



OPEN Association of impaired pulmonary function and objectively measured physical activity in a population study

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Due to modern lifestyles, physical activity (PA) has decreased at a population level, resulting in health concerns worldwide. Increased level of PA can reduce mortality and morbidity in pulmonary diseases, such as asthma and chronic obstructive pulmonary disease (COPD). Many previous studies on the association between pulmonary function and PA assessed PA by questionnaires. We aimed to study the cross-sectional association between pulmonary function and objectively measured PA and sedentary behavior (SB) in population-based data. A total of 4729 subjects participated in the Health 2011 survey, which represents the Finnish adult population. Of these, 1511 completed spirometry and the required 4-day accelerometer wear time. Spirometry values of forced expiratory volume in 1s (FEV₁) and forced vital capacity (FVC) were determined. We compared the differences in daily PA measured with triaxial accelerometer between those with obstructive or restrictive spirometry results (defined as FEV₁/FVC < -1.65 z-score, lower limit of normal [LLN] and FVC < -1.65 z-score, respectively) and those with FEV₁ < -1.65 z-score to those with normal spirometry in adjusted logistic regression analysis. Airway obstruction, pulmonary restriction, and FEV₁ < LLN were associated with less time spent in moderate (adjusted odds ratio [OR] 0.63, 95% confidence interval [CI] 0.40–0.99; OR 0.65, 95% CI 0.43–1.00; OR 0.58, 95% CI 0.39–0.87, respectively) and moderate-to-vigorous level of PA (OR 0.65, 95% CI 0.43–0.98; OR 0.63, 95% CI 0.42–0.94; OR 0.56, 95% CI 0.38–0.82, respectively). Those with restrictive spirometry had greater time spent sedentary and a lower daily step count when compared to those with normal spirometry. Respective ORs with 95% CIs were 1.09 (1.01–1.19) and 0.85 (0.75–0.96). Our results show the association between impaired pulmonary function and measured lower level of daily PA. Restriction associated with greater time spent sedentary and a lower daily step count when compared with those with normal spirometry, airway obstruction, and FEV₁ < LLN.

Keywords Physical activity, Pulmonary function, Impaired spirometry, Accelerometer, Population study

Abbreviations

BMI	Body mass index
CI	Confidence interval
COPD	Chronic obstructive pulmonary disease
DALY	Disability-adjusted life-year
FEV ₁	Forced expiratory volume in one second
FVC	Forced vital capacity
LLN	Lower limit of normal
MAD	Mean amplitude deviation
MET	Metabolic equivalent

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mMRC	Modified Medical Research Council
MVPA	Moderate-to-vigorous physical activity
OR	Odds ratio
SB	Sedentary behavior
SD	Standard deviation
PA	Physical activity
VO ₂	Oxygen consumption

Chronic obstructive pulmonary disease (COPD) and asthma are both global public health problems and central causes of morbidity, mortality, and healthcare expenses. In 2017, COPD accounted for 1068/100 000 disability-adjusted life-years (DALYs); the corresponding value for asthma was 298/100 000^{1–3}. COPD originates from exposure to tobacco smoke or pollution. No such exposure is necessarily observed in asthma, excluding allergens^{4,4}. The most important comorbidities in COPD include cardiovascular diseases and metabolic syndrome; in asthma these are allergic rhinitis and obesity. COPD tends to be more prevalent in older individuals, while asthma is common across all age groups³. Causes for pulmonary restriction include diseases such as pulmonary fibrosis, chest-wall disorders, and obesity, with varying prevalence and clinical symptoms. Generally, a restrictive spirometry pattern is associated with several comorbidities, such as diabetes and metabolic syndrome^{5,6}.

Modern lifestyles have resulted in low volume of physical activity (PA), which is a major health risk worldwide and in Finland⁷. In Finland, the general children and adult population tends to be sedentary during most waking hours, and only proportion fulfills the recommendations of weekly PA^{8–10}. Physical inactivity results in an elevated risk of non-communicable diseases, increasing morbidity, work disability, premature retirement, and mortality^{11,12}.

As smoking cessation and avoiding overweight are crucial in preserving long-lasting pulmonary health, PA seems to be vital in decreasing mortality and morbidity in pulmonary diseases^{13–15}. In COPD, daily PA reduces hospital visits and decreases mortality^{6,14,16,17}. People with asthma seem to benefit from daily PA also in the long term, as PA is associated with slower rate of deterioration of pulmonary function^{18,19}. The association of a restrictive spirometry pattern and self-reported PA has been recognized previously in population-based studies^{20,21}. During the last decades, planned, systematic, pulmonary rehabilitation has become a central tool in the management of COPD and other pulmonary diseases^{22,23}.

Many previous studies analyzing the association of PA and pulmonary function have concerned small or specific populations^{16,24–28}. Most of the larger studies investigating these associations at the population level assessed PA by questionnaires and revealed an association between self-reported PA and pulmonary function^{29–34}. However, self-reported PA tends to be inaccurate and the participants overestimate their PA level and underestimate time spent sedentary^{35,36}. Only a few studies have investigated objectively measured, daily PA and pulmonary function in population-based sample of adults and the results claim for confirmation^{24,37,38}.

Our aim was to study the association of impaired pulmonary function and objectively measured PA and sedentary behavior (SB) in a sample representing Finnish adult population.

Methods

Participants

The Finnish Institute for Health and Welfare coordinated a large health examination survey representing the Finnish adult population in 2000 (Health 2000)³⁹. In 2011, those invited in the original Health 2000 survey and living in Finland were invited to a follow-up survey, Health 2011⁴⁰. This study considers those aged > 30 years ($n = 7964$) from the Health 2011 sample. Of these, 59% ($n = 4729$) participated in the Health 2011 survey (Fig. 1).

A Physical Activity and Fitness sub-study (PA sub-study) was managed in 2011 together with the UKK Institute for Health Promotion Research (UKK institute)⁴⁰. Of the 4821 (59% of the invitees in Health 2011) participants invited, 2455 (51%) attended the PA sub-study. The participants of the PA sub-study participated in tests and interviews to study physical ability and habits of PA and exercise, such as measurement of PA and SB by accelerometry.

This study included the 1511 individuals who wore the accelerometer for at least 4 consecutive days in the PA sub-study and completed spirometry.

The Health 2011 Survey was approved by the Coordinating Ethics Committee of the Hospital District of Helsinki and Uusimaa. All participants provided written informed consent. All research was performed in accordance with relevant guidelines and regulations.

Measurements

Questionnaires and interviews

Information on age and sex were collected from the population register. Age was considered as a continuous factor. Categories of 30–44 years, 45–64 years, and ≥ 65 years are also shown in (Table 1).

Smoking history was gathered in the questionnaire and the following three categories were defined: never smokers, current smokers, and former smokers (who had continuously smoked more than 1 year and quit at least 1 month before the survey). No pack years were defined.

Education level was defined according to the questionnaire as lower level (< 9 years), medium level (9–12 years), and higher level (> 12 years). The Modified Medical Research Council (mMRC) scale points were determined by the questions considering breathlessness in the questionnaire. Information on asthma, COPD, and comorbidities (acute myocardial infarction, angina pectoris, heart failure, other heart disease, stroke, rheumatoid arthritis, arthrosis, diabetes, and cancer) were collected by asking the participants if a physician had ever diagnosed them with each of the diseases and then categorized as having a disease or not.

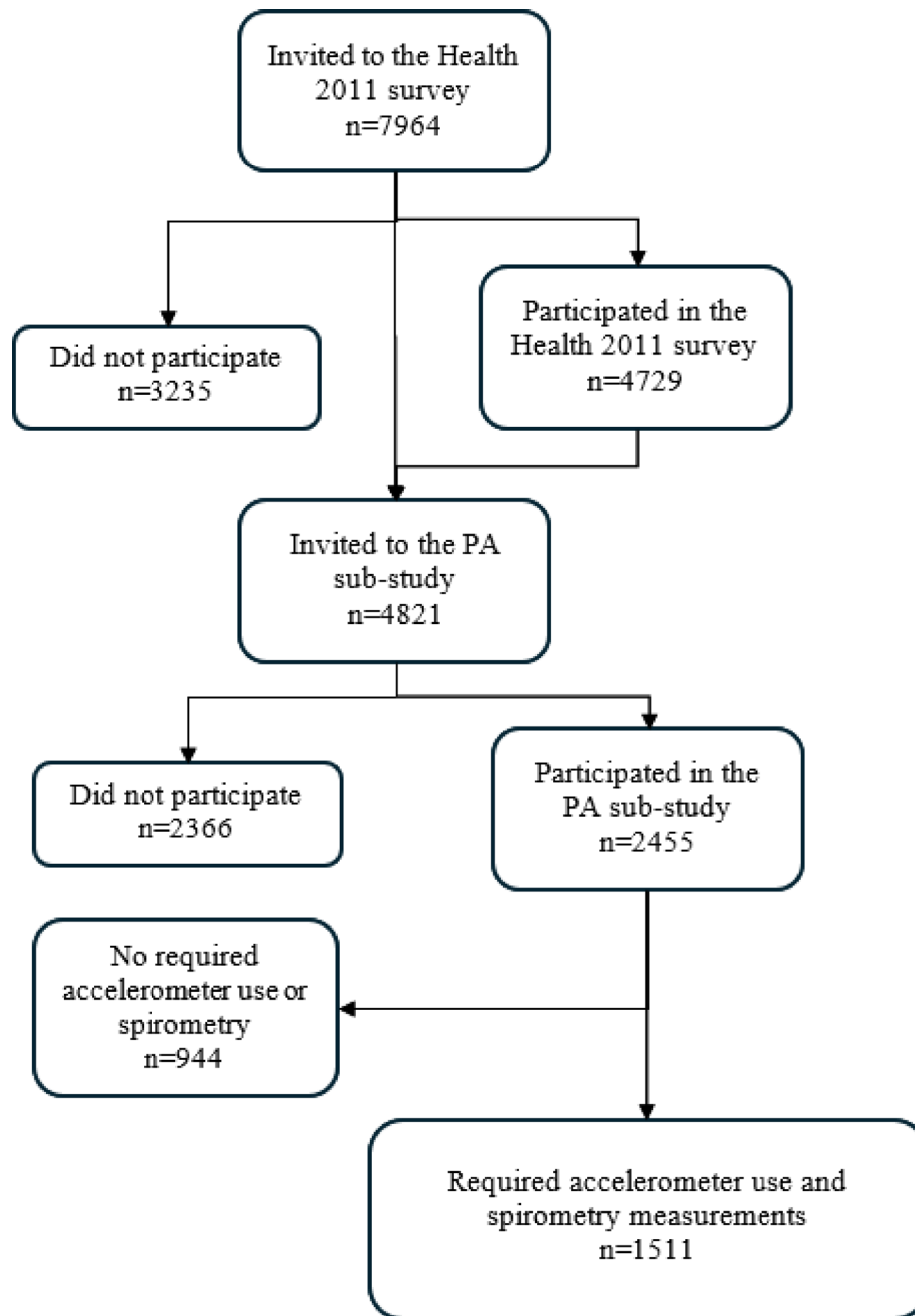


Fig. 1. Flow chart of the participants. *PA* physical activity.

Anthropometric measurements

Height and weight were measured and body mass index (BMI, kg/m^2) was determined accordingly. BMI was considered as a continuous factor in the analyses. BMI was also categorized as follows: $<25 \text{ kg}/\text{m}^2$ (normal weight or under), $25\text{--}29.9 \text{ kg}/\text{m}^2$ (overweight), and $\geq 30 \text{ kg}/\text{m}^2$ (obese) (Table 1).

Spirometry

Medikro SpiroStar flow-volume spirometer and Medikro Spiro2000 software were applied for spirometry measurements in the Health 2011 Survey. The participants completed spirometry after careful instruction by nurses or laboratory technicians. At least two efforts were made to obtain as consistent curves as possible. The best results were recorded. The equipment was checked daily before measurements and spirometers were calibrated regularly⁴⁰. Results of forced expiratory volume in 1 s (FEV_1), forced vital capacity (FVC), and FEV_1/FVC were included in the survey. A bronchodilatation test was applied only if FEV_1/FVC was $<70\%$. In this study, we used LLN values of pulmonary function to determine impaired spirometry, and therefore only pre-bronchodilatation values were applied^{40,41}.

		All ¹	Normal lung function ²	Airway obstruction ³	Pulmonary restriction ³	FEV ₁ < LLN ³
n		1511	1354	66	73	94
Age, n (%)	30–44	379 (29.7)	347 (30.3)	15 (27.8)	14 (21.9)	13 (16.7)
	45–65	538 (42.1)	477 (41.7)	20 (37.0)	32 (50.0)	37 (47.4)
	65+	360 (28.2)	320 (28.0)	19 (35.2)	18 (28.1)	28 (35.9)
Women/men, n (%)		856/655 (56.7/43.3)	774/580 (57.2/42.8)	33/33 (50/50)	32/41 (43.8/56.2)	47/47 (50/50)
BMI (kg/m ²), mean (SD)		26.7 (4.6)	26.7 (4.5)	25.1 (3.8)	28.9 (5.5)	27.7 (4.9)
BMI	<25	598 (39.6)	537 (39.7)	37 (56.1)	15 (20.5)	32 (34.0)
	25–29.9	595 (39.5)	540 (39.9)	23 (34.8)	32 (43.8)	33 (35.1)
	≥30	317 (21.0)	276 (20.4)	6 (9.1)	26 (35.6)	29 (30.9)
Smoking, n (%)	Never	873 (58.4)	807 (60.1)	27 (42.2)	31 (43.7)	40 (43.0)
	Former	395 (26.1)	347 (25.9)	19 (29.7)	24 (33.8)	26 (28.0)
	Current	277 (15.0)	188 (14.0)	18 (28.1)	16 (22.5)	27 (29.0)
Education, n (%)	Lower	136 (9.1)	121 (9.0)	5 (7.7)	6 (8.5)	11 (11.8)
	Medium	945 (62.9)	844 (62.6)	41 (63.1)	49 (69.0)	63 (67.7)
	Higher	421 (28.0)	383 (28.4)	19 (29.2)	16 (22.5)	19 (20.4)
FEV ₁ mean, L (SD)		3.09 (0.87)	3.17 (0.85)	2.45 (0.78)	2.20 (0.65)	2.10 (0.59)
FVC mean, L (SD)		3.95 (1.07)	4.03 (1.05)	3.90 (1.14)	2.77 (0.73)	3.01 (0.84)
Asthma ⁴		141 (9.4)	105 (7.8)	21 (32.3)	9 (12.7)	25 (26.9)
COPD ⁴		13 (0.9)	4 (0.3)	6 (9.2)	2 (2.8)	7 (7.5)
Chronic bronchitis ⁴		23 (1.5)	18 (1.3)	3 (4.6)	2 (2.8)	4 (4.3)
Other pulmonary disease ⁴		63 (4.3)	48 (3.6)	7 (10.9)	7 (10.1)	11 (12.1)
AMI ⁴		25 (1.7)	21 (1.6)	2 (3.1)	2 (2.8)	3 (3.2)
Angina pectoris ⁴		60 (4.0)	51 (3.8)	4 (6.2)	5 (7.0)	6 (6.5)
Heart failure ⁴		24 (1.6)	16 (1.2)	4 (6.2)	5 (7.1)	5 (5.4)
Other heart disease ⁴		141 (9.5)	123 (9.3)	4 (6.3)	11 (15.9)	13 (14.3)
Stroke ⁴		25 (1.7)	18 (1.3)	1 (1.5)	4 (5.6)	6 (6.5)
Rheumatoid arthritis ⁴		34 (2.3)	30 (2.2)	2 (3.1)	2 (2.8)	2 (2.2)
Arthritis ⁴		376 (25.1)	336 (25.0)	15 (23.1)	21 (29.6)	23 (24.7)
Diabetes ⁴		95 (6.3)	78 (5.8)	2 (3.1)	14 (19.7)	12 (12.9)
mMRCscale, mean (SD)		0.48 (0.75)	0.45 (0.72)	0.65 (0.85)	0.87 (0.94)	0.90 (1.02)

Table 1. Participant characteristics. *BMI* body mass index, *FEV₁* forced expiratory volume in one second, *FVC* forced vital capacity, *COPD* chronic obstructive pulmonary disease, *AMI* acute myocardial infarction, *mMRC* scale modified Medical Research Council. ¹All participants who completed required accelerometer use and spirometry. ²Those who had FEV₁, FVC and FEV₁/FVC > -1.65 (LLN). ³Groups were not exclusive of each other. ⁴Self-reported diseases, n (%).

Reduced FEV₁/FVC represents airway obstruction and was categorized by the lower limit of normal (LLN) and $z < -1.65$ defining airway obstruction (FEV₁/FVC < LLN). The individual results were calculated according to the GLI (Global Lung Function Initiative) reference values⁴². Reduced FVC represents pulmonary restriction and was categorized by the LLN and $z < -1.65$, referred hereafter as pulmonary restriction (FVC < LLN). FEV₁ was categorized by the LLN ($z < -1.65$) and is referred to as FEV₁ < LLN.

Physical activity – triaxial accelerometer

A total of 1511 participants of the PA sub-study agreed to wear a tri-axial accelerometer (Hookie AM 20, Hookie Technologies Ltd, Espoo, Finland) over 7 consecutive days⁴⁰. The accelerometer was attached with an elastic belt on the right side of the hip. Participants were instructed to wear the accelerometer all waking hours except when swimming, showering, or bathing. After the 7-day study period, the accelerometer along with the diary was sent to the UKK Institute for analysis.

In this study, we included those 1511 participants who wore the accelerometer at least 10 h a day in 4 days during the 7-day measurement period, which was defined as required accelerometer use. Earlier studies used the same criterion for accelerometer wear time^{43,44}.

The volume of PA and SB were analyzed with validated algorithms. The mean amplitude deviation (MAD) is an analysis algorithm to classify the intensity of PA from accelerometer raw data. MAD is calculated from the resultant value of the tri-axial acceleration signal and concerns velocity and gravity components of the acceleration. MAD was analyzed in 6-s epoch length. MAD is validated to represent oxygen consumption (VO₂) accurately, and therefore precisely indicates the intensity of PA^{45,46}.

As MAD values correlate with VO₂, we were able to convert the accelerometer data to metabolic equivalents (MET). One MET is defined as the resting metabolic rate for quietly sitting and is approximately 3.5 ml * kg⁻¹ *

min-1 when expressed as VO_2 rate⁴⁷. The waking hours of the participants were then divided by the MET values into sedentary behavior (<1.5 METs), standing (<1.5 METs), light (1.5–3.0 METs), moderate (3.0–6.0 METs), and vigorous (≥ 6.0 METs) PA. SB was defined as awake time spent in a sitting or reclining posture while energy expenditure is <1.5 MET⁴⁸. Standing still was recorded separately. As the time spent in vigorous activity was minimal, we combined those with moderate-to-vigorous physical activity (MVPA). The time spent in each MET level was analyzed as a continuous factor.

In addition, daily step count data were collected and analyzed as continuous factor.

Statistical analysis

The participants were divided into groups according to their pulmonary function (airway obstruction or pulmonary restriction and those with $\text{FEV}_1 < \text{LLN}$). Adjusted binary logistic regression analysis was conducted to define the differences in daily physical activity level between those with normal pulmonary function and those with impaired spirometry. Analyses were first performed with adjustment of age, sex, BMI, education level, and smoking and then with comorbidities in addition to those previously mentioned. Differences between these groups in total step count were also calculated.

Analysis of covariance was conducted to analyze the association between pulmonary function and PA as continuous factors (not presented in tables).

Not all participants completed the questionnaire accurately, which explains the few missing values in the analysis. Possible sample bias was considered by inverse probability weighting⁴⁹.

All analyses were performed using SPSS (IBM SPSS Statistics, version 28).

Results

Participants

The main characteristics of the participants are shown in (Table 1). Altogether, 141 participants had asthma, 13 had COPD, 66 had airway obstruction ($\text{FEV}_1/\text{FVC} < \text{LLN}$), 73 had pulmonary restriction ($\text{FVC} < \text{LLN}$), and 94 had $\text{FEV}_1 < \text{LLN}$. Groups were partly overlapping (Fig. 2).

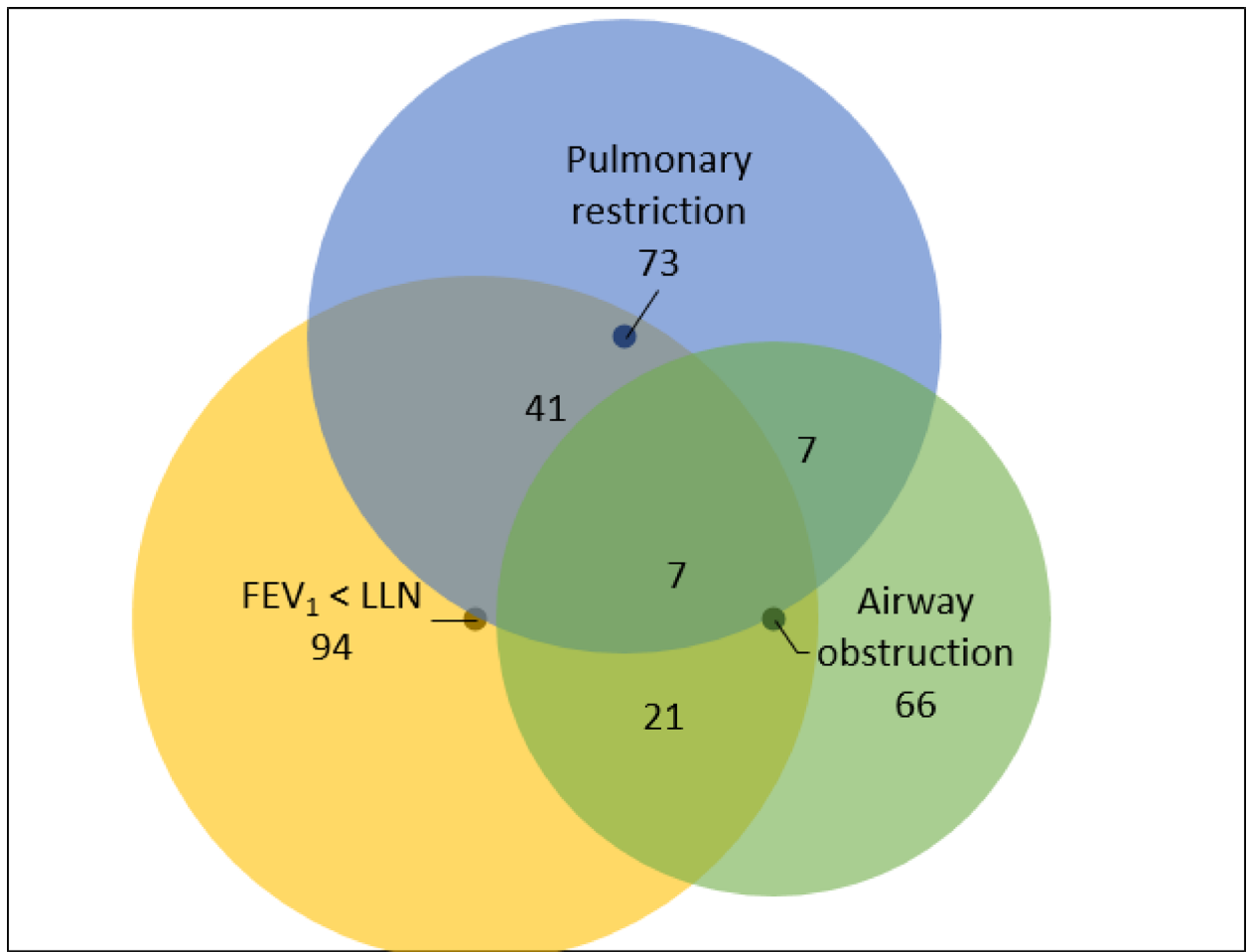


Fig. 2. Groups of impaired spirometry. FEV_1 forced expiratory volume in one second, LLN lower limit of normal.

	FEV ₁ < LLN				Pulmonary restriction				Airway obstruction			
	OR ^a (CI)	p	OR ^b (CI)	p	OR ^a (CI)	p	OR ^b (CI)	p	OR ^a (CI)	p	OR ^b (CI)	p
SB	1.09 (0.92–1.28)	0.021	1.06 (0.98–1.14)	0.135	1.12 (1.04–1.22)	0.003	1.09 (1.01–1.19)	0.036	0.97 (0.88–1.06)	0.500	0.96 (0.88–1.05)	0.452
Standing still	0.97 (0.86–1.08)	0.639	0.99 (0.90–1.11)	0.848	0.85 (0.74–0.98)	0.026	0.88 (0.77–1.02)	0.089	1.11 (1.00–1.27)	0.084	1.10 (0.96–1.23)	0.158
Light PA	0.89 (0.80–1.00)	0.053	0.94 (0.66–1.06)	0.336	0.90 (0.80–1.12)	0.104	0.96 (0.85–1.09)	0.499	1.02 (0.89–1.15)	0.813	1.03 (0.91–1.18)	0.642
Moderate PA	0.63 (0.43–0.90)	0.012	0.58 (0.39–0.87)	0.009	0.71 (0.49–1.05)	0.090	0.65 (0.43–1.00)	0.048	0.59 (0.38–0.92)	0.019	0.63 (0.40–0.99)	0.045
Vigorous PA	0.38 (0.08–1.75)	0.216	0.12 (0.01–1.20)	0.074	0.55 (0.12–2.56)	0.451	0.14 (0.01–0.56)	0.131	0.58 (0.91–2.22)	0.422	0.63 (0.17–2.38)	0.493
MVPA	0.63(0.44–0.88)	0.008	0.56 (0.38–0.82)	0.003	0.72 (0.50–1.04)	0.079	0.63 (0.42–0.94)	0.026	0.61 (0.40–0.91)	0.016	0.65 (0.43–0.98)	0.040
Steps/day	0.84 (0.75–0.93)	0.001	0.82 (0.73–0.93)	<0.001	0.88(0.79–0.98)	0.020	0.85 (0.75–0.96)	0.008	0.88 (0.78–0.99)	0.027	0.89 (0.79–0.99)	0.067

Table 2. Association between impaired pulmonary function and physical activity level compared with those with normal spirometry. FEV₁ forced expiratory volume in 1 s, OR odds ratio, CI confidence interval. SB sedentary behavior, PA physical activity, MVPA moderate-to-vigorous physical activity. OR expressed for one unit (30 min) change in the time spent for physical activity and change for 1000 steps in daily step count. ^aAdjusted for BMI, age, sex, smoking, and education level. ^bAdjusted for BMI, age, sex, smoking, education level, and comorbidities.

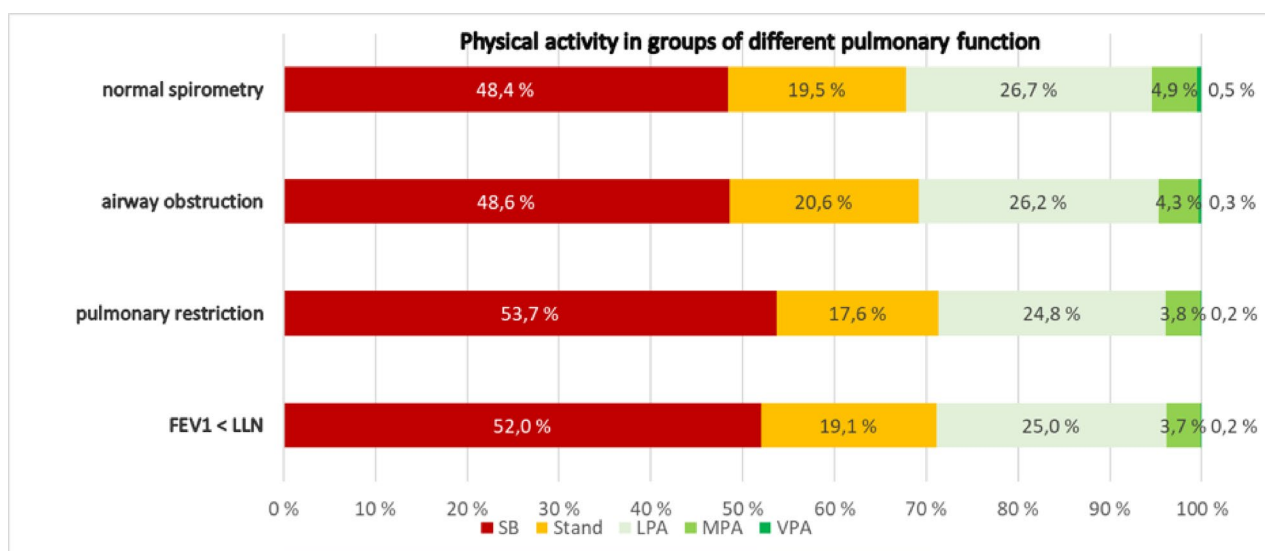


Fig. 3. Daily physical activity during waking hours in groups of different pulmonary function. FEV₁ forced expiratory volume in 1 s, LLN lower limit of normal, SB sedentary behavior, LPA light physical activity, MPA moderate physical activity, VPA vigorous physical activity.

Association between pulmonary function and measured physical activity

We found a significant association between moderate PA and MVPA and airway obstruction, pulmonary restriction and FEV₁ < LLN (Table 2). Less time spent in moderate PA (OR 0.63, 95% CI 0.40–0.99 and OR 0.65, 95% CI 0.43–1.00, respectively) and MVPA (OR 0.65, 95% CI 0.43–0.98 and OR 0.63, 95% CI 0.42–0.94 respectively) was associated with airway obstruction and pulmonary restriction when compared with normal pulmonary function. Similarly, less time spent in moderate PA (OR 0.58, 95% CI 0.39–0.87) and MVPA (OR 0.56, 95% CI 0.38–0.82) was associated with FEV₁ < LLN when compared with normal pulmonary function. These associations were calculated with adjustment for age, sex, BMI, education level, smoking, and comorbidities.

There were no associations between self-reported asthma or COPD and PA.

Association between pulmonary function, sedentary behavior and daily step count

Greater time spent sedentary was associated with pulmonary restriction but not with airway obstruction or FEV₁ < LLN. The ORs (95% CIs) after adjustment for age, sex, BMI, education level, smoking, and comorbidities were 1.09 (1.01–1.19), 0.96 (0.88–1.05) and 1.06 (0.98–1.14), respectively.

The intensity of PA in all the participants' (both those with impaired spirometry and those with normal pulmonary function) was mainly light, and only 5% of waking hours were in MVPA (Fig. 3). A major portion of the waking hours was sedentary (48%). Participants with restrictive spirometry accumulated 43 min more sedentary time than those with normal spirometry. Those with impaired spirometry also suffered more from breathlessness (according to mMRC scale, see Table 1) than those with normal spirometry. Moreover, those with pulmonary restriction, had higher mMRC scale points than those with airway obstruction.

Additionally, we found an association between lower daily step count and pulmonary restriction and $FEV_1 < LLN$ but not with airway obstruction (Table 2). These associations remained after adjusting for BMI, smoking, education level, and comorbidities. The ORs (95% CIs) for these associations were 0.85 (0.75–0.96), 0.82 (0.73–0.93), and 0.89 (0.79–0.99), respectively.

Discussion

We studied the cross-sectional association of impaired pulmonary function and objectively measured daily PA and SB in a population-based sample representing Finnish adults. According to our findings, those with airway obstruction or pulmonary restriction were physically less active. Pulmonary restriction was also associated with greater sedentary time, and lower daily step count. In addition, $FEV_1 < LLN$ was associated with lower level of PA. These associations persisted after adjustment of age, sex, BMI, smoking, education level, and comorbidities.

Several prior studies have shown the association of greater amount of PA and better pulmonary function^{24,27,29–31,34,37,38}. However, many of these findings were based on questionnaires or other self-reporting of PA. In a population-based study, self-reported PA was associated with better FEV_1 ³⁰. Self-reported PA was associated with better pulmonary function in patients with or without asthma³⁴. In middle-aged and older adults without pulmonary disease, higher activity levels as determined by a questionnaire were associated with better pulmonary function³¹. A study based on the European Respiratory Health Survey reported that self-reported vigorous PA was associated with higher FEV_1 and FVC²⁹. In some studies, PA has been evaluated objectively with accelerometer, but only few of these have been population-based with larger number of participants. One study of 341 participants found a weak association between better objectively measured pulmonary function and higher PA levels in healthy adults²⁴. A larger follow-up study of 1910 participants showed also a positive association, but the study population comprised inhabitants of only one city³⁸. Positive association was shown in a population-based study of 3063 British civil-servants based on accelerometer data, but the participants were limited to only those over 60 years³⁷. Our study supports this evidence with reliable accelerometer-based PA assessment.

Secondly, we found an association between pulmonary restriction and PA. The association remained after adjusting for BMI. Moreover, those with pulmonary restriction had higher mMRC points than those with airway obstruction. Pulmonary restriction is usually found in parenchymal pulmonary diseases, chest-wall disorders, and obesity⁵. Low PA levels are associated with developing a restrictive spirometry pattern in overweight individuals²¹. A restrictive spirometry pattern was still associated with diminished PA levels also after adjustment for BMI in the analysis²⁰. Several comorbidities, such as hypertension, diabetes, and obstructive sleep apnea, are associated with a restrictive spirometry pattern, similarly after adjustment of BMI⁶. These associations are likely to be multifactorial.

Thirdly, we found an association between lower daily step count and airway obstruction, pulmonary restriction, and $FEV_1 < LLN$. This may be due to experienced breathlessness in those with impaired spirometry⁵⁰. According to our data, those with impaired spirometry suffered more from breathlessness than those with normal spirometry as they had higher mMRC points. However, according to previous data, those with COPD or other pulmonary disease benefit from exercise and should, in a clinical context, be motivated to be active daily and to increase their daily step count to retard further deterioration in pulmonary function¹⁶.

In contrast to previous findings, we found no association between asthma or COPD and accelerometer-measured PA. For asthma, this could be due to the availability of good asthma treatment in Finland, which allows participants with asthma to live an active life^{51,52}. There were very few participants with COPD ($n = 13$, 0.9%), which probably explains why no statistically significant association between COPD and PA could be detected. The low prevalence of COPD in this study is at least partly due to underdiagnosis. A larger part of the participants ($n = 66$, 4.4%) had obstruction in spirometry, and part of them may have undiagnosed COPD. Moreover, those COPD patients suffering from more severe breathlessness may not have attended the study as also the low points in mMRC scale show.

Previous research indicates that pulmonary function may be modified by PA^{29,53}. Systematic pulmonary rehabilitation especially benefits patients with COPD, but also those with asthma and other pulmonary disease^{22,23}. In a longitudinal study, higher PA was associated with better pulmonary function in active smokers⁵⁴. In an analysis of middle-aged and elderly Canadian adults, more active movement behavior was associated with better pulmonary function³¹, and exchanging 30 min of sedentary time with sleep or any intensity of activity increased FEV_1 and FVC among healthy adults and those with obstructive pulmonary disease^{29,55}.

Bedard et al. explored the possible bidirectional effects between PA and pulmonary function⁵³. However, even in a longitudinal setting, separating these effects is challenging. Daily PA can be affected by several other factors, such as socioeconomic status, comorbidities, education, and personal habits and preferences, which influence the ability to engage in daily exercise and healthy eating and to have sufficient rest. Those with better pulmonary function at baseline may be more physically capable than those with already decreased pulmonary function. PA and pulmonary function also typically change during follow up. Nevertheless, as reported by Bedard et al., PA seems to have an actual preventive effect on pulmonary function at least in current smokers⁵³.

Possible explanation for the association between PA and pulmonary function may lie in the inflammatory environment⁵⁶, fat distribution, or weight change leading to better respiratory mechanics⁵⁷ and better respiratory muscle strength⁵⁸. In addition, PA promotes better general health and therefore ability for an active lifestyle, which may result in even better pulmonary function.

Further research on the modifying effects of PA on pulmonary function is needed. Modifying pulmonary function may be especially important not only for those with asthma or COPD, but also for those without recognizable pulmonary disease but at risk of developing one. For example, those with risk factors of COPD, (such as exposure to tobacco smoke or pollution, low birth weight, or genetic risk), with preserved ratio

impaired spirometry (PRISm), and with restrictive spirometry pattern, may benefit from all means to prevent deterioration of pulmonary function.

Further studies and more advanced analysis considering the characteristics of those with lower levels of PA would clarify the more specific reasons behind the diminished amount of daily PA. However, due to the small number of those with lower levels of PA, advanced analysis was not possible in this study. The reasons for the lower levels of PA may be different in the pulmonary restriction and airway obstruction groups. Prior studies suggest that those with pulmonary restriction have more obesity and metabolic syndrome, and therefore their reasons for lower level of daily PA may lie for example in arthrosis, other musculoskeletal problems, or sedentary lifestyle caused by the modern living environment, as those with airway obstruction may suffer from the systemic burden of the pulmonary disease such as COPD.

For those aged 18–64 years, the WHO currently recommends least 150 min of moderate-intensity PA or 75 min of vigorous-intensity PA in a week in at least 10 min-bouts⁵⁹. Finnish PA recommendations are similar⁶⁰. However, as already mentioned, only 5.8% of Finns aged 18–64 years fulfill these recommendations⁸.

Strengths

The current study reports the association between impaired pulmonary function and objectively measured PA and SB in a large-numbered population-based sample. The Health 2011 survey collected comprehensive data and exceptionally diverse measurements representing the Finnish adult population. Spirometry and PA measures were systematically collected with standardized methods. Information gathered by questionnaires included data on confounding factors such as smoking, education level, comorbidities, and BMI, which were considered in the analysis. Data on PA were collected by triaxial accelerometer instead of a questionnaire, which improves the reliability of the results.

Limitations

Participants of the Health 2011 PA sub-study were likely to be more physically active than those not participating, which may affect the analysis⁴⁹. Nevertheless, we found an association between decreased pulmonary function and decreased PA, which could be even stronger in more inactive population. The sample of those with impaired spirometry was limited and may affect the results and the possibilities of analysis. Non-responsiveness can also affect the results but was addressed by inverse probability weighting. Restriction was defined as FVC <LLN, but to confirm a restrictive syndrome static lung volumes (total lung capacity) would be needed. Additionally, causal inferences cannot be made due to the cross-sectional nature of the study which is also why we cannot rule out the possibility of reverse causation affecting the results. However, in a population study, these results highlight the importance of daily physical activity.

Conclusion

Airway obstruction and pulmonary restriction associated with lower levels of physical activity. Our results support the scarce earlier findings of the association between impaired pulmonary function and less time spent physically active in a population study with objective accelerometer measurements. PA has well-recognized health benefits for those with respiratory diseases. Increasing daily PA, especially at moderate-to-vigorous level, can be recommended for those with obstructive or restrictive pulmonary disease or to otherwise healthy population with impaired spirometry in order to improve respiratory health.

Data availability

The data that support the findings of this study are available from The Finnish Institution of Health and Welfare, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data may be applied in a routine protocol from The Finnish Institution of Health and Welfare, and the corresponding author (maria.lopmeri@helsinki.fi) may be contacted for further inquiries.

Received: 11 October 2024; Accepted: 17 July 2025

Published online: 24 July 2025

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Acknowledgements

The Finnish Institute for Health and Welfare collected the data. Medikro Oy provided the spirometers used in the survey.

Author contributions

Data collection was completed before by the Finnish Institute for Health and Welfare and UKK Institute. TJ and JL contributed to the data transmission. KT and ML analyzed the data. ML outlined the first version of the manuscript. ML, TM, TV (Tommi Vasankari) and TV (Tuula Vasankari) interpreted the results and contributed to the writing process. All authors have read and agreed to the published version of the manuscript.

Funding

This work was supported by the Väinö and Laina Kivi Foundation; The Finnish Anti-Tuberculosis Foundation, and The Tuberculosis Foundation of Tampere. The funders had no role in the design of the study, in the collection, analysis, or interpretation of data, or in the writing of the manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Ethics approval and content to participate

The Health 2011 Survey was approved by the Coordinating Ethics Committee of the Hospital District of Helsinki and Uusimaa. All participants provided written informed consent. All research was performed in accordance with relevant guidelines and regulations.

Additional information

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