

Postural stability during low-intensity respiratory loading in pre-COPD and healthy adults: a cross-sectional study

Leonel A. T. Alves^{1,2}, Edgar Ribeiro¹, Carlos Crasto^{1,2,3}, Cristina Argel de Melo¹, Rita Santos¹, Rubim Santos¹, João Paulo Vilas-Boas⁴, António Mesquita Montes^{1,2}

¹CIR, ESS, Polytechnic of Porto, Porto, Portugal

²Department of Physiotherapy, ESS, Polytechnic of Porto, Porto, Portugal

³Department of Physiotherapy, Santa Maria Health School - Portugal

⁴Center for Research, Education, Innovation and Intervention in Sport, CIFI2D and Porto Biomechanics Laboratory, LABIOME, Faculty of Sport, University of Porto, Porto - Portugal

ABSTRACT

Introduction: Pre-COPD is characterized by the presence of respiratory symptoms and/or structural abnormalities, without spirometry-confirmed airflow limitation. However, pre-COPD may be associated with extrapulmonary manifestations that are not apparent at rest. The aim of this study was to assess postural stability through center of pressure (CoP) dynamics during low-intensity inspiratory and expiratory loading between adults with pre-COPD and healthy adults.

Methods: This cross-sectional observational study included 31 volunteer adults (17 with pre-COPD, 14 healthy adults; mean age 47.9 years). CoP was calculated from ground reaction forces and torques recorded with a force plate during quiet standing across three breathing conditions (without, inspiratory, and expiratory loads). Respiratory loads were set at 10% of the individuals' maximal inspiratory and expiratory pressures. CoP mean amplitude (m^{-1}) and velocity ($m^{-1}\cdot s^{-1}$) in anteroposterior and mediolateral directions, normalized by the base of support area, were calculated from a 30-second period, averaged across three trials.

Results: During inspiratory loading, all mean velocity outcomes were significantly higher in adults with pre-COPD compared to healthy adults (anteroposterior: $p = 0.002$, 95% CI [0.991, 4.014]; mediolateral: $p < 0.001$, 95% CI [0.971, 3.324]; total: $p = 0.002$, 95% CI [1.314, 5.270]). Although mean amplitude showed no overall group difference, significant load $\times$ group interaction revealed that adults with pre-COPD exhibited a greater postural disturbance during inspiratory loading than healthy adults. Expiratory loading only significantly differentiated groups for mediolateral velocity ($p = 0.034$, 95% CI [0.096, 2.292]).

Conclusions: During quiet standing, low-intensity inspiratory loading was associated with increased CoP differences between adults with pre-COPD and healthy adults.

Keywords: Biomechanical phenomena, Chronic obstructive pulmonary disease, Postural balance, Respiratory mechanics

What is already known about this topic?

- Balance impairment and atypical center of pressure dynamics are documented in COPD, but postural-respiratory responses remain unexplored in pre-COPD.

What does the study add?

- Low-intensity inspiratory loading was associated with higher center of pressure amplitude and velocity in adults with pre-COPD compared to healthy adults.

Introduction

Chronic obstructive pulmonary disease (COPD) is a common, treatable, and preventable chronic condition. It is

characterized by chronic respiratory symptoms arising from alterations in the airways and/or alveoli, which lead to persistent airflow limitation that is not fully reversible (1,2). In 2021, COPD accounted for 79.8 million disability-adjusted life-years globally, and the number of prevalent cases is projected to rise 23% by 2050, highlighting the increasing burden of this disease (3,4). Despite the obstructive ventilatory defect, extrapulmonary manifestations, such as reduced exercise capacity, peripheral muscle performance, and functional mobility, contribute to the overall disability (5). For instance, people with COPD have impaired balance control across several levels of severity, with slower recovery after

Received: December 1, 2025

Accepted: June 22, 2026

Published online: July 10, 2026

This article includes supplementary material

Corresponding author:

Leonel AT Alves

email: lta@ess.ipp.pt.

the application of external perturbations and an abnormal center of pressure (CoP) behavior during quiet standing (6,7). These deficits are associated with increased fall risk, reduced physical activity, and loss of functional independence (6,8).

Breathing acts as an internal perturbation to balance. Ribcage motion displaces the body's center of mass (CoM), which in healthy adults is partially counteracted by the activity of the trunk and lower limbs, causing minor rhythmic CoP displacements during quiet standing (9). When respiratory demand increases, through voluntary hyperventilation or inspiratory resistive loading, anteroposterior (AP) CoP sway increases and decreases during apnea (9,10). Evidence for the effect of expiratory loading on postural stability is emerging but remains limited. In COPD, increased airflow limitation and respiratory loading reduce the capacity of the trunk and lower limb muscles to compensate for breathing-related CoM displacement, amplifying CoP motion during inspiratory loading (9,11).

Expanding the characterization of individuals at increased risk of developing COPD is fundamental to refining the pre-COPD concept and better understanding the clinical and physiological features associated with this population. These individuals, referred to as pre-COPD, may exhibit respiratory symptoms and/or structural abnormalities and/or physiological alterations without spirometry-confirmed airflow limitation [i.e., forced expiratory volume in 1 second (FEV_1)/forced vital capacity (FVC) ≥ 0.70]. Thus, the pre-COPD concept encompasses a heterogeneous group, where not all individuals will progress into spirometric obstruction (2,12,13). Despite this, symptomatic individuals with risk factor exposure and preserved spirometry represent a clinically accessible subgroup that may exhibit subtle balance alterations under low respiratory loads, as seen during activities of daily living, that are not apparent at rest. Assessing extrapulmonary manifestations in this population may contribute to a more comprehensive characterization beyond spirometric findings (1). Therefore, the aim of this study was to assess the CoP dynamics while breathing without a respiratory load and under low-intensity inspiratory and expiratory loads during quiet standing in adults with pre-COPD versus healthy adults.

Methods

Study design

This cross-sectional study was conducted in a biomechanical laboratory at a university rehabilitation research center among pre-COPD and healthy subjects. Reporting follows the checklist for Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement (14).

Participants

The target population for this study was community-dwelling adults with pre-COPD and healthy subjects. Participants were recruited from February to June 2015 from the university community and its surrounding areas through emails and telephone outreach.

This study addresses a symptom and risk factor exposure subset of the broader pre-COPD construct and does

not include individuals identified through structural imaging abnormalities or advanced physiological testing (2,13). Accordingly, the pre-COPD group included individuals with dyspnea, chronic cough, or sputum production for at least three months in each of two consecutive years; history of recurrent lower respiratory tract infections and/or history of exposure to risk factors (e.g., cigarette smoking for ≥ 15 years); grade 1 or higher in the modified Medical Research Council (mMRC) dyspnea scale; score ≥ 1 in the 1-4 items of the COPD Assessment Test (CAT) (i.e., presence of cough, phlegm, chest tightness, and breathlessness); and a FEV_1 /FVC ratio above the lower limit of normal (i.e., ≥ 5 th percentile of the predicted values) (13,15). The healthy group consisted of asymptomatic individuals (mMRC = 0; CAT items 1-4 = 0), who were never-smokers or had smoked fewer than 100 cigarettes in their lifetime, with no history of environmental or occupational inhalation exposure, and normal spirometry values (16).

Exclusion criteria included leg-length discrepancy or other postural asymmetries; current trunk or lower limb pain; history of spinal, gynecological, or abdominal surgery, as well as lower limb pathology in the previous year; chronic respiratory disease diagnosis (e.g., asthma) or acute illness within the previous 4 weeks; cardiac and metabolic conditions expected to interfere with postural control; known neurological (i.e., vestibular problems) and inflammatory disorders affecting balance; pregnancy or postpartum < 6 months; regular participation in moderate-intensity (i.e., ≥ 150 minutes/week) or vigorous-intensity aerobic activities (i.e., ≥ 75 minutes/week) for ≥ 12 months; and medications interfering with data collection (e.g., bronchodilator intake in the previous 12h).

This study was approved by the Institutional Research Ethics Committee (4136/2013). All participants provided written informed consent in accordance with the Declaration of Helsinki. Data anonymity and confidentiality were maintained throughout.

Data collection

Data collection was conducted at a biomechanical laboratory in a controlled environment within a single session. To avoid measurement bias, each researcher was responsible for a specific procedure. An online questionnaire was used to verify eligibility and collect demographic data (sex, age) and clinical information (e.g., smoking status).

Anthropometric and clinical assessments

Height (m) was measured using a wall-mounted stadiometer (seca 222; seca – Medical Scales and Measuring Systems®, Hamburg, Germany) with participants standing with heels, buttocks, and occiput in contact with the wall. Body mass (kg), muscle mass (kg), body fat (%), and visceral fat were assessed with Tanita BC-543 InnerScan™ (Tanita – Monitoring Your Health, Amsterdam, Netherlands) bioelectrical bioimpedance scale. Prior to this assessment, participants were instructed to abstain from drinking water for at least two hours and from eating for eight hours. Participants underwent a postural assessment to identify asymmetries. They were asked to stand barefoot in an upright orthostatic position,

gazing forward, with their upper limbs relaxed alongside the body. Foot positioning was standardized: shoulder-width apart for males, and hip-width apart for females (17). Leg length was measured bilaterally with participants in a prone position, from the anterior superior iliac crest to the medial malleolus, using a non-elastic measuring tape, to assess for discrepancies.

Spirometry was performed with a MasterScreen body plethysmograph of volume-constant type (Jaeger–CareFusion Corporation, San Diego, CA, USA), according to the American Thoracic Society/European Respiratory Society standards (18). Participants performed FVC maneuvers to assess pulmonary function in a seated position. At least three acceptable and reproducible maneuvers were recorded, each encouraged verbally. The following parameters were recorded: FEV_1/FVC ratio (%), FEV_1 (% predicted), and FVC (% predicted). Spirometry was performed without bronchodilator administration.

Respiratory pressure assessment

Maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) were assessed using a respiratory pressure meter (MicroRPM, CareFusion Corporation, San Diego, CA, USA), following the American Thoracic Society/European Respiratory Society standards (19). MIP was measured through a forceful maximal inspiration from residual volume, and MEP was measured through a forceful maximal expiration from total lung capacity. All maneuvers were verbally encouraged, and the highest pressure sustained for at least one second within the first two seconds of effort was recorded. A rest interval of three minutes was provided between attempts. Three reproducible maneuvers were selected for analysis. The highest value of each maneuver was used to calculate 10% MIP and 10% MEP for subsequent balance assessment. This low-intensity threshold was selected to avoid inducing respiratory muscle fatigue or compensatory postural strategies, while ensuring sensitivity to postural-respiratory perturbations (20).

Postural stability assessment

CoP dynamics were recorded during three breathing conditions: unloaded breathing, inspiratory loading, and expiratory loading. Data collection began with unloaded breathing, and the order of the loaded breathing conditions was randomized.

Participants stood barefoot in an upright position, with arms alongside the body, knees in a loose-packed position, and foot positioning visually standardized to shoulder-width apart in males and hip-width in females. The base of support (BoS) was then outlined on a paper sheet to maintain the same foot position across trials and breathing conditions. Participants were assessed while on a force plate (FP4060-08; Bertec Corporation®, Columbus, OH, USA), connected to an AM6500 amplifier. CoP displacement was calculated from ground reaction forces and torques. Data were recorded and sampled at 100 Hz using the Qualisys Motion Capture System (Qualisys AB, Gothenburg, Sweden).

During all conditions, participants followed an audio-paced respiratory pattern (inspiratory time = 2 seconds; expiratory time = 4 seconds), previously defined through pilot testing.

Participants were familiarized with this externally paced rhythm before data collection, and adherence during testing relied only on the auditory cue. For loaded breathing conditions, inspiratory loading was applied using the Threshold IMT® device (Respironics Inc., Murrysville, PA, USA), and expiratory loading using a positive expiratory pressure PEP® device (Respironics Inc., Murrysville, PA, USA). Participants gazed forward and used a mouthpiece and nose clip during all tasks. Three repetitions of 40 seconds were performed for each condition, with a 3-minute resting interval to prevent carryover effects.

Data processing

Data were processed using MATLAB (MathWorks, Natick, MA, USA). Ground reaction forces and torques were low-pass filtered with a 4th-order digital Butterworth filter with a cut-off frequency of 10 Hz. This cut-off is consistent with methodological recommendations for quiet standing CoP analysis, as it effectively attenuates high-frequency noise while preserving the physiologically relevant sway signal (21). CoP position in the AP and mediolateral (ML) directions was extracted from the central 30 seconds of each 40-second recording. CoP metrics were normalized by BoS area, calculated from the outlined foot position using: $BoS = [(HD+IMD)/2] \times EFL$, where HD is hallux distance, IMD is inter-malleolus distance, and EFL is effective foot length (see Supplementary Fig. 1) (22). Then, mean amplitude (m^{-1}), mean velocity ($m^{-1} \cdot s^{-1}$), and mean total velocity were calculated for both directions. All metrics were averaged across three repetitions of each task.

Data analysis

Descriptive and inferential analyses were conducted using the IBM Statistical Package for Social Sciences® version 29.0 (IBM Corporation, Armonk, NY, USA). Continuous variables are presented as mean (SD), and categorical variables as frequencies (%). The Shapiro-Wilk test was used to assess normality. Between-group comparisons for sample characterization and study outcomes were performed using an independent-samples t-test. Categorical variables were compared with the chi-square test. A 2×3 mixed-design ANOVA was used to compare the CoP outcomes, with one between-subjects factor (Group: pre-COPD vs. healthy) and one within-subjects factor (Load: without load, inspiratory load, expiratory load). Bonferroni correction was used for post-hoc analysis. Effect sizes were quantified using partial eta square (η_p^2) and interpreted according to Cohen's recommendations: 0.01 = small effect, 0.06 = medium effect, and 0.14 = large effect (23). For all analyses, the significance level was set at 0.05.

Results

Sample selection and characterization

A total of 31 subjects (17 adults with pre-COPD and 14 healthy adults) were included in this study. The overall mean age was 47.94 years (range: 33–58 years). Demographic, anthropometric, and body composition data were similar between the pre-COPD and healthy groups. Except for FVC, all lung function parameters were significantly lower in the pre-COPD group compared to the healthy group (Table 1).

TABLE 1 - Demographic and clinical characteristics of the pre-COPD and healthy groups

Variables	Pre-COPD (n = 17)	Healthy (n = 14)	p-value
Sex, n female (%)	12 (71)	8 (57)	0.477*
Age, years	47.71 ± 5.11	48.21 ± 6.87	0.815
Height, m	1.67 ± 0.11	1.67 ± 0.10	0.917
Body mass, kg	70.85 ± 14.37	79.65 ± 15.28	0.110
Body mass index			
Normal weight, n (%)	7 (41)	2 (14)	0.100*
Overweight, n (%)	8 (47)	6 (43)	
Obesity class I, n (%)	2 (12)	6 (43)	
Muscle mass, kg	48.51 ± 11.21	52.27 ± 13.02	0.395
Body fat, %	28.85 ± 9.29	32.66 ± 8.91	0.256
Visceral fat rating	7.12 ± 3.14	9.21 ± 2.83	0.063
Smoking status			
Current, n (%)	12 (71)	N.A.	N/A
Never, n (%)	5 (29)		
Smoking exposure, pack-years	23.50 ± 12.44	N.A.	N.A.
Lung function			
FEV ₁ /FVC ratio, %	74.30 ± 6.25	82.75 ± 1.67	<0.001
FEV ₁ , % pred	95.23 ± 14.87	117.30 ± 13.04	<0.001
FVC, % pred	107.79 ± 15.35	118.47 ± 14.75	0.059

Data are presented as mean (SD) or frequencies (%), unless otherwise noted.

*chi-square test.

Bold values indicate statistically significant differences (<0.05).

BMI = body mass index; FEV₁ = forced expiratory volume in 1 second; FVC = forced vital capacity; pred = predicted; N.A. = not applicable.

Center of pressure outcomes

Mean amplitude

A significant main effect of load was found on mean amplitude for both directions (AP: $p = 0.003$, large effect; ML: $p < 0.001$, large effect). Post-hoc pairwise comparisons revealed that mean amplitude was significantly higher during inspiratory loading compared to breathing without load (AP: $p = 0.013$, 95% CI [0.089, 0.887]; ML: $p < 0.001$, 95% CI [0.175, 0.633]) or expiratory loading (AP: $p = 0.031$, 95% CI [0.025, 0.657]; ML: $p = 0.011$, 95% CI [0.053, 0.486]) (Table 2). Although no significant main effect of group was observed, a significant load $\times$ group interaction was found for mean amplitude in both directions (AP: $p < 0.001$, large effect; ML: $p < 0.001$, large effect), with the pre-COPD group exhibiting a different response pattern during inspiratory loading, with increased CoP amplitude, compared to the healthy group (see Supplementary Table 1) (Fig. 1).

Mean velocity

A significant main effect of load was found for mean velocity in both directions (AP: $p = 0.001$, large effect; ML: $p = 0.001$, large effect) and for total mean velocity ($p = 0.005$, large effect). Post-hoc pairwise comparisons revealed that velocity was

significantly higher during inspiratory loading compared to breathing without load (AP: $p = 0.008$, 95% CI [0.223, 1.722]; ML: $p = 0.004$, 95% CI [0.166, 1.027]; total: $p = 0.015$, 95% CI [0.183, 2.009]) or expiratory loading (AP: $p = 0.032$, 95% CI [0.036, 1.014]; ML: $p = 0.002$, 95% CI [0.113, 0.583]; total: $p = 0.033$, 95% CI [0.036, 1.070]) (Table 2) (Fig. 1).

Mean velocities were significantly higher in the pre-COPD group compared to the healthy group across all conditions (AP: $p = 0.034$, large effect; ML: $p = 0.008$, large effect; total: $p = 0.016$, large effect) (Table 2). A significant load $\times$ group interaction was found for all velocity outcomes (AP: $p < 0.001$, large effect; ML: $p = 0.002$, large effect; total: $p = 0.003$, large effect), indicating that the pre-COPD group exhibited a different and accentuated response pattern during inspiratory loading compared to the healthy group (see Supplementary Table 1) (Fig. 1).

Discussion

This study aimed to assess the CoP dynamics during quiet standing without a respiratory load and under low-intensity inspiratory and expiratory loads in pre-COPD versus healthy adults. To our knowledge, this is the first study to explore postural stability under respiratory loads in subjects with pre-COPD. Previous studies have documented postural

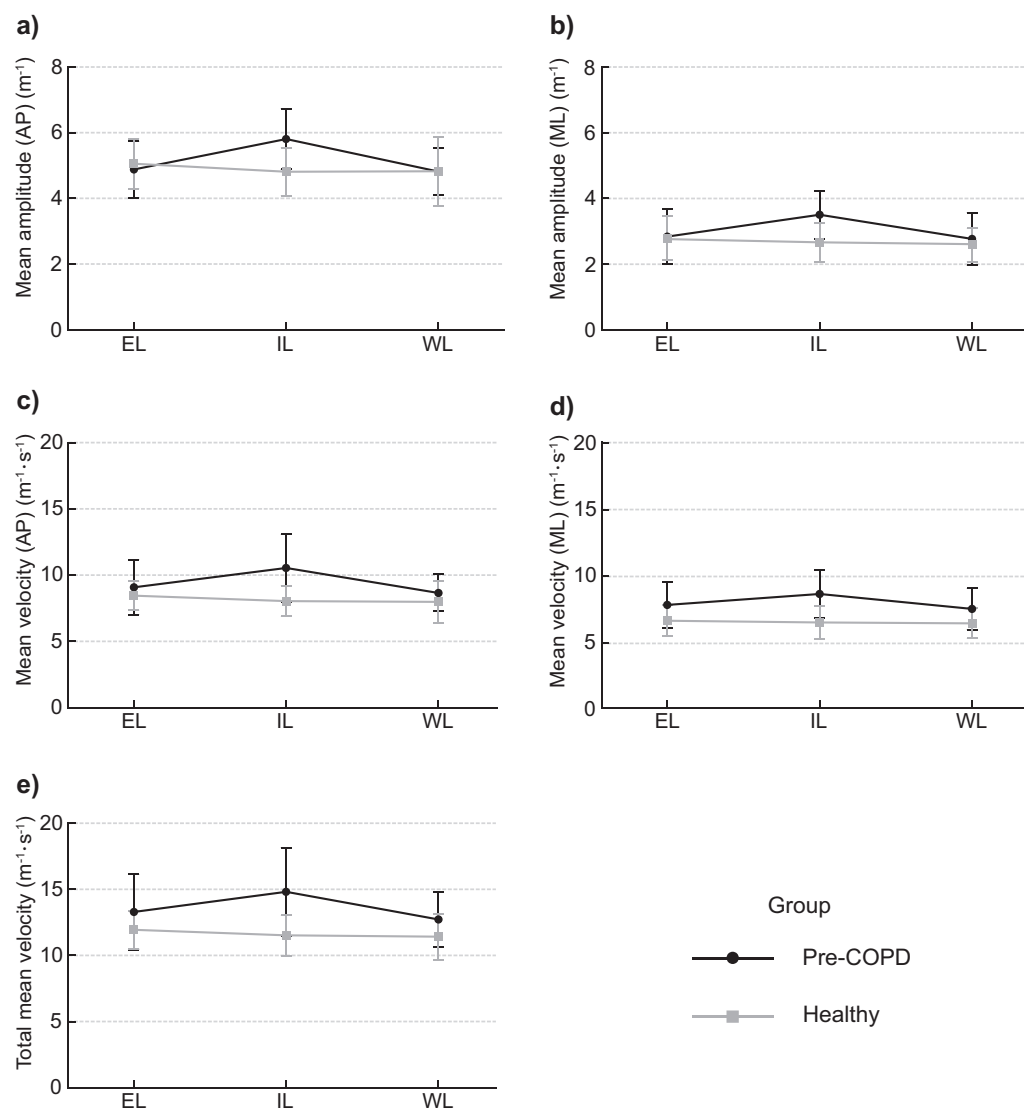


FIGURE 1 - Center of pressure outcomes (normalized by base of support area) across breathing conditions in pre-COPD and healthy groups. a-b) Mean amplitude (m⁻¹); c-e) Mean velocity (m⁻¹·s⁻¹). Black lines represent the pre-COPD group, and grey lines represent the healthy group. Error bars represent standard deviations. AP, anteroposterior; ML, mediolateral; EL, expiratory loading; IL, inspiratory loading; WL, without loading.

control deficits in COPD, including slower recovery after external perturbations and increased postural sway during quiet standing (6,9,24). Moreover, it remains unclear if these extrapulmonary alterations are also present in these symptomatic, exposure-defined individuals with pre-COPD. In our study, between-group comparisons showed no significant differences in the mean CoP amplitude for either direction. However, the mean CoP velocities were significantly higher in pre-COPD. Furthermore, all CoP variables showed significant load × group interactions, indicating that pre-COPD individuals exhibit a particular postural response to respiratory loading compared to healthy subjects.

One of the main results of our study was that inspiratory loading was associated with higher CoP amplitude and velocity in subjects with pre-COPD relative to healthy subjects. This load-specific response, observed even at a low-intensity load (10% MIP), may reflect alterations in the postural-respiratory integration in this pre-COPD sample. Thus, the greater postural perturbation observed during inspiratory

loading, evidenced by the increased CoP displacement, is consistent with differences in this sample that may not be limited to respiratory symptoms.

The low intensity of 10% MIP/MEP was selected to avoid muscle fatigue or compensatory postural strategies that could confound the CoP variables, in contrast with higher respiratory loading intensities typically used for inspiratory muscle training (25). Despite this reduced intensity, inspiratory loading was associated with significant disturbances in subjects with pre-COPD, in line with prior evidence that 10% MIP can increase CoP sway in healthy subjects (20). No equivalent results exist for 10% MEP. Given that expiration during quiet tidal breathing is primarily driven by passive elastic recoil, 10% MEP may have been below the threshold required to elicit detectable postural perturbations in this sample (26). Also, the absence of differences for most expiratory loading outcomes should not be interpreted as evidence that expiratory loading does not affect postural control in pre-COPD. Whether higher expiratory loading intensities would reveal group differences comparable

TABLE 2 - Mixed ANOVA results for center of pressure main effects, interactions, and post-hoc comparisons

Outcome	Load condition	Pre-COPD (n = 17)	Healthy (n = 14)	Load (within-subjects) Partial Eta² (p-value)	Bonferroni adjusted <i>post-hoc</i> 95% CI (p-value)	Group (between-subjects) Partial Eta² (p-value)	Interaction (Load × Group) Partial Eta² (p-value)
Mean amplitude (m ⁻¹)							
Anteroposterior	Without load	4.82±0.72	4.82±1.05	0.179 (0.003)	IL≠WL 0.089-0.887 (0.013)	0.036 (0.304)	0.259 (<0.001)
	Inspiratory load	5.81±0.92	4.81±0.73		IL≠EL 0.025-0.657 (0.031)		
	Expiratory load	4.88±0.86	5.05±0.77				
Mediolateral	Without load	2.77±0.80	2.59±0.51	0.270 (<0.001)	IL≠WL 0.175-0.633 (<0.001)	0.075 (0.135)	0.284 (<0.001)
	Inspiratory load	3.51±0.74	2.66±0.59		IL≠EL 0.053-0.486 (0.011)		
	Expiratory load	2.84±0.83	2.79±0.67				
Mean velocity (m ⁻¹ ·s ⁻¹)							
Anteroposterior	Without load	8.65±1.40	7.98±1.57	0.219 (0.002)	IL≠WL 0.223-1.722 (0.008)	0.146 (0.034)	0.253 (<0.001)
	Inspiratory load	10.54±2.55	8.04±1.15		IL≠EL 0.036-1.014 (0.032)		
	Expiratory load	9.08±2.07	8.45±1.08				
Mediolateral	Without load	7.47±1.56	6.38±1.13	0.248 (0.001)	IL≠WL 0.166-1.027 (0.004)	0.222 (0.008)	0.237 (0.002)
	Inspiratory load	8.59±1.84	6.44±1.22		IL≠EL 0.113-0.583 (0.002)		
	Expiratory load	7.78±1.71	6.57±1.15				
Total	Without load	12.72±2.09	11.42±1.73	0.201 (0.005)	IL≠WL 0.183-2.009 (0.015)	0.184 (0.016)	0.212 (0.003)
	Inspiratory load	14.81±3.33	11.52±1.53		IL≠EL 0.036-1.070 (0.033)		
	Expiratory load	13.29±2.86	11.94±1.43				

Data are presented as mean (SD) unless otherwise noted. Bold values indicate statistically significant differences (<0.05). IL = inspiratory load; WL = without load; EL = expiratory load.

to those observed with inspiratory loading remains to be determined.

While all CoP variables showed significant group differences during inspiratory loading, expiratory loading only differentiated groups for ML velocity. Notably, ML CoP mean velocity was consistently higher in the pre-COPD group across all breathing conditions, including unloaded breathing, suggesting a direction-specific association that was not solely load-dependent. ML balance control depends largely on hip and trunk movements rather than ankle strategies (24,27). These differences may be consistent with alterations in the dual postural-respiratory role of trunk muscles described in established COPD (9,11) and in subjects at risk for COPD, who exhibited altered rectus abdominis recruitment under respiratory loading (28). However, this interpretation remains speculative, since electromyography was not performed. Future studies combining electromyography and CoP analysis could clarify whether ML velocity differences relate to altered trunk muscle recruitment.

The clinical significance of the observed CoP differences remains to be established. While CoP velocity during quiet standing has been associated with fall risk in older adults, no minimal clinically important difference has been established for force plate CoP metrics in COPD or pre-COPD (29). Furthermore, the BoS-normalized units used in this study preclude any direct comparison with existing thresholds. Accordingly, the present findings should be interpreted as sensitive biomechanical markers of altered postural-respiratory integration in this sample, rather than indicators of clinically meaningful balance impairment. Future studies should evaluate whether these load-dependent CoP differences are associated with clinically meaningful outcomes such as fall incidence or functional mobility limitations, using prospective designs and validated clinical balance instruments.

The results of our study should be interpreted in consideration of its limitations. No a priori sample size calculation was performed, and the small sample (n = 17 pre-COPD, n = 14 healthy) limits the precision and stability of effect size

estimates, particularly for interaction effects. The observed large partial eta-squared values should be interpreted with caution, as these may be inflated, and these findings should be considered exploratory pending replication in larger samples. Participants were recruited through convenience sampling, which may limit generalizability to broader at-risk populations. The pre-COPD characterization relied on respiratory symptoms and exposure history without structural abnormalities or advanced physiological testing; our sample, therefore, represents a pragmatically defined subgroup within the broader pre-COPD construct. Relatedly, spirometry was performed without bronchodilator administration, which means that a small number of participants may have been misclassified as having preserved spirometry, although pre-bronchodilator spirometry can effectively rule out COPD in most individuals (30,31). Smoking exposure should also be considered a potential confounder, as the independent contributions of smoking and pre-COPD status to the observed CoP differences cannot be separated in this cross-sectional design.

Regarding measurement procedures, ventilatory parameters were not objectively monitored during testing. The audio-paced respiratory pattern was used to standardize the respiratory rate across participants and conditions to reduce variability in minute ventilation so that between-group differences in CoP could be better attributed to the resistive loads. Foot positioning was standardized using sex-specific instructions, and CoP variables were normalized by individualized BoS area calculated from each participant's outlined foot placement. This approach was intended to mitigate the influence of morphological differences on the results. However, foot placement was visually standardized rather than instrumentally measured, and the sex-specific stance instructions may have introduced residual variability, particularly for mediolateral outcomes.

Given the cross-sectional design, these results should be interpreted as preliminary evidence of between-group differences in postural responses during respiratory loading. Future longitudinal studies are needed to determine whether these CoP responses have prognostic value in relation to pulmonary function decline or later airflow obstruction.

Conclusions

Low-intensity respiratory loading during quiet standing was associated with differences in postural stability between subjects with pre-COPD and healthy adults in this sample. Inspiratory loading was associated with greater CoP responses, particularly in ML velocity, in the pre-COPD group. These findings support further investigation of postural-respiratory integration as part of the functional characterization of adults with pre-COPD, defined through respiratory symptoms, exposure history, and preserved spirometry. Larger longitudinal studies should clarify whether these differences translate into clinically meaningful outcomes.

Acknowledgements

A special thanks to Susana Pereira, BSc, from the Cardiopneumology Department of the School of Health, Polytechnic of Porto, Porto, Portugal. We also thank Gonalo Oliveira, MA from the CIR, ESS, Polytechnic of Porto, Porto, Portugal, for the assistance provided with graphical design and editing.

Disclosures

Conflict of interest: The authors declare no conflict of interest.

Financial support: The authors of this study received no financial support or grants for this study.

Authors' contribution: LA: Methodology; Validation; Formal analysis; Data curation; Writing — original draft; Writing — review & editing. ER: Investigation. CC: Methodology; Investigation. CM: Methodology; Investigation; Resources. Rita S: Methodology; Investigation. Rubim S: Software; Resources. JVB: Conceptualization. AM: Conceptualization; Methodology; Software; Validation; Formal analysis; Investigation; Resources; Data curation; Writing — original draft; Writing — review & editing.

Data Availability Statement: All data supporting this study are available within the article and its supplementary material. Raw data are available from the corresponding author upon reasonable request.

References

1. Celli B, Fabbri L, Criner G, et al. Definition and nomenclature of chronic obstructive pulmonary disease: time for its revision. *Am J Respir Crit Care Med*. 2022;206(11):1317-1325. [CrossRef PubMed](#)
2. Global Initiative for Chronic Obstructive Lung Disease (GOLD). Global Strategy for the Diagnosis, Management, and Prevention of Chronic Obstructive Pulmonary Disease: 2026 Report. 2025. [Online](#)
3. Boers E, Barrett M, Su JG, et al. Global burden of chronic obstructive pulmonary disease through 2050. *JAMA Netw Open*. 2023;6(12):e2346598. [CrossRef PubMed](#)
4. Safiri S, Carson-Chahhoud K, Noori M, et al. Burden of chronic obstructive pulmonary disease and its attributable risk factors in 204 countries and territories, 1990-2019: results from the Global Burden of Disease Study 2019. *BMJ*. 2022;378:e069679. [CrossRef PubMed](#)
5. N   ez-Cort  s R, Padilla-Acevedo P, Vergara-Pe  a F, et al. Clinical assessment of balance and functional impairments in people with stable chronic obstructive pulmonary disease: a systematic review and meta-analysis. *ERJ Open Res*. 2022;8(4):00164-2022. [CrossRef PubMed](#)
6. Beauchamp MK, Janaudis-Ferreira T, Parreira V, et al. A randomized controlled trial of balance training during pulmonary rehabilitation for individuals with COPD. *Chest*. 2013;144(6):1803-1810. [CrossRef PubMed](#)
7. Strandkvist V, Lindberg A, Larsson A, et al. Postural control among individuals with and without chronic obstructive pulmonary disease: a cross-sectional study of motor and sensory systems. *PLoS One*. 2023;18(4):e0284800. [CrossRef PubMed](#)
8. Chuatrakoon B, Uthairakun S, Ngai SP, et al. The effectiveness of home-based balance and pulmonary rehabilitation program in individuals with chronic obstructive pulmonary disease: a randomized controlled trial. *Eur J Phys Rehabil Med*. 2022;58(3):478-486. [CrossRef PubMed](#)
9. Janssens L, Jacobs N, Goossens N, et al. The effect of acute respiratory demand on postural control: a systematic review. *Gait Posture*. 2024;113:310-318. [CrossRef PubMed](#)
10. Clavel L, Attali V, Rivals I, et al. Decreased respiratory-related postural perturbations at the cervical level under cognitive load. *Eur J Appl Physiol*. 2020;120(5):1063-1074. [CrossRef PubMed](#)
11. Jolley CJ, Moxham J. A physiological model of patient-reported breathlessness during daily activities in COPD. *Eur Respir Rev*. 2009;18(112):66-79. [CrossRef PubMed](#)

12. Divo MJ, Liu C, Polverino F, et al. From pre-COPD to COPD: a Simple, Low cost and easy to IMplement (SLIM) risk calculator. *Eur Respir J*. 2023;62(3):2300806. [CrossRef PubMed](#)
13. Han MK, Agusti A, Celli BR, et al. From GOLD 0 to pre-COPD. *Am J Respir Crit Care Med*. 2021;203(4):414-423. [CrossRef PubMed](#)
14. von Elm E, Altman DG, Egger M, et al.; STROBE Initiative. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Ann Intern Med*. 2007;147(8):573-577. [CrossRef PubMed](#)
15. Martinez FJ, Agusti A, Celli BR, et al. Treatment trials in young patients with chronic obstructive pulmonary disease and pre-chronic obstructive pulmonary disease patients: time to move forward. *Am J Respir Crit Care Med*. 2022;205(3):275-287. [CrossRef PubMed](#)
16. Celli BR, Christenson S, Rabe KF, et al. Current smoker: a clinical COPD phenotype affecting disease progression and response to therapy. *Am J Respir Crit Care Med*. 2025;211(5):729-736. [CrossRef PubMed](#)
17. Johnson J. Postural assessment. *Human Kinetics*; 2012. [CrossRef](#)
18. Miller MR, Hankinson J, Brusasco V, et al.; ATS/ERS Task Force. Standardization of spirometry. *Eur Respir J*. 2005;26(2):319-338. [CrossRef PubMed](#)
19. American Thoracic Society/European Respiratory Society. ATS/ERS Statement on respiratory muscle testing. *Am J Respir Crit Care Med*. 2002;166(4):518-624. [CrossRef PubMed](#)
20. Van Hove O, Van Muylem A, Leduc D, et al. Validation of the Wii Balance Board to assess balance modifications induced by increased respiratory loads in healthy subjects. *Gait Posture*. 2019;68:449-452. [CrossRef PubMed](#)
21. Ruhe A, Fejer R, Walker B. The test-retest reliability of centre of pressure measures in bipedal static task conditions--a systematic review of the literature. *Gait Posture*. 2010;32(4):436-445. [CrossRef PubMed](#)
22. Chiari L, Rocchi L, Cappello A. Stabilometric parameters are affected by anthropometry and foot placement. *Clin Biomech (Bristol)*. 2002;17(9-10):666-677. [CrossRef PubMed](#)
23. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Lawrence Erlbaum Associates; 1988.
24. Smith MD, Chang AT, Hodges PW. Balance recovery is compromised and trunk muscle activity is increased in chronic obstructive pulmonary disease. *Gait Posture*. 2016;43:101-107. [CrossRef PubMed](#)
25. Langer D, Charususin N, Jácome C, et al. Efficacy of a novel method for inspiratory muscle training in people with chronic obstructive pulmonary disease. *Phys Ther*. 2015;95(9):1264-1273. [CrossRef PubMed](#)
26. West JB, Luks AM. *West's Respiratory Physiology: The Essentials*. 11th ed. Lippincott Williams & Wilkins, a Wolters Kluwer business; 2021.
27. Smith MD, Chang AT, Seale HE, et al. Balance is impaired in people with chronic obstructive pulmonary disease. *Gait Posture*. 2010;31(4):456-460. [CrossRef PubMed](#)
28. Mesquita Montes A, Crasto C, de Melo CA, et al. The effect of inspiratory and expiratory loads on abdominal muscle activity during breathing in subjects "at risk" for the development of chronic obstructive pulmonary disease and healthy. *J Electromyogr Kinesiol*. 2017;34:50-57. [CrossRef PubMed](#)
29. Quijoux F, Vienne-Jumeau A, Bertin-Hugault F, et al. Center of pressure displacement characteristics differentiate fall risk in older people: a systematic review with meta-analysis. *Ageing Res Rev*. 2020;62:101117. [CrossRef PubMed](#)
30. Tan DJ, Lodge CJ, Walters EH, et al. Can we use lung function thresholds and respiratory symptoms to identify pre-chronic obstructive pulmonary disease? A prospective, population-based cohort study. *Am J Respir Crit Care Med*. 2024;209(12):1431-1440. [CrossRef PubMed](#)
31. Singh D, Stockley R, Anzueto A, et al. GOLD Science Committee recommendations for the use of pre- and post-bronchodilator spirometry for the diagnosis of COPD. *Eur Respir J*. 2025;65(2):2401603. [CrossRef PubMed](#)