FALL RISK ASSESSMENT AND PREVENTION IN COPD

STRATEGIES FOR FALL RISK ASSESSMENT AND PREVENTION IN PEOPLE WITH COPD

BY: STEPHANIE CHAUVIN, BHK

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AUTHOR: Stephanie Chauvin (McMaster University)

SUPERVISOR: Dr. Marla Beauchamp

SUPERVISORY COMMITTEE: Dr. Julie Richardson & Dr. Evelyne Durocher

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Abstract

Chronic obstructive pulmonary disease (COPD) is a progressive lung disease comprising of respiratory-related and systemic effects, including impairments in balance. Balance impairments are especially problematic as they increase the risk of falling, potentially leading to negative outcomes such as hospitalization, disability, and death. The main objectives of this thesis were to 1. determine underlying balance impairments that distinguish between individuals with COPD with and without a history of falls and 2. explore facilitators and barriers of a home-based fall prevention program for people with COPD. The first study of this thesis was a secondary analysis of cross-sectional data that showed that the stability limits/verticality and postural responses subcomponents of the Balance Evaluation Systems Test (BESTest) distinguished between those with and without a fall history among 72 patients with moderate to severe COPD. The stability limits/verticality subcomponent also showed acceptable accuracy in identifying individuals with COPD at high risk of falls (cut-off score of 73.8%). In the second study, a qualitative analysis of interviews with 15 patients who completed a home-based fall prevention program, participants indicated that programs that are personalized and focus on providing support for older adults with COPD may help to improve adherence and reduce participants' risk of falling. The findings from the two studies included in this thesis provide new knowledge for informing fall risk assessment and prevention for people with COPD.

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Declaration of Academic Achievement

The following is a declaration that the content of the research in this thesis has been completed by Stephanie Chauvin. From September 2018 to June 2020, Stephanie was responsible for study design, data collection, data analysis, and drafting of the manuscripts. The thesis supervisor, Dr. Marla Beauchamp, was responsible for supervision of study design, data collection, data analysis, and reviewing of manuscripts. The supervisory committee members, Dr. Julie Richardson and Dr. Evelyne Durocher, provided guidance and feedback in committee meetings, assisted with study design, and reviewed the thesis document. Dr. Evelyne Durocher also assisted with study design and data analysis for chapter 3. Furthermore, Dr. Renata Kirkwood (data analysis, review of manuscript), Dr. Dina Brooks (interpretation of data, review of manuscript), and Dr. Roger Goldstein (interpretation of data, review of manuscript) were co-authors of chapter 2.

Chapter 1: Introduction

1.1 Summary of problem

Chronic obstructive pulmonary disease (COPD) is an increasingly prevalent respiratory disease affecting more than 175 million individuals globally.[1] Aside from respiratory-related symptoms such as coughing, sputum production, and dyspnea,[2] multisystem secondary symptoms also typically arise; these can include systemic inflammation,[3–5] skeletal muscle dysfunction,[6,7] weight loss,[8] osteoporosis,[9–11] anxiety,[12] depression,[12] and particularly impairments in balance.[13–17]

Balance impairments can be problematic as they increase the likelihood of falls in older adults,[18] potentially leading to an increase in morbidity, mortality, and reduced functioning.[18,19] Individuals with COPD are approximately 55% more likely to fall compared to their non-COPD counterparts.[20] Despite a growing awareness of balance problems and an increased risk of falling for individuals with COPD, there is a lack of evidence about the best methods for both assessing and managing fall risk with this population.

The general objective of this thesis was to address evidence gaps related to fall risk assessment and management with people with COPD. In Study 1, I examine underlying balance subsystems most important for identifying people at greater risk of falling among individuals with COPD. In study 2, facilitators and barriers of a novel home-based fall prevention program are identified from the perspective of individuals with COPD. Together, these studies contribute new evidence to better inform fall risk assessment and prevention strategies for people with COPD.

1.2 Literature review

1.2.1 Overview of COPD

1.2.1.1 COPD: Definition, prevalence, and clinical presentation

Chronic obstructive pulmonary disease (COPD) is a respiratory disease characterized by chronic expiratory airflow limitation caused by progressive airway and/or alveolar abnormalities.[2] It affects between 174.5 and 384 million individuals globally,[1,21,22] and causes approximately three million deaths worldwide each year, making COPD a leading cause of mortality.[1,2] The prevalence of COPD increases with age and is most common in older adults.[23]

Development and progression of COPD is triggered by modifiable and non-modifiable environmental (smoking;[24–26] passive exposure to smoke;[27] occupational exposure;[28–30] indoor air pollution;[31] urban air pollution),[32] sociodemographic (asthma;[33] gestation and birth processes;[34,35] low socioeconomic status),[36,37] and genetic risk factors (alpha-1-antitrypsin deficiency).[38] While COPD is irreversible, it is possible to reduce the likelihood of its development by reducing an individual's modifiable risk factors.[2]

The most common primary symptoms associated with a diagnosis of COPD include dyspnea, chronic coughing, and chronic sputum production.[2] If an individual presents with these symptoms and has risk factors for COPD such as genetic susceptibility, smoking history, or exposure to pollution (indoor, outdoor, occupational), spirometry can then be used for diagnosis. A post-bronchodilator forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) ratio (FEV_1/FVC) of <0.7 is used to diagnose COPD. Following the diagnosis, FEV_1 can be then used to determine

COPD severity ranging from mild ($FEV_1 \geq 80\%$ predicted), moderate ($50\% \leq FEV_1 < 80\%$ predicted), severe ($30\% \leq FEV_1 < 50\%$ predicted), and very severe ($FEV_1 < 30\%$ predicted) using the Global Initiative for Chronic Obstructive Pulmonary Disease (GOLD) classification.[2]

1.2.1.2 Secondary impairments in COPD

Aside from the expected pulmonary effects of COPD, secondary manifestations impacting the whole body also occur.[2,6,15,39,40] Systemic inflammation,[3–5] skeletal muscle dysfunction,[6,7] weight loss,[8] osteoporosis,[9–11] as well as anxiety and depression[12] are associated with the development and progression of COPD; these secondary manifestations demonstrate that COPD is much more systemic than previously thought. Secondary impairments associated with COPD are problematic as they can lead to reduced exercise capacity,[41,42] a decrease in quality of life,[41,43–45] worse prognosis,[46,47] and an increase in respiratory-related symptoms.[48,49]

1.2.1.3 Management of COPD

The overall goal of COPD management is to reduce symptoms and risks of future exacerbations. This is achieved through pharmacological and non-pharmacological treatments.[2] Pharmacological therapies prescribed to individuals with COPD include inhaled bronchodilators and inhaled corticosteroids to improve symptoms, health status, and reduce exacerbations.[2] Non-pharmacological treatments to manage COPD include smoking cessation interventions, education, pulmonary rehabilitation, nutritional support, oxygen therapy, ventilatory support, and surgery.[2]

1.2.1.4 Pulmonary rehabilitation

Pulmonary rehabilitation is a complex and comprehensive intervention for individuals with chronic respiratory disease and is recognized as the cornerstone of COPD management.[50] Components of pulmonary rehabilitation programs include education, exercise training, nutritional guidance, and psychosocial support provided by a multidisciplinary team, and has proven to be successful in reducing dyspnea, increasing exercise capacity, and improving quality of life for individuals with COPD.[2,50] It is suggested by the American Thoracic Society and European Respiratory Society[51] that pulmonary rehabilitation programs be a minimum of eight weeks with two to three sessions per week, and that longer programs may provide greater benefit.[51]

1.2.2 Balance and falls in older adults

1.2.2.1 Falls in older adults

Falls are one of the leading causes of unintentional injury death globally,[52] with up to 35-40% of healthy adults 65 years and older falling annually.[18,53] In addition to having significant economic consequences (over $2.4 billion annually in Canada),[54] falls can also result in considerable detrimental physical and psychological effects for individuals such as injuries leading to decreased physical functioning, loss of independence, fear of falling, and reduced quality of life, leading to an increase in morbidity and mortality.[18,55]

Falls, for older adults, can be complex and multifaceted. Risk factors with the strongest association for falling include: a history of falls (odds ratio (OR)=2.8), gait and balance impairments (OR=2-2.1), antiepileptic drug usage (OR=1.9), and vertigo

(OR=1.8).[56,57] To determine whether an older adult may be at risk of falling, a fall risk assessment can be completed to better understand the individual's risk factors.

Fall risk assessments with older adults comprise of an evaluation of their medical and falls history, medications, vision, gait, balance, lower limb joints, and neurological and cardiovascular examinations.[18] Similar to tobacco smoking and COPD, reducing individuals' modifiable risk factors can minimize the risk of falling; modifiable risk factors for falls include balance, gait, medications, and the environment.[18] Specifically, balance deficits can be targeted through rehabilitation to reduce the risk of falling.[18,57]

1.2.2.2 Balance control

Balance control is the ability to maintain, achieve, or restore one's centre of gravity over their base of support throughout various postures and activities.[58,59,60] When an individual loses their balance, their centre of gravity has fallen outside of their base of support. Balance control is often classified as either static (balancing when not moving) such as tandem stance (standing with one foot in front of the other, heel-to-toe), or dynamic (balancing while in motion) such as tandem walking (walking heel-to-toe).[61] To effectively maintain balance, multiple systems work together simultaneously; these include the sensory system, central nervous system, and musculoskeletal system.[60,61]

The sensory system is comprised of the visual, somatosensory, and vestibular systems, which each play a key role in balance control. The visual system is responsible for providing information about the environment as well as perceiving where and how one's body is oriented within that environment;[61,62] this system is the basis for proactive balance mechanisms, which are the small adjustments one makes based on the visual information they perceive in order to maintain their balance.[63] The somatosensory system uses messages from muscles, joints, and cutaneous receptors to gather internal information such as length of the muscles or body segment positions in relation to each other, and external environment information like the pressure distribution of a surface.[61] Lastly, the vestibular system is involved in balance control by providing information about one's body orientation, motion, and head position.[61]

The central nervous system (CNS) has a critical role in predictive and reactive balance control. Predictive balance control uses anticipatory postural adjustments to prepare for and maintain balance in the event of an expected perturbation or movement.[63–65] Anticipatory postural adjustments utilize a feedforward mechanism where muscles begin to activate prior to the perturbation; these adjustments are often based on past experiences.[64] In contrast, reactive balance control uses compensatory postural adjustments in response to unexpected perturbations.[63,65–67] Instead of using feedforward mechanisms, compensatory postural adjustments utilize feedback-based mechanisms; sensory feedback signals are sent following an external perturbation to activate compensatory postural adjustments and thus maintain balance.[65]

Finally, the musculoskeletal system is a major component of balance control. In order for the musculoskeletal system to successfully respond to perturbations and signals from the CNS, there needs to be sufficient muscle strength, endurance, power, and joint range of motion to meet external demands being placed on the body.[60] For example, if an individual's ankle range of motion is limited, they may not be able to use the appropriate ankle strategy in order to control their upright posture.[60,68,69] Importantly, deficits in the sensory system, CNS, and musculoskeletal system increase as adults age, increasing the incidence of issues related to balance control and consequently fall risk.[65,68,70–72] Thus, assessing balance is imperative for determining the risk of falling for older adults.

1.2.2.3 Balance assessment

Balance assessments can be used to identify if an individual is at risk of falling and to guide exercise prescription. A plethora of balance assessment tools exist that can be divided into three approaches: 1. functional assessments, 2. systems assessments, and 3. quantitative assessments.[73] Each type of assessment varies in its purpose, the practice settings in which they are utilized, how they are administered, and the length of the assessment.

Functional balance assessments use a variety of motor tasks to assess and track changes in balance, and identify functional limitations.[73] Commonly used functional tests include: 1. Berg Functional Balance Scale (BBS),[74] 2. Functional reach test,[75] 3. One-leg stance,[76] 4. Tinetti Balance and Gait Assessment,[77] and 5. Timed Up and Go (TUG).[78] These functional balance tests can be found in more detail in Table 1. However, the most commonly used balance tests by physiotherapists in Ontario (CAN) include the one-leg stance, BBS, and TUG.[79] While functional balance tests can inform predictions of older adults' risk of falling, are quick to administer, and are relatively inexpensive, they only help to determine whether a balance impairment exists.

Table 1: Functional balance tests

Balance measure	***Description***		***Cut-off for fall prediction***
Berg Functional Balance Scale (BBS)[74] - rating individuals' ability to perform functional activities - clinician-administered	**# of items**	14 items	≤46[80]
	Scoring	0 to 4 (higher=better)	
	Length of test	15 minutes	
Functional reach[75] - maximum distance individuals can reach forward with arms while keeping feet flat on the ground - clinician-administered	**# of items**	1 item	≤15cm
	Scoring	Centimetres (higher=better)	
	Length of test	1 minute	
One-leg stance[76] - how long individuals can stand on one leg unassisted with eyes open and hands on hips - clinician-administered	**# of items**	1 item	<5 seconds[81]
	Scoring	Seconds (higher=better)	
	Length of test	1 minute	
Tinetti Balance and Gait Assessment[77] - rating individuals' ability to perform balance and gait tasks - clinician administered	**# of items**	14 balance items 10 gait items	<19
	Scoring	0 to 2 (higher=better)	
	Length of test	15 minutes	
Timed Up and Go (TUG)[78] - how long it takes for individuals to stand up from a chair, walk 3m, turn back and sit down - clinician-administered	**# of items**	1 item	≥13.5 seconds[82]
	Scoring	Seconds (lower=better)	
	Length of test	3 minutes	

Systems-based balance assessments are more comprehensive than functional balance assessments and can help with the identification of specific balance system(s) underlying the overall balance impairment.[73] By understanding the underlying balance systems that are most impaired, treatment can be targeted to focus on the most affected balance systems. Examples of balance tests that utilize a systems approach include: 1. Balance Evaluation Systems Test (BESTest),[83] 2. Mini-BESTest,[84] and 3. Brief BESTest.[85] These systems assessments measure different subcomponents of balance (biomechanical constraints, stability limits/verticality, anticipatory postural adjustments, postural responses, sensory orientation, stability in gait) based on the Systems Theory of Postural Control, first described by Shumway-Cook and colleagues.[86–88] In the Shumway-Cook model, multiple systems interact to contribute to balance control; these systems include musculoskeletal components, internal representations, sensory strategies, somatosensory system, vestibular system, visual system, and movement strategies.[86–88] Additional systems assessments include: 4. Physiological Profile Assessment (PPA) comprehensive version,[89] and 5. PPA screening version.[89] Details about these systems balance tests can be found in Table 2.

Table 2: Systems balance tests

<table>
<tr><th>Balance measure</th><th colspan="2">Description</th><th>Systems measured</th></tr>
<tr><td rowspan="2">Balance Evaluation Systems Test (BESTest)[83]
- rating individuals on their ability to complete specific tasks from 6 balance systems
- clinician-administered</td><td># of items</td><td>36 items</td><td rowspan="2">1. Biomechanical constraints
2. Stability limits/verticality</td></tr>
<tr><td>Scoring</td><td>0 to 3
(higher=better)</td></tr>
</table>

	Length of test	30 minutes	3. Anticipatory postural adjustments 4. Postural responses 5. Sensory orientation 6. Stability in gait
Mini-BESTest[84] - shortened version of BESTest - rating individuals on their ability to complete specific tasks from 4 balance systems - clinician-administered	**# of items**	16 items	1. Anticipatory postural adjustments 2. Postural responses 3. Sensory orientation 4. Stability in gait
	Scoring	0 to 2 (higher=better)	
	Length of test	15 minutes	
Brief BESTest[85] - shortened version of BESTest - rating individuals on their ability to complete specific tasks from 6 balance systems - clinician-administered	**# of items**	8 items	1. Biomechanical constraints 2. Stability limits/verticality 3. Anticipatory postural adjustments 4. Postural responses 5. Sensory orientation 6. Stability in gait
	Scoring	0 to 3 (higher=better)	
	Length of test	10 minutes	
Physiological Profile Approach (comprehensive version)[89] - rating individuals on their sensorimotor and balance abilities - computer software programme computes overall falls risk score (score of zero=average, above zero=above average, below zero=below average) - clinician-administered	**# of items**	11	1. Visual acuity 2. Contrast Sensitivity 3. Depth perception 4. Tactile sensitivity 5. Vibration sense 6. Proprioception 7. Lower-limb strength 8. Reaction time 9. Postural sway 10. Maximal balance range 11. Coordinated stability
	Scoring	Varies for each task	
	Length of test	60 minutes	

Physiological Profile Approach (screening version)[89] - shortened version of the comprehensive PPA - rating individuals on their sensorimotor and balance abilities - computer software programme computes overall falls risk score (score of zero=average, above zero=above average, below zero=below average) - clinician-administered	**# of items**	5	1. Contrast sensitivity 2. Proprioception 3. Lower-limb strength 4. Reaction time 5. Postural sway
	Scoring	Varies for each task	
	Length of test	20 minutes	

Quantitative assessments can be utilized as objective, technology-based measures of balance to prevent assessor subjectivity in assessment. Examples of quantitative balance tests include: 1. posturography (static and dynamic), and 2. wearable inertial sensors.[90] Static posturography aims to measure an individual's postural sway (the horizontal movement of their centre of gravity while standing still); equipment such as force plates, accelerometers, and wearable inertial sensors are required.[90] In comparison, dynamic posturography measures postural sway in response to external perturbations, surface alterations, or changing visual conditions and provides information about an individual's motor and sensory contributions while balancing; however, the equipment needed for dynamic posturography is expensive and requires a large amount of time and space.[90,91] Wearable inertial sensors provide a cost-effective way to monitor postural sway and movements throughout various tasks on a daily basis, allowing for more feasible measurements than posturography, however there remains limited data about the most important parameters from wearable sensors for predicting fall risk.[90]

1.2.2.4 Balance training

Once a balance assessment has been conducted, exercise training to improve balance and reduce fall risk can begin. Specifically, adding balance training to fall prevention exercise programs has consistently shown to reduce the rate of falls in older adults, and is a strongly recommended component of fall prevention exercise programs.[18,92–95] Balance training components typically include 1. static and dynamic stance exercises (e.g. one-legged stance, tandem stance), 2. transition exercises (e.g. sit to stand, going up and down stairs), 3. gait exercises (e.g. backward walk, tandem walk), and 4. functional strength exercises (e.g. heel raises, squats).[14,96] These balance exercises can also be adapted to challenge different systems, such as performing the one-legged stance with eyes closed or on an uneven surface, or by increasing speed or the number of repetitions.

In addition to balance training, among older adults, a variety of other fall prevention exercise programs have been examined to determine their effect on the rate and risk of falls. Multicomponent group-based and home-based exercise programs have been found to reduce both the rate and risk of falls, with multicomponent programs including at least two or more categories of exercise.[95] Additionally, group-based Tai-Chi significantly reduced the rate and risk of falls in older adults;[95] however, it is thought that Tai-Chi programs reduced the risk of falls primarily because balance training is incorporated in Tai-Chi movements.[93] In comparison, the evidence is less clear about whether group/individual resistance training programs and walking programs reduce the rate and risk of falls. Thus, based on a recent systematic review, it is not suggested that resistance training and walking programs are prescribed as fall prevention interventions on their own; however, they may be included in addition to balance training.[97] Overall, the American Geriatrics Society, British Geriatrics Society, American Academy of Orthopaedic Surgeons,[18] and previous systematic reviews[93,94] strongly recommend that fall prevention programs include balance training that is sustained over time for a minimum of ten weeks to impact fall risk.[18,93,94]

1.2.3 Balance and falls in COPD

1.2.3.1 Balance in COPD

Over the last 10-15 years, numerous studies have shown that balance deficits are a common problem among patients with COPD. Individuals diagnosed with moderate and severe COPD have consistently shown deficits in balance compared to their healthy age-matched counterparts in a variety of functional (TUG, BBS, one-legged stance), systems (BESTest), and quantitative assessments (posturography).[14–16,98–100] A recent systematic review and meta-analysis that included 23 studies and a sample size of 2,751 found that individuals with COPD performed significantly worse on the TUG, BBS, and one-legged stance compared to healthy controls with mean differences of 2.77 seconds, -6.66 points, and -11.75 seconds respectively.[101]

While it is clear that balance deficits are frequently observed in individuals with COPD, the underlying mechanisms that contribute to these impairments in balance remain unclear. Hypotheses for potential causes of balance impairments in people with COPD include skeletal muscle dysfunction,[14,101–103] decreased physical activity,[13,98,101,104] hypoxemia,[105–107] increased dyspnea,[103,105] and somatosensory deficits.[16] Additionally, a recent systematic review suggested that there may be an association between balance and muscle strength, physical activity, and exercise capacity.[101]

Balance is a complex skill that is made up of underlying components; these include 1. biomechanical constraints, 2. stability limits/verticality, 3. anticipatory postural adjustments, 4. postural responses, 5. sensory orientation, and 6. stability in gait.[83] Although systems balance tests have been used to characterize balance problems in a variety of other populations at risk of falls, little research has been conducted so far in COPD. To inform fall risk assessment particularly, a further understanding of the specific types of balance deficits that may be contributing to falls is needed. Only two studies have been conducted utilizing the BESTest to identify the underlying balance impairments in people with COPD compared to healthy controls.[14,108] The first study utilized a cross-sectional design with 37 patients with COPD and 20 age-matched healthy patients. In this study, individuals with COPD demonstrated significantly lower scores in all BESTest subcomponents when compared to the healthy control group, showing marked deficits in the biomechanical constraints, stability in gait, and anticipatory postural adjustments.[14] A second cross-sectional study included 35 patients with COPD and 35 age and sex-matched healthy patients; the authors of this study also found that the patients with COPD had significantly lower scores in all BESTest subdomains.[108] However using the BESTest, it is not clear which balance systems are able to discriminate between people with COPD with and without a fall history. By examining differences in how individuals with COPD with and without a fall history perform on the BESTest subcomponents, the specific balance subcomponents that characterize individuals with an increased fall risk can be identified. This information may have implications for focusing balance assessment and fall prevention strategies on the most important underlying balance systems.

1.2.3.2 Falls in COPD

Individuals with COPD have been shown to be more likely to fall than general populations of community-dwelling older adults.[20,109,110] A retrospective matched cohort study was conducted with 219,945 participants (44,400 COPD patients; 175,545 non-COPD patients) utilizing a UK primary care database from 2000 to 2014.[20] The authors of this study found that people with COPD were 55% more likely to fall than their healthy age- and sex-matched counterparts.[20] Additionally, three prospective observational studies have shown higher incidence rates of falls by individuals with COPD compared to individuals without COPD. The first of these three studies was a six-month cohort study conducted in 2009 comprising of 101 participants with COPD. The fall incidence rate was found to be 1.2 falls per person-year.[109] The second was a 12-month prospective cohort study conducted between 2011 and 2012. Forty-one individuals with COPD participated, and an incidence rate of 1.17 falls per person-year was found.[110] Lastly, a 12-month prospective cohort study was conducted between 2016 and 2017; the study looked at the incidence of falls in 747 patients with COPD. It was found that patients with COPD had a fall incidence rate of 1.49 per person-year.[111] Taken together, the observed incidence rate of falls in patients with COPD to date (1.17 to 1.49 falls/person-year)[109–111] is higher than data reported for community-dwelling older adults without COPD (0.24 to 0.49 falls/person-year).[112–115] Risk factors for falls in people with

COPD are hypothesized to include reduced balance confidence,[13] fear of falling,[110] supplemental oxygen usage,[13] smoking history,[110] increased number of medications,[110] comorbidities,[110] history of falls,[109,110] and balance deficits.[13,16]

1.2.3.3 Balance training and fall prevention in COPD

Balance can be improved through exercise. Multicomponent pulmonary rehabilitation programs that included exercise training have been found to increase functional balance in people with COPD.[116,117] A single-arm longitudinal study of 29 participants with COPD was conducted, where the authors found that a six-week bout of pulmonary rehabilitation improved TUG scores by 1.5 seconds and BBS scores by 2.8 points on average.[116] Additionally, a single-arm quasi-experimental study of 26 participants with COPD found that participation in a 12-week pulmonary rehabilitation program improved TUG scores by 1.1 seconds on average.[117] However, it is notable that the two studies had small sample sizes.

Although general exercise training has been shown to improve balance in COPD, greater improvements are typically seen when balance-specific training is added to the exercise training. For example, in a single-arm quasi-experimental study of 22 patients with COPD, it was found that a 12-week pulmonary rehabilitation program that included balance training improved TUG scores by an average of 1.7 seconds.[118] Additionally, a randomized controlled trial of 39 participants with COPD who either completed six weeks of pulmonary rehabilitation concurrently with balance training (intervention), or six weeks of only pulmonary rehabilitation (control) found that those who were in the intervention group had significantly improved BBS and BESTest scores compared to those in the control group by an average of 5.4 and 9.6 points, respectively.[96] Furthermore, results of a randomized controlled trial of 68 participants with COPD who either completed six months of balance training with pulmonary rehabilitation (intervention) or six months of only pulmonary rehabilitation (control) showed that participants in the intervention group had significantly greater improvements in the TUG (mean difference (MD)=2.3 seconds,), Tinetti test (MD=2.9 points), BBS (MD=6.5 points), one-legged stance (MD=4.1 seconds), and Activities-Specific Balance Confidence scale (MD=17.9%).[119]

These studies demonstrate that general exercise training in pulmonary rehabilitation has been found to improve balance in people with COPD, but balance improvements may be more substantial if balance-specific training is concurrently included. However, more prospective research that incorporates longer-term falls reporting is needed to determine if such programs can impact the frequency or severity of falls. Additionally, we found no studies to date that have evaluated the effects of standalone fall prevention interventions in people with COPD.

In order to reduce fall risk, evidence has shown that balance training exercise needs to be undertaken on a long-term basis. However, in people with COPD, long-term exercise adherence can be difficult. Illness and comorbidities are often perceived as barriers to attending and adhering to an exercise program; COPD-specific barriers include breathlessness, exacerbations, pneumonia, flu, and the unpredictability of health status.[120–126] Individuals with COPD have also cited the disruption of their established routines as a barrier to adherence; specific examples that affected their adherence included providing childcare, acting as a caregiver, working, and hobbies.[121,122,126,127] Location and transportation is a commonly mentioned barrier to attendance and adherence to an exercise program. Patients with COPD may be too unwell to drive, have restricted mobility such as the inability to walk long distances or climb stairs, or live alone and without a car.[120,121,124–126,128] Lastly, lack of support is a perceived barrier for patients with COPD; contributing factors to perceived lack of support can include living alone and feeling socially isolated by their condition.[121,124,128] In terms of increasing participation and adherence, home-based exercise programs have been shown to be successful in populations of both older adults and people with COPD.[129–132] Further studies of home-based exercise programs for reducing the risk of falls for people with COPD is warranted. In particular, given the noted challenges to long-term exercise adherence in people with COPD, it would also be important to understand barriers and facilitators to participation in such a program, from the perspective of people with COPD.

1.3 Summary of research objectives

It is evident that balance problems and falls are major concerns for people with COPD. More research is needed to better understand 1. the types of balance deficits that are most important for fall risk in people with COPD and 2. feasible intervention approaches for reducing falls in people with COPD. To that end, the specific research objectives of this thesis are:

1. to determine the specific balance subcomponents and cut-off scores that discriminate between individuals with COPD with and without a fall history; (Chapter 2)

2. to describe the experiences of older adults with COPD who participated in a home-based fall prevention exercise program. (Chapter 3)

Chapter 2: Which balance subcomponents distinguish between fallers and non-fallers in people with COPD?

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Contributions of the authors:

S. Chauvin: Conceptualization, design, analysis, interpretation of results, drafting of manuscript

R. Kirkwood: Analysis, interpretation of results, critical review of manuscript

D. Brooks: Interpretation of results, critical review of manuscript

R. Goldstein: Interpretation of results, critical review of manuscript

M. Beauchamp: Conceptualization, design, analysis, interpretation of results, critical review of manuscript

2.1 Abstract

Background: Chronic obstructive pulmonary disease (COPD) is an increasingly prevalent lung disease linked to dysfunctional balance and an increased risk of falls. The Balance Evaluation Systems Test (BESTest) evaluates the six underlying subcomponents of functional balance. The aim of this study was to determine the specific balance subcomponents and cut-off scores that discriminate between fallers and non-fallers with COPD to guide fall risk assessment and prevention.

Methods: A secondary analysis of cross-sectional data from two prior studies in COPD was performed. Independent samples t-tests were used to explore the differences in the BESTest sub-system scores between fallers and non-fallers. Receiver operating characteristic curves were used to determine the optimal subcomponent cut-off scores that identified fallers, and the area under the curve (AUC) was used to assess test accuracy.

Results: Data from 72 subjects with COPD (mean age, 70.3±7.4y; mean forced expiratory volume in 1 second, 38.9±15.8% predicted) were analyzed. Two BESTest subcomponents, stability limits/verticality (fallers: 75.4%, non-fallers: 83.8%; p=0.002) and postural responses (fallers: 67.5%, non-fallers: 79.7%; p=0.008) distinguished between fallers and non-fallers. Stability limits/verticality had an AUC of 0.70 and optimal cut-off score of 73.8% for identifying fallers; postural responses had an AUC of 0.67 and optimal cut-off score of 69.4%.

Conclusions: The stability limits/verticality and postural responses subcomponents of the BESTest distinguished between fallers and non-fallers with COPD. The stability

limits/verticality subcomponent can also be used to identify whether an individual with COPD is at risk of falling using a cut-off score of 73.8%. These findings suggest that specific subcomponents of balance could be targeted to optimize fall risk assessment and prevention in COPD.

2.2 Introduction

Chronic obstructive pulmonary disease (COPD) is an increasingly prevalent multi-system disease[5,15] stemming from chronic airflow limitation[21] affecting between 174.5 and 384 million individuals globally.[1,21,22] Symptoms of COPD are predominantly presumed to be respiratory-related such as dyspnea, coughing, sputum production, and wheezing;[21] however, secondary symptoms also include poor lower extremity function, decreased muscle strength, and balance impairments. [13–15,109] Balance impairments are specifically problematic as individuals with COPD are up to 55% more likely to suffer a fall compared to their non-COPD counterparts.[20] Falls are one of the leading causes of accidental injury death worldwide,[52] and can lead to devastating consequences such as injuries, decreased functioning, loss of independence, reduced quality of life, and an increased risk of morbidity and mortality.[18,55] These risks are especially relevant in people with COPD given they have a high number of comorbidities, specifically osteoporosis,[133] which may lead to a greater risk of complications from a fall injury.

Decreasing falls incidence in COPD can be accomplished by conducting a balance assessment to evaluate whether individuals may be at risk for falling and providing balance-specific exercises to those at risk.[134] The Balance Evaluation Systems Test (BESTest) is the most comprehensive balance assessment tool available in any population and has strong construct validity in COPD.[14,135–137] The BESTest is comprised of six subcomponents to assess various areas of balance consistent with the systems framework for postural control: 1) biomechanical constraints, 2) stability limits/verticality, 3) anticipatory postural adjustments, 4) postural responses, 5) sensory orientation, and 6) stability in gait.[83] From these six subcomponents, the underlying systems leading to balance dysfunctions can be determined to guide fall prevention treatment.[83]

Although previous research has demonstrated that total BESTest scores are able to differentiate between individuals with COPD with and without a fall history,[138] studies have not yet examined which specific subcomponents of the BESTest can best identify fallers. By identifying the balance subcomponents associated with fall risk in COPD, fall risk assessment and prevention strategies could be optimized to target the specific balance systems linked to falls in this population. The aim of this study was to determine which BESTest subcomponent scores could discriminate between fallers and non-fallers with COPD and to examine the accuracy and optimal cut-off scores for identifying fallers.

2.3 Methods

2.3.1 Participants

This study was a secondary analysis of data from 72 subjects who participated in either a randomized controlled trial (RCT) of balance training (n=35)[96] or a cross-sectional study on balance systems in COPD (n=37).[14] Both studies were conducted at West Park Healthcare Centre in Toronto, Canada, and inclusion/exclusion criteria were similar; participants required a diagnosis of COPD,[139] and were excluded if they were unable to communicate or had either neurological or musculoskeletal conditions that limited mobility.[14,96] Additionally, participants in the RCT needed to have self-reported balance problems or a fall in the past five years,[96] and participants in the cross-sectional study had to have a smoking history of at least ten pack years.[14] The RCT had a total of 35 patients with 15 (42.9%) having reported a fall in the past year, and the cross-sectional study had a total of 37 patients with 19 (51.1%) having reported a fall in the past year. Fallers were defined as individuals with a history of at least one fall in the previous 12 months, with a fall being defined as an occasion where you find yourself unintentionally on a lower level.[140] Written informed consent was provided by all participants in both studies, study approval was obtained by the Bridgepoint/West Park research ethics board (No. 10-001; 13-011-WP),[14,96] and was conducted in accordance with the Declaration of Helsinki.

2.3.2 Measures

2.3.2.1 Balance Evaluation Systems Test

Participants in both studies were assessed at baseline using the BESTest.[14,96] The BESTest is a comprehensive balance assessment tool developed in 2009 to screen for balance impairments in six different postural control systems.[83] There are 36 tasks to complete in the BESTest that are divided into the following subcomponents; 5 in biomechanical constraints, 7 in stability limits/verticality, 6 in anticipatory postural adjustments, 6 in postural responses, 5 in sensory orientation, and 7 in stability in gait.[83]

Each subcomponent of the BESTest assesses different systems of balance, which can be found in Table 3.

Table 3: BESTest subcomponent descriptions

Subcomponent	**Assessment focus**
Biomechanical constraints	Constraints affecting standing balance
Stability limits/verticality	Distance the body can move from its base of support before losing balance, and vertical posture
Anticipatory adjustments/transitions	Actively moving the body's center of mass in anticipation of body position transitions
Postural responses	In-place and compensatory stepping corrections in response to external perturbations
Sensory orientation	Body sway when performing stances with altered visual or surface somatosensory information
Stability in gait	Evaluation of balance while walking

Individuals are scored in each task by an assessor using a 4-point Likert scale with 0 being "worst performance" and 3 being "best performance". Scores are calculated per system as well as for the total test, and can then be converted into percentages where the higher the score, the better the balance.[83] The BESTest has strong inter-rater reliability and validity in individuals with COPD.[138]

2.3.3 Statistical analyses

Statistical analyses were conducted using IBM SPSS Statistics version 25 (IBM Corp, Armonk, New York). Descriptive statistics were conducted in the form of means and standard deviations (SD) to summarize the sample. Variables that were explored included: age, body mass index (BMI), 6-minute walk distance, forced expiratory volume in one second (FEV_1), forced vital capacity (FVC), FEV_1/FVC ratio, males and females, Medical Research Council (MRC) dyspnea, and supplemental oxygen usage.

Two-tailed independent samples *t*-tests were used to examine whether the BESTest and its different subcomponents were able to discriminate between fallers and non-fallers with COPD. An α value of ≤ 0.0085 was considered significant based on a Šidák correction to prevent Type I Error for examining differences in the six subcomponents.[141] All BESTest scores and sub-scores were based on percentages out of 100. Effect sizes were calculated to understand the magnitude of differences between fallers and non-fallers based on the following equation: Cohen's $d = (M_2 - M_1) / SD_{pooled}$.[142]

To identify the optimal cut-off score for identifying fallers for each of the BESTest subcomponent scores, receiver operating characteristic (ROC) curves were used. The datapoint closest to the left-hand corner of the curve was chosen as the cut-off that optimized both sensitivity and specificity. Based on convention, an acceptable area under the curve (AUC) was deemed as 0.7 or greater.[143]

2.4 Results

2.4.1 Subjects

Subject characteristics are provided in Table 4. A total of 34 (47%) participants were categorized as fallers and 38 (53%) as non-fallers. Participants were 70.3 years of age on average (SD=7.4) and had moderate to very severe COPD diagnoses (GOLD stages 2-4)[21] with a mean FEV_1 % predicted of 38.9% (SD=15.8). Participants had an average 6-minute walk test distance of 304.3m (SD=104.5), and 26 (36%) were supplemental oxygen users.

Table 4: Characteristics for fallers (n=34) and non-fallers (n=38)

Variable	Fallers (n=34)	Non-fallers (n=38)	Combined (n=72)
Age, y	71 ± 8.0	70 ± 6.0	70 ± 7.0
BMI, kg/m^2	26.5 ± 5.8	26.9 ± 8.0	26.7 ± 7.0
6MWD, m	288.1 ± 111.1	318.2 ± 98.1	304.3 ± 104.5
FEV_1, L	0.9 ± 0.3	0.9 ± 0.4	0.9 ± 0.3
FEV_1, % predicted	39.5 ± 14.5	38.3 ± 17.3	38.9±15.8
FVC, L	2.5 ± 0.6	2.4 ± 0.7	2.4 ± 0.6
FEV_1/FVC, %	42.5 ± 13.5	42.1 ± 15.9	42.3 ± 14.6
Men, No. (%)	16 (47)	15 (39)	31 (43)
MRC dyspnea	3.6 ± 1.2	3.3 ± 1.0	3.5 ± 1.1
On oxygen, No. (%)	8 (24)	18 (47)	26 (36)

Note: Data are presented as mean ± SD.

Abbreviations: BMI, body mass index; 6MWD, 6-minute Walk Distance; FEV_1, forced expiratory volume in 1-second; FVC, forced vital capacity; MRC, Medical Research Council.

2.4.2 Comparison of fallers and non-fallers

Results comparing the BESTest sub-scores in fallers versus non-fallers are provided in Table 5. Total BESTest scores were significantly different between fallers and non-fallers with a mean difference of 7.9%; p=0.005. Non-fallers had higher (better) BESTest scores within each subcomponent compared to fallers; however this difference reached statistical significance (p=0.0085) only for stability limits/verticality and postural responses. Within the stability limits/verticality subcomponent of the BESTest, fallers significantly differed from non-fallers by a mean difference of 8.5%; p=0.002. Within the postural responses subcomponent, fallers significantly differed from non-fallers by a mean difference of 12.2%; p=0.008.

Table 5: BESTest scores in fallers (n=34) compared to non-fallers (n=38)

Variable	Fallers (n=34)	Non-fallers (n=38)	Mean difference	Effect size	95% CI	p-value
BESTest total[a]	65.5 ± 12.7	73.39 ± 10.4	7.9	0.68	2.5 to 13.3	0.005
Biomechanical constraints	58.6 ± 17.7	63.16 ± 17.2	4.5	0.26	-3.7 to 12.8	0.276
Stability limits/verticality[b]	75.4 ± 13.3	83.83 ± 8.3	8.5	0.77	3.3 to 13.6	0.002
Anticipatory postural adjustments	63.7 ± 15.5	71.93 ± 13.6	8.2	0.56	1.4 to 15.0	0.019
Postural responses[b]	67.5 ± 22.9	79.68 ± 14.7	12.2	0.48	3.2 to 21.2	0.008
Sensory orientation	73.7 ± 16.0	81.93 ± 11.9	8.2	0.58	1.6 to 14.8	0.015
Stability in gait	54.5 ± 17.9	60.03 ± 19.5	5.5	0.30	-3.3 to 14.4	0.214

Notes: Data are presented as mean ± SD.

[a]Statistically significant at 0.05 level.

[b]Statistically significant at 0.0085 level.

2.4.3 Predictive accuracy and cut-off scores

Results of the ROC curve analysis for each of the BESTest subcomponent scores are provided in Table 6, and the ROC curves are shown in Figure 1. The only subcomponent score with an acceptable AUC (≥0.7) for identifying fallers was stability limits/verticality with an AUC of 0.70 (Figure 2). The optimal cut-off for identifying fallers was 73.8% with a sensitivity and specificity of 0.87 and 0.47, respectively. The remaining subcomponent scores did not achieve an AUC of 0.7.

Table 6: BESTest total and subcomponent AUCs and cut-off scores

Variable	AUC (95% CI)	Cut-off point	Sensitivity	Specificity
BESTest total	0.69 (0.57-0.81)	70.8	0.66	0.65
Biomechanical constraints	0.57 (0.44-0.70)	56.7	0.66	0.41
Stability limits/verticality	0.70 (0.58-0.83)	73.8	0.87	0.47
Anticipatory postural adjustments	0.67 (0.55-0.80)	69.4	0.63	0.71
Postural responses	0.67 (0.54-0.80)	69.4	0.79	0.50
Sensory orientation	0.67 (0.54-0.79)	83.3	0.53	0.77
Stability in gait	0.56 (0.43-0.70)	64.3	0.45	0.71

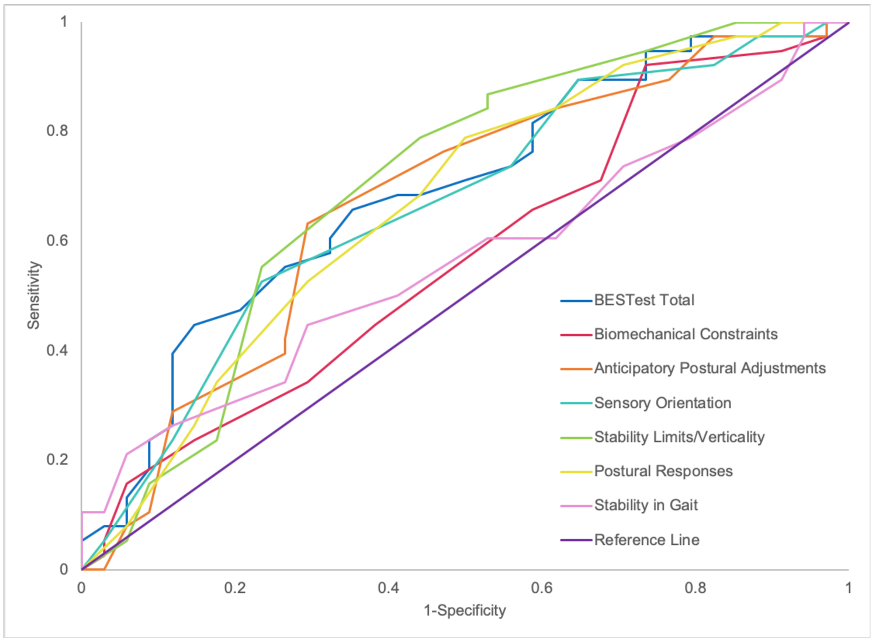

Figure 1: ROC curve for BESTest total and subcomponent scores for identifying fallers with COPD

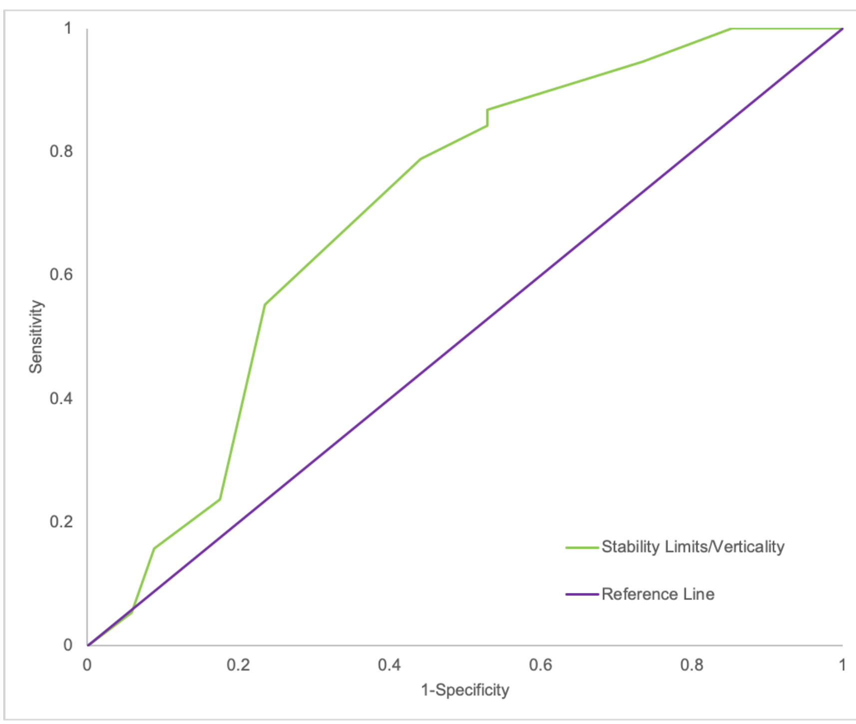

Figure 2: ROC curve for stability subcomponent score for identifying fallers with COPD

2.5 Discussion

Individuals with COPD have known balance dysfunctions and an increased fall risk. To our knowledge, this is the first study to examine the specific subcomponents of the BESTest that discriminate between fallers and non-fallers with COPD. The findings of this study indicate that stability limits/verticality and postural responses were the two subcomponents that best characterized fallers with COPD. Additionally, a cut-off score of 73.8% was found to have acceptable accuracy for identifying fallers within the stability limits/verticality subcomponent. These findings have relevant implications for optimizing fall risk assessment and prevention in COPD.

Consistent with previous work, our study found that the total BESTest score discriminated between fallers and non-fallers with COPD.[138] The mean difference between fallers and non-fallers' total score was 7.9% in the current study with an effect size of 0.68, compared to 10.1% in Jácome (2016) with an effect size of 0.87.[138] Additionally, we showed that the stability limits/verticality and postural responses subcomponents of the BESTest were the only subcomponents that differentiate between fallers and non-fallers. Although the other subcomponents were not significantly different between fallers and non-fallers, it is important to note that the magnitude of the difference (8.2%) in anticipatory postural adjustments and sensory orientation subcomponents approached the previously reported clinically important difference on the full BESTest in COPD.[144] Taken together, this information may have relevance for informing fall prevention strategies in COPD by allowing therapists to target these specific underlying subsystems within fall prevention exercise programs (e.g., functional reaching, perturbation training, body position changes and altering sensory stimuli).

This secondary analysis also determined that the stability limits/verticality subcomponent may be used to identify whether an individual with COPD is at risk of falling using a cut-off score of 73.8% within that subcomponent to identify fallers. The AUC for stability limits/verticality (0.70) was greater than the entire BESTest as well as all other subcomponents; and it was the only subcomponent to attain acceptable accuracy for screening. This suggests it may be possible to administer the stability limits/verticality tasks independent of the other subcomponents; instead of 36 tasks, only 7 tasks would need to be administered to gain similar information on fall risk. However, it is worth noting that the stability limits/verticality subcomponent had relatively low specificity (0.47) for identifying fallers. To our knowledge, this is the first study utilizing ROC curves to explore BESTest subcomponents to determine fall risk in individuals with COPD and thus we are unable to compare our findings to other literature. However, previous work in stroke patients has shown that four BESTest subcomponents (biomechanical constraints, anticipatory postural adjustments, sensory orientation, and stability in gait) had acceptable accuracy in identifying fallers.[145] Although these findings need to be validated prospectively, our results suggest that within this COPD cohort, stability limits/verticality sub-scores may have an important role both when trying to identify fall status and implement effective balance interventions. It is worth noting that the full BESTest and three other subcomponents (anticipatory postural adjustments, postural responses, and sensory orientation) demonstrated borderline acceptable accuracy with AUCs of 0.67 to 0.69.

It is interesting to note that the stability in gait subcomponent, which includes the Timed Up and Go Test (TUG), showed poor sensitivity (0.45) for identifying fallers. Although many studies have reported on use of the TUG in patients with COPD, there is very little evidence related to fall risk within this population. To our knowledge, only one prior study with a relatively small sample size has looked at the predictive validity of the TUG for falls in individuals with COPD. In this study (n=50), time to complete the TUG predicted fall recurrence with a sensitivity exceeding 0.90.[146] In contrast, a systematic review examining the TUG's ability to predict fall risk in community-dwelling older adults found limited predictive ability for the TUG with a pooled sensitivity of only 0.31.[147] The mixed evidence across populations demonstrates the need for more research exploring the best tests for fall risk prediction in people with COPD.

One interesting finding of this study was supplemental oxygen usage in fallers vs. non-fallers; 47% of non-fallers were on supplemental oxygen compared to only 24% of fallers. This finding is similar to a previous prospective cohort study where individuals with COPD who used supplemental oxygen were less likely to fall compared to those who were not supplemental oxygen users.[148] However, this is contrary to past cross-sectional and observational studies.[13,109] While examining the link between supplemental oxygen usage and falls was not the primary aim of the current study, the conflicting findings highlight the need for further studies to elucidate risk factors for falls in this population.

2.6 Limitations

Several limitations need to be taken into account when interpreting our results. The data were cross-sectional; thus, we are unable to determine whether balance impairments preceded or succeeded fall events. Participants reported falls in the past 12 months retrospectively, potentially leading to recall bias and underestimation of the number of fall events. Additionally, due to being a secondary analysis of two prior studies, the inclusion criteria varied slightly and there were different assessors evaluating BESTest performances, possibly leading to measurement error. This work was retrospective and therefore hypothesis generating; as such, future work would benefit from a prospective study to confirm which BESTest subcomponents accurately identify future fallers. Finally, it is possible there was insufficient power to detect differences in other subcomponents. Based on the data collected, a sample size upwards of 300 would have been needed to detect smaller differences in some subcomponents (e.g. stability in gait and biomechanical constraints). However, given the smaller effect sizes noted for these subcomponents, these differences are unlikely to be clinically important.

2.7 Conclusions

In summary, the stability limits/verticality and postural responses subcomponents of the BESTest were able to differentiate between fallers and non-fallers with COPD. Additionally, stability limits/verticality may be used to identify whether an individual with COPD is at risk of falling using a cut-off score of 73.8%. However, the specificity of stability limits/verticality was low and prospective studies are needed to draw conclusions on its validity for fall risk assessment. If confirmed prospectively, these findings suggest that the stability limits/verticality and postural responses subcomponents may play a vital role in optimizing fall risk assessment and prevention in individuals with COPD.

Chapter 3: Experiences of a home-based fall prevention exercise program among older adults with chronic lung disease

Stephanie Chauvin, Evelyne Durocher, Julie Richardson, Marla K Beauchamp

Under review: Disability and Rehabilitation

Contributions of the authors:

S. Chauvin: Conceptualization, design, data collection, analysis, interpretation of results, drafting of manuscript

E. Durocher: Design, analysis, interpretation of results, critical review of manuscript

J. Richardson: Design, critical review of manuscript

M. Beauchamp: Conceptualization, design, analysis, interpretation of results, critical review of manuscript

3.1 Abstract

Background: Individuals with chronic obstructive pulmonary disease (COPD) often have mobility limitations; these may include challenges with balance and being at high risk of falling. Risk of falling can be reduced through exercise programs targeting balance; however, older adults with COPD may experience many barriers to exercise adherence. In this paper we present qualitative findings about the feasibility of a six-month home-based fall-prevention exercise program for older adults with COPD. The aim of the study was to describe the experiences of older adults with COPD who participated in a home-based fall prevention exercise program.

Methods: 15 participants with COPD who had completed the six-month home-based program participated in one-on-one semi-structured interviews over the phone. Interpretive description methodology and thematic analysis were used.

Results: Two major themes emerged with respect to participants' perspectives of the intervention and facilitators and barriers to participation: program personalization based on each individual's characteristics, lifestyles, and preferences; and self-motivation and support from family, friends, and healthcare providers.

Conclusions: Fall prevention exercise programs that are personalized and focus on providing support for older adults with COPD may help to improve adherence and reduce participants' risk of falling.

3.2 Introduction

Chronic obstructive pulmonary disease (COPD) is a highly prevalent age-dependent respiratory condition and a leading cause of morbidity and mortality globally.[2,149,150] Coughing, dyspnea, and sputum production are among the most common respiratory-related symptoms,[2] along with multi-system symptoms such as reduced exercise capacity, a decline in mobility, and notably, balance impairments.[13,15,109,151] Deficits in balance increase the risk of falls in older adults,[18] and particularly high fall incidence rates have been reported among older adults diagnosed with COPD (1.17 to 1.49 falls/person-year)[109–111] compared to community-dwelling older adults (0.24 to 0.49 falls/person-year).[112–115] This is concerning as falls can have enormous personal and economic consequences with over $2 billion in direct healthcare costs spent each year in Canada.[54] Falls have also been found to cause approximately 95% of all hip fractures,[152,153] which in turn can lead to disability and death.[154]

Impairments in balance, and subsequently risk of falls, can be reduced through exercise programs aimed at improving balance for individuals with COPD; such improvements have been demonstrated through the combination of pulmonary rehabilitation programs and balance exercises.[96,119] However, a plethora of barriers to attendance and adherence to exercise programs for individuals with COPD have been identified including illness and comorbidities,[120–126] the disruption that such programs may present to individuals' established routines,[121,122,126,127] location/transportation of the programs,[120,121,124–126,128] and lack of social support.[121,124,128] To reduce these participation barriers and encourage exercise adherence, home-based exercise programs have been implemented and have been shown to be effective with various populations .[129–132]

In order to address risk of falls in people with chronic lung disease and to overcome common barriers to participating in exercise for a prolonged period of time, we recently conducted a pilot trial of a tailored home-based fall-prevention program for older adults with COPD. This paper reports the results of our qualitative analysis; the quantitative findings will be reported elsewhere. The aim of this research was to explore the experiences of participants with COPD who participated in the home-based fall prevention exercise program in order to determine their perceived facilitators and barriers to participation. Exploring the experiences of individuals with COPD who were enrolled in the program will enable us to optimize our interventions aimed at reducing falls in this at-risk population.

3.3 Methodology

3.3.1 Study design

In this qualitative paper, we utilized an interpretive description approach[155] to explore the perspectives of individuals about their experiences participating in the six-month home-based fall prevention program. Interpretive description was developed by Thorne (1997) as a method for conducting research aimed at informing healthcare and clinical practice.[155,156]

This study was part of a larger pilot study exploring the feasibility and preliminary efficacy of a six-month home-based fall prevention program for older adults with COPD (ClinicalTrials.Gov ID: NCT02695342), and was approved by the Hamilton Integrated Research Ethics Board (HiREB ID #1072) and the West Park Joint Research Ethics Board (JREB Number: 15-027-WP). This is the first paper reporting on results from the pilot trial.

3.3.2 Home-based fall prevention program

The six-month home-based fall prevention program was a single-group, non-randomized clinical trial intended to determine the feasibility and preliminary efficacy of a fall prevention program completed at home by older adults with COPD. The intervention consisted of six months of home-based fall prevention exercises, which were taught to participants through four home visits by a physiotherapist during the first six weeks of the study; during these home visits, the therapist also individualized the exercises based on the participant's ability. Thereafter, participants were encouraged to complete 40 minutes of independent exercise three times per week where they tracked their activity in an exercise diary. Participants were provided with paper and DVD/online visual demonstrations to guide them through the exercises and received bimonthly phone calls for support by the therapist. In addition, an optional visit was offered for patients to help resume their exercises if they experienced a COPD exacerbation.[157]

Participants were included in the study if they were older adults (≥60 years) from West Park Healthcare Centre (Toronto, ON) or the Firestone Institute for Respiratory Health (Hamilton, ON), had a clinical diagnosis of COPD based on the Global Initiative for Chronic Obstructive Lung Disease (GOLD) guidelines,[2] and who either self-reported a fall in the past year, were worried about falling, or had self-reported balance difficulties. Individuals were excluded if they had a history of significant cardiovascular disease, had marked oxygen desaturation at rest or with exertion, had musculoskeletal or neurological co-morbidities severely limiting their mobility or risking safety, were unable to communicate in English, had completed pulmonary rehabilitation in the past six months, or were on a waitlist for pulmonary rehabilitation.

3.3.3 Participants & recruitment

Purposive sampling was used to recruit participants based on their completing at least three months of the home-based fall prevention program as well as meeting the program inclusion criteria mentioned above.[158] Thirty-six individuals had enrolled and participated in the home-based fall prevention program; of those 36 individuals, 26 were eligible to be included in the qualitative study based on completing at least three months of the program, being accessible for follow-up, and were not deceased. The 26 potential participants had previously consented to be contacted for further research and were contacted by telephone by a research assistant who had no previous contact or relationship with the participants. During this call, individuals were provided with information about the qualitative study and screened for eligibility. If individuals were interested and eligible for the study, a one-on-one semi-structured telephone interview was scheduled at the end of the recruitment phone call and a consent form was mailed to the participant for their review prior to the interview.

3.3.4 Data collection

One-on-one semi-structured interviews were conducted with participants over the phone by author (SC) between August 2019 and January 2020. The interview guide was informed by a guide used in a previous qualitative study[159] that explored the experiences of participants with COPD who had completed an exercise maintenance program in a community centre. Examples of questions included “What did you like best about the home balance exercise program? What did you like least?”, “What made it difficult or easy to complete the program?”, and “Do you think the program benefitted you?”. Interviews were audio-recorded and began with the interviewer reviewing the mailed consent form and obtaining verbal consent from the participant.

3.3.5 Data analysis

Interviews were transcribed verbatim by a professional transcriptionist. As is suggested using interpretive description methodology, the analysis began with the first author, SC, reading over the transcripts several times to become immersed in the data.[156] Following immersion, SC began inductive thematic analysis using basic word processing software. In line with interpretive description methodology, descriptive coding was utilized where a code summarized the main topic of a passage.[160,161] An inductive approach to coding was taken and so the codebook was developed as the analysis proceeded, with new codes being added as well as merged with previous codes. Once the codebook was completed, all transcripts were recoded using the final version of the codebook. After all of the data had been coded, the information from each code was extracted into an Excel spreadsheet so that the data could easily be organized and manipulated for the identification of patterns and discrepancies. At this point in the analysis the codes were organized into categories, which were discussed and refined in collaboration with authors ED and MKB. Further manipulation of the data enabled the identification of the initial themes. A glossary of the categories and initial themes was developed and guided a final discussion between authors to further refine the identified themes.

Following the Consolidated Criteria for Reporting Qualitative Studies (COREQ) guidelines, it is important to note the research team's characteristics and relationships with participants.[162] SC is a rehabilitation science graduate student, and ED is a rehabilitation science professor with a background in occupational therapy and experience with qualitative research methods. MKB is a rehabilitation science professor with a background in physiotherapy; she is the principal investigator of the pilot study. None of the investigators involved in the analysis had previous contact with participants.

3.4 Results

Of the 26 potential participants from the pilot study: 2 declined, 9 could not be reached, and 15 consented to participate. Participants were older adults aged 60 years to 86 years (mean age=75 years), 11 (73%) were female, and all had COPD diagnoses ranging from mild to severe based on GOLD criteria;[2] further demographic characteristics can be found in Table 7. The interviews ranged from 18 to 40 minutes in length with an average length of 25 minutes, and included 174 double-spaced pages of data. The main themes identified included program personalization and self-motivation and support. These will be discussed in more depth below. From these two themes, we can begin to identify facilitators and barriers faced by people with COPD in completing a home-based fall prevention exercise program.

Table 7: Participant demographics (n=15)

Variables	**n=15** **mean (SD)**
Age (years)	74.6 (7.5)
Sex, female, n (%)	11 (73.3)
BMI	27.3 (4.6)
FEV_1 (% predicted)	47.8 (14.6)
6MWD (m)	347.6 (57.5)
Fall history, yes, n (%)	4 (26.7)
On oxygen, yes, n (%)	4 (26.7)
Number of Comorbidities	5.3 (2.5)

SD = Standard Deviation; BMI = Body Mass Index; FEV_1 = Forced Expiratory Volume in 1-second; 6MWD = 6-Minute Walk Distance.

3.4.1 Program personalization based on each individual's characteristics, lifestyles, and preferences

Throughout the interviews, participants discussed their perspectives of the exercise program and how their personal characteristics, lifestyles, and preferences shaped their experiences. Categories discussed included adaptation in light of health conditions, physical fitness levels, exercise guidance from healthcare providers, personal commitments, context preferences, and paper- vs DVD-based implementation.

Adaptation in light of health conditions

Individuals who had participated in the fall prevention program had COPD diagnoses and were close in age, but the similarities stopped there. For example, individuals typically had varying health limitations such as frequent exacerbations, arthritis causing limited physical functioning, limited mobility, and back pain; ten participants explained that having these health limitations sometimes made it difficult to complete certain exercises, or even any exercises at all. One participant (P8) who had mobility limitations stated: "There were activities for certain exercises that I couldn't do. But that was because I was limited. [The physiotherapists] both came to the house and agreed about certain exercises not to do." Another participant (P7) said: "during the program, I had a cold and we put [the program] off… put it off for a couple of weeks… until I kind of could breathe better… So that was good for me". While both P8 and P7 had differing health limitations (limited mobility and seasonal illness, respectively) preventing them from completing specific exercises, the program was tailored to suit their needs on differing days depending on their abilities or illnesses, therefore enabling them to move forward despite the limitations.

Physical fitness levels of individuals

In addition to individuals having varying health limitations, participants also had differing physical fitness levels. Because of their different fitness levels, five individuals mentioned that the exercises were either too easy or too difficult. P3 said that "obviously some of the exercises were pretty challenging and I never quite think I mastered them". In reference to the same exercises, P1 stated:

> A lot of [the exercises] were very interesting but personally I had such strong legs they weren't doing me much good at the time. But you have to realize I've been a skier all my life… I worked outside… it's just in the past, oh, I don't know, 6 to 8 months I guess, I started losing muscle.

It is clear that P3 and P1 had differing physical fitness levels based on their ability to perform similar exercises within the program. While P3 thought the exercises were difficult, P1 led an active life which made the same exercises seem easy.

Exercise guidance from healthcare providers

Individuals stressed the benefits of incorporating personal exercise guidance from healthcare providers via home visits and phone calls. Seven participants reflected on the guidance and instruction provided by the supervising physiotherapist, commenting on their assistance with exercise pacing, utilizing the space in their home, breathing tips, and providing general personal assistance. Participant P8 discussed pacing, saying "I was very quick… [the physiotherapist] was there to make me slow down. So therefore it was great that she came in the odd time". Another participant, P6, commented on the personal assistance they received and how to exercise within the space available to them:

> Well, the [physiotherapist] was very good at checking the house out and saying, "Here, you're going to hold onto the buffet when you do this step. You're going to walk from the TV all the way to the couch in the living room. That's your 10 steps"… [The physiotherapist] was very good at working within the constraints of this old house and this old woman.

The quotations from P8 and P6 demonstrate participants' appreciation for the healthcare providers in assisting them with their exercises within the fall prevention program, personalizing the program to each individual and their context. Whether it be through pacing advice, guidance on space, or general personal assistance, participants were instructed on how to perform their exercises properly to decrease the risk of injury and allow them to feel safe and comfortable completing the program at home.

Personal commitments of individuals

Building on the individuality of each participant, seven participants noted that they had varying personal commitments throughout the program such as participating in other exercises, hobbies and housework or taking pre-booked holidays. P7 discussed the many different exercises they were completing on a daily basis, saying "I've also got to do breathing exercises, and I have to do weights stuff. By the time I'm finished, the morning's shot". Another participant, P11, mentioned they felt they did not have enough hours in a day while completing the program:

> What was difficult finishing [the program] was the fact I'm thinking I've got all these birthdays coming up and I've got Christmas coming up. I knit for [the hospital], and I knit for the women's shelter. And gosh, it's coming on and I haven't got all this stuff done… I just didn't have enough hours in the day… I do my breathing exercises… I do exercises for my neck, I do exercises for my lumbar spine. And I felt I was over-exercising.

These quotations demonstrate the challenges some participants faced in juggling many commitments participants have in addition to the fall prevention program, making it difficult to find enough time in the day to complete all of their tasks.

Context preferences based on each individual

Individuals had differing preferences on where they participated in an exercise program. Four participants mentioned drawbacks to completing the program at home such as having a lack of space, requiring too much equipment, and being alone. For example, P5 stated "I think I would have felt a lot safer if [the program] was at a community centre, … having someone be there just in case". In contrast, nine participants preferred completing the program at home due to the familiarity of their surroundings and the lack of distractions, the flexibility the home context afforded in their schedule, and that there were no associated costs or wait times. Participant P14 said:

> [the program] was easier here because I could sort of do my own timeframe. It would usually be in the morning. I have more energy in the morning. But I'd also incorporate it with my daily activities like… take my medication, have a little breakfast, and then do it… Sometimes I'd do [the exercises] in the afternoon… And I could just do it just about anywhere. So that was really neat.

Individuals' personal preferences were based on many contextual factors such as the feeling of safety that comes with having others around, or the flexibility of being able to exercise whenever/wherever as shown in the quotations above. P5 would have chosen to complete the fall prevention program in the community to feel safer, whereas P14 preferred the flexibility of being able to complete the program at home.

Paper- vs. DVD-based implementation

Along with setting preferences, participants also discussed whether they utilized the paper-or DVD-based version of materials they were provided to follow exercises. Of the 15 individuals, 11 preferred paper-based, 3 DVD-based, and one utilized both versions. Individuals who preferred the paper-based medium commented on its ease, portability, and concision. P1 stated:

> I used [the DVD]… until I got used to all the exercises. [The physiotherapist] also left me a sheet of paper with the exercises on it… So I was able to follow that much [more easily] than looking at this little screen hardly being able to see it. With the paper, I had no problem.

Participants who preferred the DVD-based medium mentioned its helpfulness in pacing and guiding them through the exercises. P3 for example said "Oh, I just used the DVD… Because I find it's paced… if you try and do it yourself, you might be too quick or whatever. So I liked to follow along at that pace". All participants had different reasons for their choice of which medium they utilized.

In conclusion, participants discussed their differing personal characteristics, lifestyles, and preferences in relation to the home-based fall prevention program. These individual differences emphasized the importance of program personalization for each participant to ensure adherence to a home exercise program.

3.4.2 Self-motivation and support from family, friends, and healthcare providers

In addition to program personalization, motivation and social support played a large role in the maintenance and completion of the fall prevention program. Participants discussed the importance of their own self-motivation, support from their family, friends, as well as healthcare providers.

Self-motivation

Eight participants discussed that their drive to continue the program was largely due to their own self-motivation via commitment, determination, and guilt. P11 said "What helped me complete [the program] is me because if I start something, I finish it… I don't even think my kids know or knew that I was doing it". When participant P14 was asked if they had any social support to help them complete the program, they stated "not really, no. I live on my own… I told people about [the program] and they looked at me like I was crazy". However, what P14 said did help them to complete the program was:

> motivation to feel stronger. I know that sounds like it was idealistic answers. But that's the way I felt. Some days I didn't feel like doing it, of course… you wake up and you're, "really, do I have to?" But then the alternative for me is… to go backwards with the COPD.

P11 and P14 relied on their own self-motivation to persevere through the program as they felt they did not have any social support throughout the process. These quotations demonstrate a strong sense of self-motivation.

Support from family and/or friends

Support from family and/or friends also played a role in the maintenance and completion of the fall prevention program for some participants. Four participants discussed the social support they received from their grandkids, wives, friends, and peers. When participant P1 was asked if they had any social support to help them complete the program, they responded with "yeah, my wife bugging me to keep going". Another participant, P5, said "the motivation was easy when the grandchildren were here… they were doing [the program] with me". This displays that while more than half of participants relied heavily on their own self-motivation, other participants relied on social support from family and/or friends to complete the program.

Support from healthcare providers

In addition to support provided by family and/or friends, support was offered by physiotherapists. Four participants commented on the encouragement, motivation, and appreciation they were provided with via the home visits and phone calls from the physiotherapist to complete the fall prevention program. Participant P15 mentioned that "for the three-month and six-month follow-up on [the program], I think it was… just the encouragement I got. Saying that … I did improve a bit". Another participant, P2, stated:

> I loved when [the physiotherapist] came because she was so appreciative of what I was doing. So she made me feel good… Because she could see the improvement… you had this person… keeping you going… And then, you know, I'd get a pat on the back because I was improving, which is nice.

The statements from P15 and P2 demonstrate that the physiotherapists provided support to participants via encouragement, motivation, and appreciation. The healthcare providers were able to point out participant improvements that otherwise may have gone unnoticed and in turn, provided support and encouragement for participants to maintain and complete the program.

Based on our analysis, it is evident that participants had differing levels of social support ranging from self-motivation, support from friends and/or family, support from healthcare providers, as well as no perceived support.

3.5 Discussion

In this paper, we explored the experiences of participants with COPD who participated in a six-month home-based fall prevention program. Based on the analysis, we identified key aspects that individuals deemed important when participating in the program, which are critical to informing future interventions targeting long-term exercise and fall risk reduction in people with chronic lung disease. Based on our findings, we have developed a list of recommendations for home-based fall prevention programs which can be found in Table 8.

Table 8: Recommendations for future home-based fall prevention programs in COPD

Recommendations
• Modify or progress exercises based on each individual's physical fitness levels • Take into account individuals' personal commitments and responsibilities outside of the program • Determine location preferences of each individual (at home or in the community) • Provide multiple implementation mediums (paper-based, DVD, online) • Incorporate social support from healthcare providers in instances when self-motivation and/or social support from family and friends is not available

The first major theme around participant experiences of the home-based program was program personalization based on each individual's characteristics, lifestyles, and preferences. This result is consistent with a recent review of the literature that identified a need for individualized pulmonary rehabilitation to accommodate the varied physical, emotional, and social traits of individuals with COPD.[163] Qualitative empirical studies exploring how to improve pulmonary rehabilitation and post-pulmonary rehabilitation exercise adherence by individuals with COPD have also identified tailored and adaptable programs as key strategies.[164,165] Participants in our study suggested various ways in how the home-based fall prevention program could be personalized such as by: adapting the program to take into account health conditions; considering the varying fitness levels of individuals; providing personalized exercise guidance from healthcare providers; accommodating for personal commitments; offering various exercise location options; and presenting multiple mediums in which the program is implemented. These strategies are consistent with previous literature in that they addressed many factors that individuals with COPD have expressed impact their exercise adherence. Barriers found by previous studies included illness and comorbidities,[120–126,165–168] potential disruption of routines or personal commitments,[121,122,126,127,167] and requirements for transportation;[120,121,124–126,128,165,167] whereas facilitators included having a range of exercise options available,[166–168] having personalized guidance from healthcare providers,[124,166,167] having variable locations,[120,121,124–126,128,165,167] and including multiple implementation preferences.[169,170] The data from these studies as well as ours suggest that a one-size fits all approach may not be optimal for people living with COPD, especially given the fluctuating and variable nature of the disease. Future iterations of this home-based fall prevention intervention may benefit from a suite of different options in which participants can select the format and delivery model most suitable for them. For example, participants can choose home- vs. community centre-based programs, individual- vs. group-based, or paper- vs. technology-based formats based on their needs and preferences.

The second major theme influencing participation in the program was self-motivation and support from family, friends, and healthcare providers. Self-motivation to adhere to the program played a large role for participants in the absence of support from family and/or friends, which is consistent with a previous study that found self-motivation to be a facilitator of exercise adherence in people with COPD who participated in a 12-week resistance training program.[124] In addition to self-motivation, participants in our study discussed the support they had from their significant others, grandkids, friends, and peers who encouraged them to complete the fall prevention program. This finding reaffirms the importance of social support in adhering to exercise programs in individuals with COPD as shown in previous qualitative studies in people with COPD where participants discussed that support from their family, friends, neighbours, and exercise group facilitated adherence.[121,128,167] Moreover, support from healthcare providers in the form of encouragement and personalised feedback was recognized by participants as beneficial in completing the program, which has previously been shown as a strong facilitator in exercise adherence.[165–167] Group and peer support is often cited as a facilitator in adhering to exercise programs.[124,128,165] However, the home-based fall prevention program was completed individually at home and participants did not have communication with other participants, thus the benefits of group and peer supports were not found within this study. Prescription of home-based exercise programs may need to take into account the sources of support available to participants to ensure participants have some form of social support. For example, individuals without support systems may require more follow-up by healthcare providers than those with stronger networks.

3.6 Strengths & limitations

This is the first study to explore the experiences of individuals with COPD who had participated in a home-based fall prevention exercise program. Previous research has shown that personalization and having support are imperative for facilitating exercise adherence in individuals with COPD in general; the results from this study built on these findings and identified specific factors that could be taken into account to help facilitate participation in home-based fall prevention programming such as inclusion of multiple delivery formats and having ongoing support and feedback from a healthcare provider.

A limitation of this study is that participants who had been interviewed had completed the entire six-month program. Our aim was to include participants who had completed at least 3 months to increase diversity, but those individuals were either no longer eligible to participate or could not be reached during recruitment. In addition, males were underrepresented given there were only 4 men out of the 15 participants interviewed. It is also important to note that these participants volunteered to be part of this research study, demonstrating they may be highly motivated individuals and may not be representative of the COPD population as a whole.

Moreover, the pilot study of the home-based fall prevention program was ongoing and had rolling recruitment; thus, some participants were interviewed over a year after they had completed the exercise program. This may have prevented participants from recalling all aspects of the program. Lastly, some participants had taken part in other exercise programs and became confused at times about which program was being discussed.

3.7 Conclusion

In conclusion, this qualitative study affirms the importance of program personalization and support to patients with COPD who participated in a six-month home-based fall prevention exercise program. By exploring perceived facilitators and barriers to program participation, future interventions can be optimized to ensure the success of fall prevention exercise programs for individuals with COPD.

Chapter 4: Discussion and conclusion

4.1 Overview of findings

The studies in this thesis contribute important new knowledge to the literature about fall risk assessment and prevention in patients with COPD. Specifically, the novel findings of this thesis are:

1. The stability limits/verticality and postural responses subcomponents of the Balance Evaluation Systems Test (BESTest) distinguished between individuals with COPD with and without a fall history. The stability limits/verticality subcomponent can also be used to identify whether an individual with COPD is at greater risk of falling using a cut-off score of 73.8%.

2. Fall prevention exercise programs that are personalized and focus on providing support for older adults with COPD may help to improve adherence and reduce participants' risk of falling.

These findings highlight potential opportunities for optimization of balance assessment and fall prevention for people with COPD. Understanding the underlying balance systems that discriminate between individuals with COPD with and without a fall history provides important information for advancing balance testing for fall risk assessment in this population. In addition, insight into the perceived facilitators and barriers of the first home-based fall prevention exercise program for individuals with COPD is important for informing the development of fall prevention interventions for people with COPD.

4.2 Balance and fall risk assessment in COPD

COPD is an increasingly prevalent chronic lung disease that includes respiratory-related symptoms and systemic secondary impairments, including balance deficits that can lead to an increased risk of falls.[2,13,15,109,151] This thesis has highlighted the underlying balance impairments in people with COPD with a positive fall history. This information can be used to inform specific strategies for balance and fall risk assessment in individuals with COPD.

In chapter 2, we used a comprehensive systems-based balance assessment tool, the BESTest, to understand specific balance systems affecting people with COPD who have a fall history. Balance is made up of a complex interaction of multiple systems; by identifying the specific systems that are impaired in individuals who fall and the cut-off values that can be used to identify individuals at greater risk of falling, fall risk assessment can be optimized in COPD. We showed that the stability limits/verticality subcomponent of the BESTest balance assessment tool had acceptable accuracy for identifying whether an individual with COPD is at risk of falling using a cut-off score of 73.8%. This finding is important as this is the first study, to our knowledge, to use ROC curves to explore the ability of the BESTest subcomponents for identifying people with COPD at greater risk of falling. If confirmed prospectively, this study suggests that the BESTest stability limits/verticality subcomponent could be administered independently of the full BESTest to quickly determine fall risk in people with COPD. Instead of assessing 36 tasks lasting upwards of 30 minutes,[83] the stability limits/verticality subsection includes four tasks and takes less than five minutes to administer. These tasks include sitting verticality (left and right), lateral leans (left and right), functional reach forward, and a lateral functional reach (left and right).[83] In line with clinical practice guidelines for fall risk assessment and prevention in older adults, once an individual with COPD is assessed and is found to be at greater risk for falling using a stability limits/verticality score <73.8%, they could then be referred to a fall prevention program aiming to improve balance and subsequently decrease fall risk.

4.3 Fall prevention programs utilizing balance training in COPD

Balance has been found to improve for people with COPD following participation in a pulmonary rehabilitation program that incorporates balance training ;[96,119] such programs are thus thought to decrease fall risk. However, in order for interventions to have the greatest impact on falls, the underlying components of balance that contribute to fall risk in people with COPD should be targeted. In chapter 2, we showed that two of the six BESTest subcomponents were able to distinguish between individuals with COPD with and without a fall history; these subcomponents were stability limits/verticality and postural responses to unexpected perturbations. Understanding the underlying balance systems that are most impaired in fallers with COPD can be used to inform exercise interventions to subsequently reduce falls. For example, perturbation-based training is a balance training technique that mimics real-life unexpected perturbations; an example of such training could include a nudge while walking to challenge one's balance. Specifically, perturbation-based training aims to improve reactive balance control (postural responses subcomponent on the BESTest) and has shown promising results.[171] A systematic review and meta-analysis of eight studies with 404 participants found that perturbation-based training may reduce fall risk in older adults as well as individuals with Parkinson disease.[172] Future work should include a prospective study exploring balance exercise with an emphasis on perturbation-based training as well as stability limits training in people with COPD to determine if targeting these balance systems can help reduce falls.

Chapter 3 explored the participant experiences of individuals with COPD who had completed a six-month home-based fall prevention program utilizing balance training to reduce fall risk. The home-based program consisted of fall prevention exercises that were completed three times a week for 40 minutes each using paper and DVD/online visual demonstrations. Participants were also taught the exercises by a physiotherapist during four home visits within the first six weeks of the program, with additional bimonthly phone calls for support. Participants were also offered booster visits following acute exacerbations. It is important to note that this was an evaluation of the first fall prevention program adapted specifically for individuals with COPD.

From the interviews conducted, it was found that program personalization and social support played large roles in facilitating adherence to the program. Specifically, program personalization included taking into account participants' health conditions, physical fitness levels, personal commitments, context preferences, and providing exercise guidance from healthcare providers and multiple implementation mediums. Support in terms of self-motivation as well as support from family, friends, and healthcare providers were also important to participants in adhering to the program. Previous studies have qualitatively explored the experiences of, as well as facilitators and barriers for, people with COPD who have participated in exercise programs in general,[127,168,173] but not home-based balance training programs specifically. By understanding participants' experiences and identifying the aspects important to them in relation to the program, researchers and clinicians can then incorporate these aspects into future programs. For example, future home programs should include options for progression of exercises based on individual physical fitness levels and preferences, and incorporate social support from healthcare providers. Incorporating program personalization and support into home-based programs may help to promote exercise adherence, thus potentially decreasing fall risk.

4.4 Limitations and future directions

The findings of this thesis should be considered in light of several limitations. Chapter 2 was a secondary analysis where participants were included from two separate studies with slightly different inclusion criteria and were assessed by different assessors. Additionally, retrospective reporting of falls was used, potentially leading to recall bias and underestimation of falls. Lastly, there may have been insufficient power to detect differences between individuals with and without a fall history; a sample size upwards of 300 would have been needed to detect smaller differences in some subcomponents (e.g. stability in gait and biomechanical constraints). Future work should include a one-year prospective cohort study to track falls with a baseline comprehensive balance assessment using the BESTest on a larger sample of patients with COPD.

In chapter 3, participants who had consented to interviews were those that had completed all six months of the home-based fall prevention program, reducing the diversity of the sample. We had intended on gathering the perspectives of those who had dropped out of the program as well, however many participants were deceased or difficult to contact by phone. Additionally, some participants were interviewed over a year after they had completed the fall prevention program; this delay may have caused participants to forget aspects of the program as well as to become confused if they had taken part in other exercise programs since the study completion. Future work should include: 1. more interventions evaluating how to reduce fall risk in COPD, and 2. interventions that take into account the needs and preferences for this specific population.

4.5 Concluding remarks

In conclusion, this thesis contributes new evidence to the field of fall risk assessment and prevention in people with COPD. The stability limits/verticality subcomponent of the BESTest can be utilized to identify individuals with COPD who may be at risk of falling, and thus who should be encouraged to partake in balance training to improve balance and reduce fall risk. Additionally, the BESTest balance subcomponents that were able to discriminate between individuals with and without a fall history (stability limits/verticality and postural responses) could be specifically targeted as part of balance training and fall prevention exercise programs in those with COPD. Finally, the success of fall prevention exercise programs for people with COPD could be optimized by incorporating program personalization and social support for people with COPD. These findings highlight important avenues for further research to help reduce the potentially devastating consequences of falls in people with COPD.

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