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Original Articles

A pilot study on the feasibility and effectiveness of treadmill-based perturbations for assessing and improving walking stability in chronic obstructive pulmonary disease

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ABSTRACT

Background: Falls risk is elevated in chronic obstructive pulmonary disease (COPD). However, there is a lack of evidence regarding the contributing factors. Here, we examined the feasibility of, and initial responses to, large walking perturbations in COPD, as well as the adaptation potential of people with COPD to repeated walking perturbations that might indicate potential for perturbation-based balance training in COPD.
Methods: 12 participants with COPD undergoing inpatient pulmonary rehabilitation and 12 age-gender-matched healthy control participants walked on an instrumented treadmill and experienced repeated treadmill-belt acceleration perturbations (leading to a forward balance loss). Three-dimensional motion capture was used to quantify the stability of participants body position during perturbed walking. Feasibility, stability following the initial perturbations and adaptation to repeated perturbations were assessed.
Findings: Using perturbations in this manner was feasible in this population (no harness assists and participants completed the minimum number of perturbations). No clear, specific deficit in reactive walking stability in COPD was found (no significant effects of participant group on stability or recovery step outcomes). There were mixed results for the adaptability outcomes which overall indicated some adaptability to repeated perturbations, but not to the same extent as the healthy control participants.
Interpretation: Treadmill-based perturbations during walking are feasible in COPD. COPD does not appear to result in significant deficits in stability following sudden perturbations and patients do demonstrate some adaptability to repeated perturbations. Perturbation-based balance training may be considered for fall prevention in research and practice in people with COPD.

1. Introduction

Chronic obstructive pulmonary disease (COPD) is characterised by long-term respiratory symptoms and airflow limitation but also by many non-pulmonary features and comorbidities (Global Initiative for Chronic Obstructive Lung Disease, 2020), including lower limb muscle weakness (Maltais et al., 2014), balance, walking and mobility restrictions (Roig et al., 2009), as well as an increased risk of falls (Beauchamp et al., 2009; Hellström et al., 2009; Lawlor et al., 2003; Oliveira et al., 2020; Porto et al., 2017; Roig et al., 2011a). Increased risk of falls during acute exacerbations have also been reported (Crişan et al., 2015; Oliveira et al., 2017; Oliveira et al., 2020). COPD leads to impaired balance performance in typical balance tests (Beauchamp et al., 2012; Boffino et al., 2019; Crişan et al., 2015; de Castro et al., 2016; Loughran et al., 2020;

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Oliveira et al., 2017; Porto et al., 2015; Porto et al., 2017; Roig et al., 2011b; Singh et al., 2019; Tudorache et al., 2015) as well as differences in movement variability and stability during walking compared to healthy participants (Annegarn et al., 2012; Liu et al., 2017; Liu et al., 2020; Sanseverino et al., 2018; Yentes et al., 2011; Yentes et al., 2015). However, many fall risk factors are interrelated in COPD, making conclusions about the origin of balance and walking deficits, as well as falls, in COPD difficult (Beauchamp et al., 2012; Janssens et al., 2013; Morlino et al., 2017; Oliveira et al., 2017; Ozalevli et al., 2011; Porto et al., 2017; Roig et al., 2009; Tudorache et al., 2015).

One issue preventing mechanistic links between fall risk factors and real falls in COPD is the lack of investigation into responses to large mechanical balance disturbances during walking (like slips and trips), which represent the most common causes of falls in the general older population (Berg et al., 1997; Crenshaw et al., 2017; McCrum, 2019; Talbot et al., 2005). Singh et al. (Singh et al., 2019) reported slower stepping reaction times in people with COPD (PwCOPD) versus control participants and Beauchamp et al. (Beauchamp et al., 2012) also found slower reaction and completion times during a forward lean-and-release task. As reduced muscle strength is often considered a potential risk factor for falls, studies in healthy older adults with reduced muscle strength may also provide insight into falls in PwCOPD. Lower limb muscle strength, power and quality have been associated with falls in older adults (Cattagni et al., 2014; Gadelha et al., 2018a; Gadelha et al., 2018b; Skelton et al., 2002) and associations have been reported between lower limb muscle strength and lab-assessed balance recovery performance following lean-and-release (Carty et al., 2012a; Carty et al., 2012b; Grabiner et al., 2005; Karamanidis et al., 2008; Karamanidis and Arampatzis, 2007), trip (Epro et al., 2018; Pavol et al., 2002; Pijnappels et al., 2005; Pijnappels et al., 2008) and slip (Ding and Yang, 2016) perturbations. However, associations have generally been small-to-moderate, and strength training does not seem to be effective as a stand-alone intervention to reduce falls in older adults (Sherrington et al., 2019a). As opposed to strength training alone, interventions including dynamic stepping and perturbation-based balance tasks appear very effective at reducing falls (McCrum et al., 2017; Okubo et al., 2017; Sherrington et al., 2019a) and may be feasible in clinical settings (Gerards et al., 2017). However, the feasibility of large balance disturbances during treadmill walking has not yet been examined in the COPD population. Feasibility may be limited by the ability of PwCOPD to walk for extended periods of time, limiting the number of perturbations that can be applied. Similarly, it is unknown if COPD leads to specific deficits in the performance of such tasks, over and above those seen with ageing. In particular, if PwCOPD show a lack of adaptability to repeated perturbations, then the feasibility of the approach as a training method may be questioned.

To address these gaps, we aimed to: 1) Examine the feasibility of treadmill-based walking perturbations in PwCOPD; 2) Determine if the stability-normalised walking speed approach developed previously (McCrum et al., 2019b) would allow for valid patient-control comparisons of perturbed walking stability as previously shown for healthy young and older adults (McCrum et al., 2018; McCrum et al., 2020); 3) Examine the responses to large walking perturbations in COPD to determine if large deficits may exist; and 4) Evaluate the adaptation potential of PwCOPD to repeated walking perturbations. Regarding aims 3 and 4, we tentatively hypothesised that PwCOPD would exhibit lower stability and would require more recovery steps following novel perturbations but would demonstrate improvement with perturbation repetition.

2. Methods

2.1. Participants

Twelve PwCOPD and 12 age-gender-matched healthy control participants were planned for this pilot study. PwCOPD were recruited during the first week of the inpatient pulmonary rehabilitation programme at Ciro (Horn, The Netherlands), prior to which, they completed an intake assessment, including measurements of isometric and isokinetic knee extension torque (Biodex Systems 3, Biodex Medical Systems Inc., New York, NY, USA; (Sillen et al., 2014a; Sillen et al., 2014b)), a post-bronchodilator lung function test (MS/PFT Body Pro, CareFusion Netherlands B.V.), measurement of body composition (whole-body dual-energy x-ray absorptiometry, Lunar iDXA, GE Healthcare–enCORE v14, Madison, WI, USA), mobility tests (Tinetti-test (Tinetti, 1986) and Short Physical Performance Battery (Guralnik et al., 1994)) and two six-minute walk tests (American Thoracic Society, 2002). Inclusion criteria were a diagnosis of COPD ($FEV_1/FVC < 0.70$), clinically stable (no exacerbation of COPD within four weeks of participating), completed the six-minute walk test without stopping and without assistive devices, no supplemental oxygen use and age 50–80 years old. Healthy participants were recruited via Ciro and were age-gender-matched to the PwCOPD. Inclusion criteria were no known musculoskeletal disease, condition or injury affecting walking or balance, no history of balance problems, dizziness or walking difficulties and the ability to walk non-stop at a comfortable speed for 30 min. Participants provided written informed consent prior to participating. The study was approved by the Medical Research Ethics Committees United (NL61317.100.17) and was performed according to the Declaration of Helsinki.

2.2. Aims assessment

Aim 1 was assessed by the number of perturbations completed by the PwCOPD (up to 10) and the number of "falls" (significant harness support) during the perturbations. A target of five perturbations was the threshold for feasibility, based on previous work (Epro et al., 2018; McCrum et al., 2014; Pai et al., 2014). Aim 2 was assessed by the percentage of participants whose mean margin of stability (MoS) of the final 10 steps prior to the first perturbation was within one SD of the target 0.15 m (see Methods section). Aim 3 was assessed by comparing stability during the recovery steps and by the number of steps needed to return to steady-state walking following the first perturbation to each leg between PwCOPD and controls. Aim 4 was assessed by the change in stability from the start to the end of the perturbation protocol and by the change in the number of recovery steps needed following these perturbations.

2.3. Experimental procedure

Measurements were performed using the Gait Real-time Analysis Interactive Lab (Motekforce Link, Amsterdam, The Netherlands), which includes a dual-belt force plate-instrumented split-belt treadmill (1000 Hz), a 10-camera motion capture system (100 Hz; Vicon Motion Systems, Oxford, UK) and a virtual environment providing optic flow. A safety harness was always used. Eight retroreflective markers were attached to anatomical landmarks (C7, sacrum, left and right lateral epicondyle of the humerus, left and right trochanter and left and right hallux).

Following explanation, trials of 1.5 min were completed at speeds of 0.6 m/s up to 1.4 m/s to familiarise participants with the setup and to determine which speeds were feasible. Measured trials were then conducted at speeds of 0.6 m/s up to 1.4 m/s (increased by 0.2 m/s every 2 min). The procedure was stopped when the participant was not able to continue, as assessed by the participant or investigator (e.g. due to discomfort, fatigue, or an inability to maintain walking at the prescribed speed).

During a rest period, data from the preceding trials were analysed and the participant's stability-normalised walking speed was determined for use in the subsequent perturbation trial (details described elsewhere (McCrum et al., 2018; McCrum et al., 2019b; McCrum et al., 2020)). Briefly, the mean anteroposterior MoS at foot touchdown of the final 10 steps of each completed walking trial (0.6 m/s to 1.4 m/s) were used to determine the walking speed that would result in MoS of 0.15 m for the individual.

The walking perturbation trial then started with two minutes unperturbed walking at the stability-normalised walking speed. Ten unilateral treadmill belt acceleration perturbations were then applied, each occurring every 30–90s. These comprised of a 3 m/s^2 acceleration of the corresponding belt until it reached 180% of the walking speed while the other belt maintained the stability-normalised walking speed. Accelerations were triggered when the hallux marker of the to-be-perturbed limb became anterior to that of the stance limb (i.e. if the right leg was to be perturbed, the acceleration started on the right belt during mid-swing of the right leg so that the belt was already moving faster when the foot touched down). The belt decelerated at the same rate when the perturbed limb left the ground (toe-off). The first and last acceleration perturbed the right leg, while the second to ninth perturbed the left leg. Participants were told that they would complete a walking balance challenge and to try to continue walking as normally as possible; they were unaware of the specifics of the perturbations and no warnings or cues were given.

2.4. Data processing

Data processing was conducted in MATLAB (2016a, The MathWorks, Inc., Natick). The three-dimensional coordinates of the markers were filtered using a low pass second order Butterworth filter (zero-phase) with a 12 Hz cut-off frequency. Foot touchdown and toe-off were determined using a combined marker (Zeni Jr. et al., 2008) and force plate (50 N threshold) method as previously described (McCrum et al., 2019a). The anteroposterior MoS at the instant of foot touchdown were calculated as defined by Hof et al. (Hof et al., 2005). The MoS is an instantaneous measure of the stability of the body configuration in terms of the centre of mass and base of support boundary relationship, accounting for centre of mass velocity during walking., This was done by subtracting the anteroposterior position of the extrapolated centre of mass (X_{CoM}) from that of the anterior boundary of the base of support (anterior hallux marker), both relative to the posterior hallux marker, using the X_{CoM} formula adapted for our reduced kinematic model (Süptitz et al., 2013). The MoS was calculated for: baseline for each perturbation (mean MoS of the eleventh to second last step before each perturbation; Base); the final step before each perturbation (Pre); and the first eight recovery steps following each perturbation (Post1–8). Within these eight analysed recovery steps, the number of steps to return to Base stability (defined as within 0.05 m of the MoS value of Base for each individual) following the perturbation was determined.

2.5. Statistics

To examine the effect of COPD on the MoS during the first perturbation to each leg ($Pert1_R$ and $Pert2_L$), a two-way repeated measures ANOVA with group (COPD or Control) and step (repeated measures: Base, Pre, Post1–8) as factors was conducted, alongside Mann-Whitney tests to compare the number of recovery steps needed by each group. Adaptation potential following repeated perturbations was analysed for each group separately using two-way ANOVAs with perturbation number (repeated measures) and step (repeated measures: Base, Pre, Post1–8) combined with Wilcoxon signed rank tests for the number of recovery steps. The analysis of adaptation potential was conducted in two ways. A conservative approach compared the steps following the first left leg perturbation with the latest perturbation that all participants could complete ($Pert2_L$ vs. $Pert4_L$). An intention to treat approach compared the first left leg perturbation with the final left leg perturbation completed by each individual participant ($Pert2_L$ vs. $PertFINAL_L$). Significance was set at $\alpha = 0.05$. Analyses were performed in GraphPad Prism version 8.4.3 for Windows (GraphPad Software, LLC, San Diego, California, USA).

3. Results

3.1. Participants

Fifteen PwCOPD participated as three PwCOPD were excluded from the analysis and replaced due to technical problems leading to insufficient data-quality (errors due to a force plate issue and problematic reflections). The 12 included PwCOPD were age and gender matched with 12 healthy control participants (maximum age difference of four years). Participant characteristics are presented in Table 1. Seven and 11 PwCOPD could not complete the measurements at the fourth (1.2 m/s) and fifth (1.4 m/s) speeds, respectively, because of dyspnoea and/or fatigue. One healthy participant stopped during the last speed, due to not being able to achieve the prescribed walking speed without running.

3.2. Feasibility of using walking perturbations and the stability-normalised walking speed in people with COPD

The PwCOPD completed an average of 8.2 walking perturbations before stopping. 11 of 12 PwCOPD completed at least five perturbations with one patient stopped after the fourth. No participants required significant harness support to catch them and prevent a fall. Nine out of 12 PwCOPD and 10 out of 12 controls were within 1 SD of the targeted MoS value of 0.15 m and all were within 0.05 m (Fig. 1).

3.3. Responses to large walking perturbations in people with COPD

For the first perturbation to each leg ($Pert1_R$ and $Pert2_L$), two-way repeated measures ANOVAs with group and step as factors did not reveal significant effects of group (Fig. 2; $Pert1_R$: $F_{(1,22)} = 0.8269$, $P = 0.3730$; $Pert2_L$: $F_{(1, 22)} = 0.1793$, $P = 0.6761$). Analysis of the number of recovery steps needed to return to MoS values within 5 cm of Base showed that PwCOPD needed a median of 6 steps for both $Pert1_R$ and $Pert2_L$, whereas the controls required a median of 5 steps (Fig. 3). These differences were not significant (Mann-Whitney test: $P = 0.18$ and $P = 0.4$).

3.4. Adaptation potential following repeated perturbations in people with COPD

The first participant with COPD to stop, stopped after $Pert4_L$. The conservative analysis ($Pert2_L$ vs. $Pert4_L$) did not show a significant effect of perturbation repetition ($F_{(1,11)} = 0.8069$, $P = 0.3883$) (Fig. 4). A Wilcoxon signed rank test on the number of recovery steps also did not reveal a significant change from $Pert2_L$ to $Pert4_L$ but a one-step improvement in the median was seen (Fig. 5). The intention to treat analysis ($Pert2_L$ vs. $PertFINAL_L$) did not show a significant perturbation repetition effect ($F_{(1, 11)} = 3.709$, $P = 0.0803$) although a medium effect was observed post hoc (partial $\eta^2 = 0.079$) which, together with a significant difference between perturbations at Post3 (Sidak's multiple comparisons test: $P = 0.0464$) are suggestive of an effect not detected due to the small sample size (Fig. 4). A significant perturbation number by step interaction was found ($F_{(9, 99)} = 2.851$, $P = 0.0050$) indicating that the stepping behaviour was generally altered. A non-significant, two-step improvement in the median number of recovery steps was seen (Fig. 5).

3.5. Additional post hoc analyses of the control group

To provide further context for the adaptation potential results in the PwCOPD, we additionally analysed the adaptation from $Pert2_L$ to $Pert9_L$ in the matched control group. A two-way repeated measures ANOVA with perturbation number ($Pert2_L$ vs. $Pert9_L$) and step as factors resulted in a significant perturbation repetition effect ($F_{(1, 11)} = 11.02$, $P = 0.0068$) and a significant perturbation number by step interaction ($F_{(9, 99)} = 3.816$, $P = 0.0004$) on the MoS (Fig. 6). Sidak's multiple

Table 1
Participant characteristics and intake assessment outcomes.

	COPD (n = 12)			Healthy (n = 12)		
	Mean ± SD	Minimum	Maximum	Mean ± SD	Minimum	Maximum
Male gender	50%	N/A	N/A	50%	N/A	N/A
Age (yr.)	66.1 ± 8.5	54	79	66.9 ± 7.7	53	78
BMI (kg/m^2)	26.8 ± 6.0	19.5	39.2	26.9 ± 2.9	22.6	33.2
FFMI (kg/m^2)	17.3 ± 2.3	14.5	19.6			
6MWD (m)	427 ± 70	327	569			
6MWD (%pred)[a]	67.9 ± 8.8	54.0	80.0			
FEV_1 (%pred)[b]	51.7 ± 23.3	24.8	93.7			
FEV_1/FVC (%)	36.3 ± 11.6	19.4	59.8			
TLC (%pred)[c]	117.4 ± 16.2	80.9	139.0			
RV (%pred)[c]	144.7 ± 41.2	81.5	219.5			
Quadriceps isometric peak torque (Nm)[d]	129.8 ± 30.4	83.5	170.8			
Quadriceps isokinetic peak torque (Nm)[d]	101.8 ± 23.4	61.9	131.0			
Quadriceps isokinetic peak torque (%pred)[d]	76.3 ± 18.3	49.7	107.4			
SPPB total score (points)	11 ± 1	9	12			
Tinetti total score (points)[e]	28 ± 1	26	28			

[a] Based on reference values by Troosters et al. (Troosters et al., 1999).
[b] Based on reference values by Quanjer et al. (Quanjer et al., 2012).
[c] Based on reference values of Stocks and Quanjer (Stocks and Quanjer, 1995).
[d] %pred based on reference values by Borges (Borges, 1989), n = 9 due to contra-indications for the test in three participants.
[e] : n = 10 due to missing data for two participants; FFMI: Fat Free Mass Index; 6MWD: 6 Minute Walk Distance;FEV_1: Forced Expiratory Volume in 1st second; FVC: Forced Vital Capacity; TLC: Total Lung Capacity; RV: Residual Volume; SPPB: Short Physical Performance Battery; %pred: Percentage of predicted value.

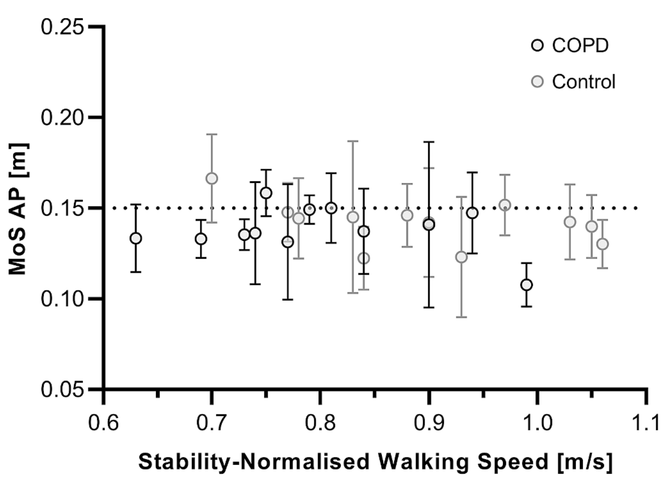

Fig. 1. Means and SDs of the final 10 steps prior to the first perturbation for each individual.

comparisons test found a significant difference between perturbations at Post3 ($P < 0.0001$). When comparing the final perturbation for each group together in a similar manner to the first perturbations, the two-way repeated measures ANOVA with group (COPD vs. Control) and step as factors does not reveal a significant difference ($F_{(1, 22)} = 2.670$, $P = 0.1165$), although this is a small effect (partial $\eta^2 = 0.032$). A comparison of the recovery steps needed during the final perturbation between groups did not reveal a significant difference (Median of 4 steps in each group; Mann-Whitney test: $P = 0.6337$).

4. Discussion

This study addressed the feasibility and potential effects of treadmill-based balance perturbations during walking in PwCOPD. Treadmill-based perturbations were feasible for PwCOPD. We found no significant differences between PwCOPD and matched control participants in stability or the number of recovery steps needed following novel perturbations, leading us to reject our hypothesis. Our hypothesis of significant improvement following repeated perturbations in PwCOPD was only partly supported.

Such perturbations seem feasible in this population as all participants recovered balance without significant harness support and almost all participants could complete the minimum number of perturbations deemed necessary for beneficial adaptations. Larger perturbations (including those initially requiring harness support) might lead to greater training effects (Liu et al., 2016; Wang et al., 2019; Yang et al., 2014) but feasibility and safety should be examined for COPD. However, high magnitudes are not necessary to improve fall-resisting skills (Lee et al., 2016; Liu et al., 2016; Yang et al., 2014), so this is not a barrier for implementation. Additionally, a shorter wash-out time could be applied in practice, allowing more perturbations before fatigue or dyspnoea onset.

Our second aim was to determine if the stability-normalised walking speed approach developed previously (McCrum et al., 2019b) would allow for valid patient-control comparisons of perturbed walking stability in a similar manner as previously shown for healthy young and older adults (McCrum et al., 2018; McCrum et al., 2020). Nine of 12 PwCOPD and 10 of 12 controls were within 1 SD of the targeted MoS of 0.15 m and all were within 0.05 m. These percentages of the samples (75% and 83%) are similar to previous studies in healthy young (83%) and older adults (82%) (McCrum et al., 2018; McCrum et al., 2019b; McCrum et al., 2020), indicating that this procedure can also be used with PwCOPD.

We found no clear deficit in reactive walking stability in PwCOPD over and above that seen with ageing. Muscle strength-related differences in walking stability following perturbations have previously been reported (Ding and Yang, 2016; Epro et al., 2018; Pavol et al., 2002) but we did not see significant group differences during the initial perturbations, despite our PwCOPD having lower quadriceps isokinetic peak torque than would be expected based on age (Borges, 1989). Despite these lack of differences, the lack of effectiveness of resistance exercise alone for falls reduction (Sherrington et al., 2019b) and the more severe consequences of falls in PwCOPD (particularly due to increased prevalence of osteoporosis and fractures (de Luise et al., 2008; Graat-Verboom et al., 2009; Regan et al., 2013; Sarkar et al., 2015; Schnell et al., 2012)), together with the promising results in step and perturbation training in other groups (for example, healthy older adults and people with Parkinson's or stroke; (Gerards et al., 2017; Mansfield et al., 2015; McCrum et al., 2017; Okubo et al., 2017)) might justify further research in PwCOPD.

We found no significant effect of perturbation repetition on stability

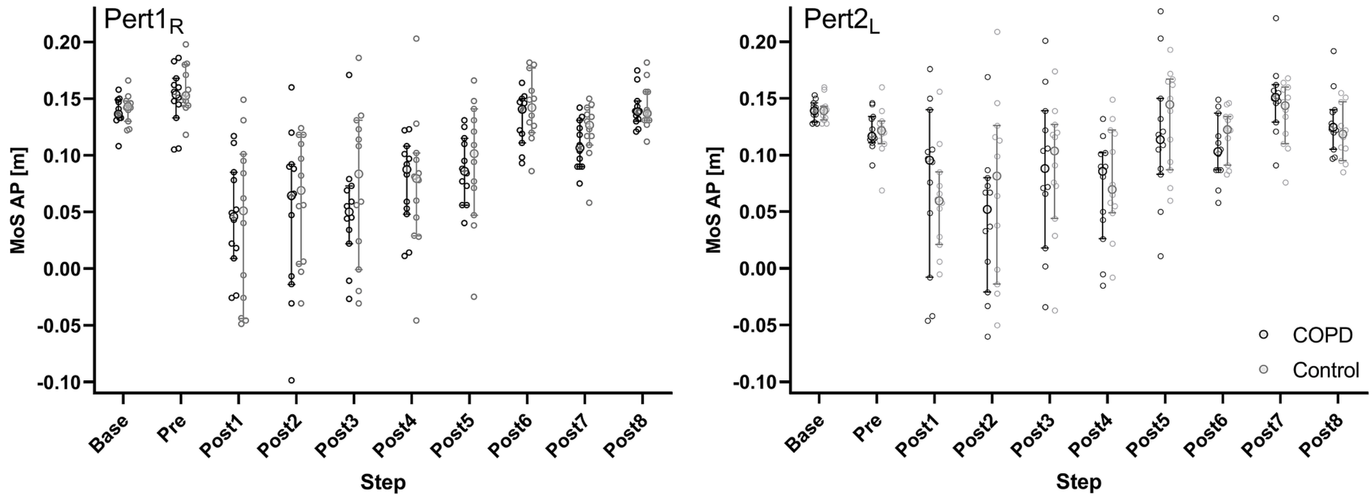

Fig. 2. Median and 95% confidence intervals (with individual data points) of the anteroposterior margins of stability (MoS AP) during the first perturbation to each leg (Pert1$_R$ and Pert2$_L$, respectively) including unperturbed walking prior to each perturbation (Base), the final step prior to each perturbation (Pre) and the first eight recovery steps following the perturbations (Post1–8) for the COPD and control groups.

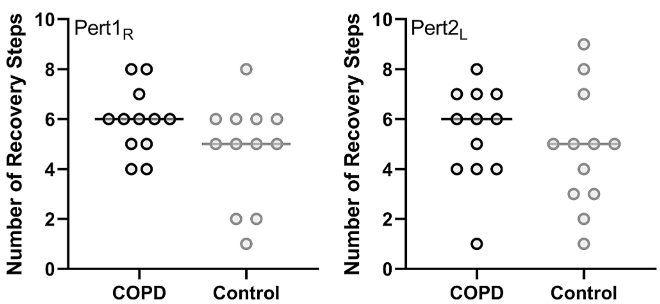

Fig. 3. Medians and individual data points for the number of recovery steps required following the first perturbation to each leg (Pert1$_R$ and Pert2$_L$, respectively) for the COPD and control groups.

in PwCOPD, although a non-significant but potentially meaningful effect was observed. A significant step by perturbation interaction was found, indicating an altered step behaviour following perturbation repetition. The number of recovery steps needed reduced by two (potentially meaningful) but this was not significant. It is well established that healthy older adults can adapt and improve their responses to perturbations with repetition (Bohm et al., 2015; Karamanidis et al., 2020; McCrum et al., 2017). This raises the question of whether PwCOPD have reduced adaptability or perhaps whether the specific perturbation protocol used here was not sufficient to trigger adaptation. Our perturbation protocol did have participants walk at a higher MoS and, therefore, a slower walking speed than our previous studies (McCrum et al., 2018; McCrum et al., 2020), perhaps resulting in less difficulty recovering balance (Krasovsky et al., 2014; Pavol et al., 1999). To check this, we analysed the adaptation from Pert2$_L$ to Pert9$_L$ in our control group and did find a larger and significant improvement in the MoS values. Therefore, the protocol was sufficient to trigger the expected adaptations. This leaves three possibilities: that the reduced number of perturbations by the PwCOPD led to suboptimal adaptation; that fatigue and/or dyspnoea may have negatively influenced adaptation; or that PwCOPD are inherently less adaptable to walking perturbations. The evidence is mixed on whether local lower limb muscle fatigue effects

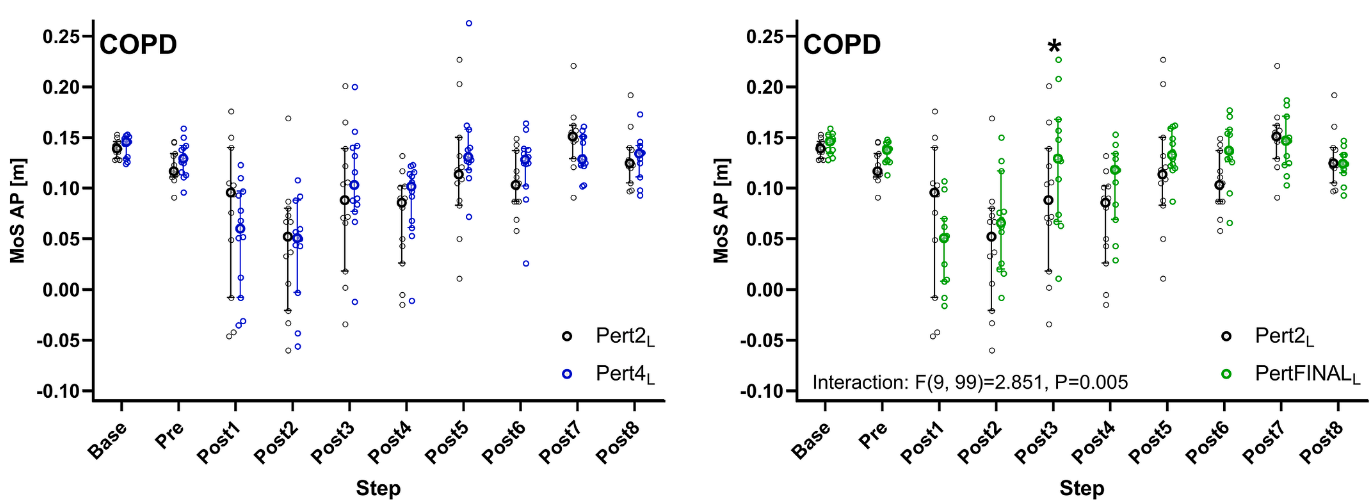

Fig. 4. Median and 95% confidence intervals (with individual data points) of the anteroposterior margins of stability (MoS AP) during the first and third perturbation to the left leg (left panel; conservative analysis; Pert2$_L$ and Pert4$_L$, respectively) and during the first and final (for each individual) perturbation to the left leg (right panel; intention to treat analysis; Pert2$_L$ and PertFINAL$_L$, respectively) including unperturbed walking prior to each perturbation (Base), the final step prior to each perturbation (Pre) and the first eight recovery steps following the perturbations (Post1–8) for the COPD and control groups. *: Significant difference (Sidak's multiple comparisons test: $P = 0.0464$).

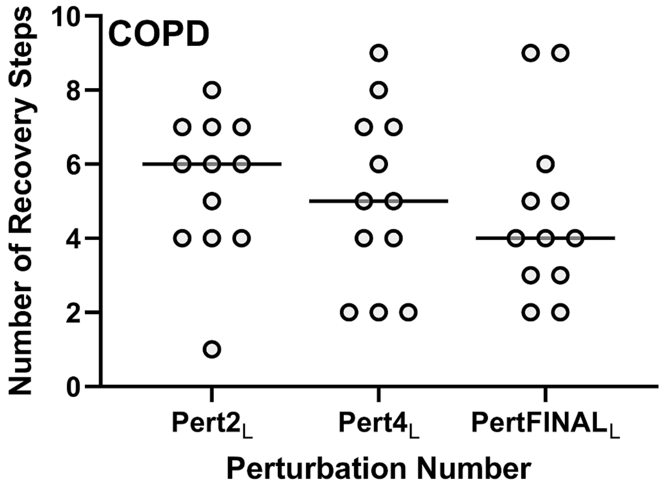

Fig. 5. Medians and individual data points for the number of recovery steps required following the first perturbation to the left leg ($Pert2_L$), the last perturbation to the left leg that all participants completed ($Pert4_L$) and the final perturbation to the left leg that each individual participant completed ($PertFINAL_L$) for the people with COPD.

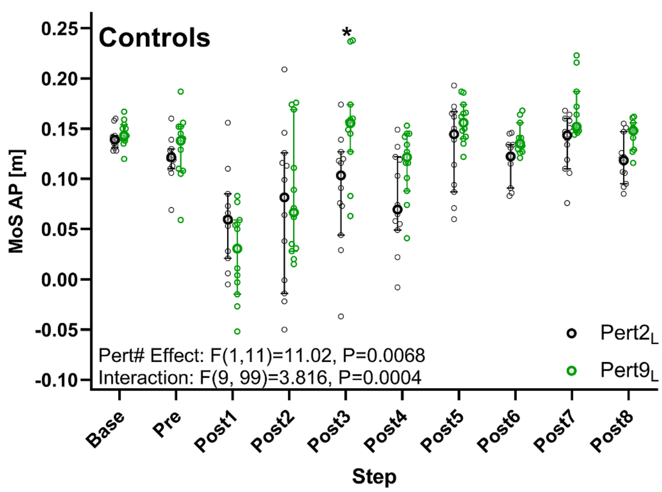

Fig. 6. Median and 95% confidence intervals (with individual data points) of the anteroposterior margins of stability (MoS AP) during the first and final perturbation to the left leg ($Pert2_L$ and $Pert9_L$, respectively) including unperturbed walking prior to each perturbation (Base), the final step prior to each perturbation (Pre) and the first eight recovery steps following the perturbations (Post1–8) for the control group. *: Significant difference at Post3 (Sidak's multiple comparisons test: $P < 0.0001$).

kinematic parameters during balance recovery (Mademli et al., 2008; Papa et al., 2015; Parijat and Lockhart, 2008; Qu et al., 2020; Toebes et al., 2014). However, no studies have examined adaptation to repeated perturbations and it is unclear how these fatigue protocols relate to walking-related fatigue experienced by PwCOPD. We do not think that inherently less adaptability in PwCOPD, independent of fatigue and perturbation repetitions, is likely, as this usually only manifests with pathology of the sensory or nervous systems (Karamanidis et al., 2020; Martelli et al., 2017; McCrum et al., 2014; Moreno Catala et al., 2016; Rand et al., 1998), which were not apparent in our participants. In summary, it seems likely that PwCOPD require an increased number of perturbation repetitions and possibly more rest during the sessions or shorter, more frequent sessions to reduce the potential influence of fatigue and/or dyspnoea.

Some limitations should be highlighted. Our results concern a small group of PwCOPD and may not generalise to all PwCOPD (particularly those with frailty and more severe mobility impairment). Our participants could complete a six-minute walk test, did not use supplemental oxygen and had a mean SPPB score of 11 (range of 9–12); a substantial number of PwCOPD score 9 or less (Mohan et al., 2020; Stoffels et al., 2020). Our control group was not thoroughly screened like the patients, so precise group differences (e.g. lung function) are unknown. Selection bias may have influenced the findings, as patients with concern about balance and falls may not have volunteered. Finally, we would like to highlight that while we have used the MoS as a measure of stability, there are other approaches to quantifying stability during such tasks and it is currently unclear which would be most appropriate in a clinical setting (Bruijn et al., 2013; Grabiner and Kaufman, 2021; Rieger et al., 2021).

5. Conclusions

Using treadmill-based perturbations during walking is feasible in PwCOPD, given appropriate walking speeds and perturbation intensities are selected. COPD does not appear to result in significant deficits in reactive walking stability and patients do demonstrate some adaptability to repeated perturbations (albeit not to the extent of healthy control participants). We recommend that perturbation-based balance training be considered as an option for fall prevention in future research and practice in PwCOPD and that the role of fatigue in balance control and adaptation following larger walking perturbations be further investigated.

Conflicts of interest

None.

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