</td>
<td>-73; -18</td>
<td>0.0016</td>
<td>0.078</td>
<td>3</td>
<td>-24; 31</td>
<td>0.80</td>
</tr>
</tbody>
</table>

a N = 125.
b Four univariate models with average daily step count as dependent variable and each outcome measure as independent variable.
c One multivariate model with average daily step count as dependent variable and all 4 outcome measures as independent variables. Model R² = 0.38.
US persons with COPD is striking. Daily step counts in healthy older adults has also been shown to be much greater than those in persons with COPD and what we observed in our COPD cohort. For examples, healthy older adults in Seattle, WA walked an average of 11,266 steps per day compared to 5646 steps per day in COPD, and healthy controls in Belgium walked 9372 steps per day compared to 5115 steps per day in 21 persons with COPD in Pittsburgh. Finally, our study is observational, while prospective and intervention studies are needed to confirm relationships between steps per day and health outcomes.

In conclusion, accurately measured, average daily step count was 5680 and decreased with increasing GOLD stage in a cohort of US persons with COPD. Daily step counts decline over the short-term partly due to season, and capture information not assessed by current measures of COPD severity. These findings can aid the design, analysis, and interpretation of studies of daily step counts in COPD.

**Contributorship**

Marilyn Moy has contributed substantially to the study design, data analysis and interpretation, and the writing of this manuscript. Dr. Moy has full access to the data and will vouch to the integrity of the work as a whole, from inception to published article.

Valery Danilack has contributed substantially to the data analysis and interpretation, and the writing of this manuscript.

Nicole Weston has contributed substantially to the acquisition of data and the writing of this manuscript.

Eric Garshick has contributed substantially to the study design, data interpretation, and the writing of this manuscript.

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This study was initiated by the investigators. The results of the present study do not constitute endorsement of the StepWatch Activity Monitor by the authors. Orthocare Innovations had no involvement in the study design, the collection, analysis, and interpretation of data, in the writing of the manuscript, or in the decision to submit the paper for publication.

**Conflict of interest statement**

None declared.

**References**


