THE INFLUENCE OF INSPIRATORY MUSCLE TRAINING UPON BALANCE AND FUNCTIONAL PERFORMANCE WITH OLDER ADULTS

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ABSTRACT

Accidental falls are the leading cause of fatal and non-fatal injuries amongst older adults in the Western world. Around 30% of people over 65 years will fall at least once a year in the UK, whereas 50% of people over 80 years will fall annually (NICE 2013). Recently, falls prevention programmes have begun to incorporate multidimensional movements with controlled breathing techniques (e.g. yoga, Tai chi and Pilates).

Based on the research of Hodges, the diaphragm muscle may contribute to balance maintenance in two ways. Firstly, the diaphragm is activated during upper limb movements, which indicates that diaphragm co-activation may assist in the mechanical stabilisation of the spine. Secondly, the diaphragm plays a key role in the development of intra-abdominal pressure that helps to stabilise the lumbar spine during balance perturbations (e.g. shoulder abduction and adduction).

This doctoral project investigates whether the effects of structured inspiratory muscle training (IMT) on respiratory function can improve indices of balance and physical performance with older adults. The project comprises three studies, each involved IMT delivered over 8 weeks, at home, and unsupervised. The IMT included: workload progression (increased according to each participant's weekly improvement), twice-daily sessions (morning and evening) and training diaries (to monitor progression, adherence and attrition).

Outcomes included: respiratory muscle function (e.g. maximal inspiratory pressure), physical performance (e.g. timed up and go), static and dynamic balance (e.g. mini-BEST) and trunk muscle strength (e.g. isometric flexion and extension) for a sample of older adults (n = 129; age 72 ± 5 years).

In study 1 IMT was found to be both feasible and safe, as an unsupervised home-based intervention with healthy older adults. In study 2 IMT proved to also be effective in improving respiratory muscle function, physical performance, dynamic balance and trunk muscle endurance. The final study (3) involved a comparison of community-dwellers performing IMT, and care home residents performing the Otago exercise programme (an established falls prevention intervention). Results showed that IMT produced similar balance improvements as the Otago exercise programme over 8 weeks, but with additional benefit to inspiratory muscle function and walking speed.

In combination, these findings support the possibility of introducing IMT as a novel intervention for falls prevention for older adults in isolation, or together with established falls prevention intervention.

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Chapter One

INTRODUCTION

“Moderns are like dwarves perched on the shoulders of giants [the Ancients], and thus we are able to see more and farther than the latter. And this is not at all because of the acuteness of our sight or the stature of our body, but because we are carried aloft and elevated by the magnitude of the giants”

Bernard of Chartres

1.1 Outline of chapter one

The following chapter introduces to the importance of falls prevention in the older population, giving a definition to “a fall” and briefly explaining the main aspects of balance. The chapter continues with a description of the respiratory system, focusing upon the inspiratory muscles. Firstly, looking at the anatomical structure of the thoracic cavity, and secondly discussing the role of the inspiratory muscles in maintaining balance, as well as the physiological effects of ageing upon the respiratory system. The chapter concludes with an overview of research that has implemented inspiratory muscle training with healthy older adults, in the context of enhancing respiratory and exercise performance outcomes.

1.2 Balance and ageing

Despite more than 50 years of research on fall accidents, there is no consensus on the definition of “a fall”. Zecevic and colleagues (Zecevic et al. 2006) demonstrated that the definition changes between participants and research literature. It is, therefore, necessary to clarify the term to avoid misconception. This thesis follows the definition of Lamb and colleagues: “a fall is an unexpected event in which the participant comes to rest on the ground floor or lower level” (Lamb et al. 2005).

Accidental falls are the leading cause of fatal and non-fatal injuries amongst older adults in the Western world. Around 30% of people over 65 years will fall at least once a year in the UK, whereas 50% of people over 80 years will fall annually (NICE 2013) with 10% of falls injuries resulting in a fracture (Campbell et al. 1990). However, also minor injuries (e.g. bruising and abrasions) and the psychological consequences (e.g. fear of falling and loss of confidence) (Yardley and Smith 2002) of fall accident, increase the risk of morbidity and mortality (Graham et al. 1993).

Unless caused by unanticipated external forces, falls accidents are consequence of a lack of balance. Balance is a multifaceted mechanism associated with three broad aspects:

- **Static.** Maintenance of posture (e.g. sitting or standing)
- **Anticipatory.** Voluntary dynamic movements (e.g. walking)
- **Reactive.** Reaction to an external disturbance (e.g. quickly reacting to prevent a fall) (Pollock et al. 2000).

Balance is achieved when the sum of the external forces (including gravity) and internal disturbance forces (e.g. respiration) is zero, such that the centre of motion (CoM) is controlled relative to the base of support (BoS) (Horak). To maintain balance, the somatosensory, visual and vestibular systems must work in a synchronised manner. With a firm base of support, healthy individuals rely on information from all three sensory systems: somatosensory by 70%, visual by 10% and vestibular by 20% (Peterka 2002).

All the components are controlled by the nervous system that organises this information and selects the appropriate postural responses according to the environmental context. The responses to perturbation are then produced by the musculoskeletal system, via the nervous system, inducing joint movements. However, age-related neuromuscular impairments reduce the reactive responses (Moreland et al. 2004) and can potentially contribute to fall accidents (Horak et al. 1989).

Balance is then a complex prerequisite for daily activities that is impaired by the process of ageing. In order to improve it, recent guidelines recommend the use of multicomponent interventions that include gait, strength and balance exercises (Sherrington 2016) (e.g. Otago exercise program (Campbell et al. 1997)).

Recently, respiratory muscles (particularly the diaphragm) have also been shown to participate directly in the production of balance proficiency (Kocjan et al. 2018), albeit the contributions of individual muscles remains unclear, it is possible to hypotheses that improvements in inspiratory muscle strength and function can consequently enhance balance ability, potentially similar to that degree observed after strength and balance exercises.

1.3 Anatomy of the inspiratory muscles

The respiratory muscles (Figure 1- 1) are divided into inspiratory (i.e. the diaphragm, external intercostals, scalenes and sternocleidomastoid) and expiratory muscles (i.e. internal intercostals, external and internal oblique, transversus abdominis and rectus abdominis).

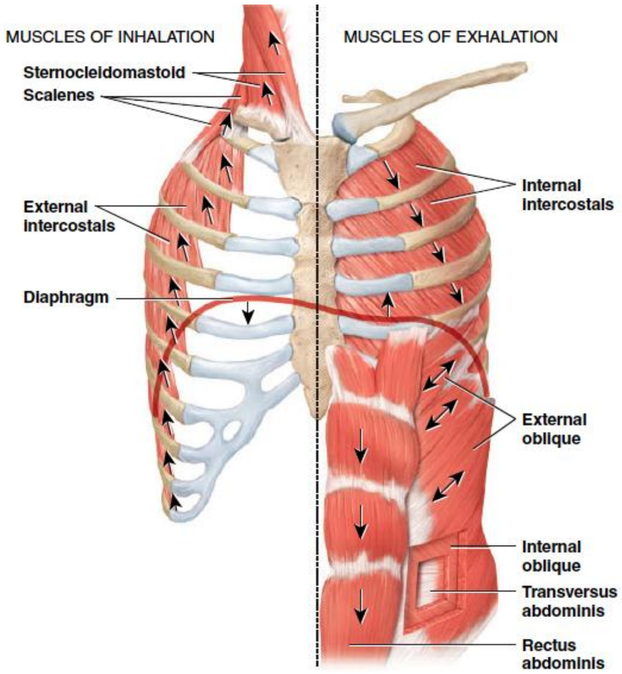

Figure 1-1 The respiratory muscles. On the left-hand side the inspiratory muscles, their percentage of fibres expression is similar to those of the lower limbs with ~60% of slow twitch fibres (ST) and ~45% of fast twitch fibres (FT) (Polkey 2004). With contraction the inspiratory muscles expand the thoracic cavity, decreasing the intrathoracic pressure forcing air into the lungs. The arrow indicates the direction of muscles contraction. From *Tortora G T et al. 2017 “Muscle of inhalation and exhalation” in Principle of anatomy and physiology. Wiley, United States of America.*

1.3.1 Thoracic diaphragm

The diaphragm is the primary muscle of inspiration (Figure 1- 2), anatomically divided into three parts

- **The sternocostal** that arises from the posterior aspect of the xiphoid process, via the xiphisternal junction and converges to the central tendon

- **The costal** arises from the internal surfaces of the lower six costal cartilages and their adjacent ribs, interdigitating with the transversus abdominis

- **The crural** originates from two aponeurotic arches and the upper lumbar vertebral bodies (Koulouris and Dimitroulis 2001). The apex and crural regions contribute to the diaphragm position and has a small role in breathing (Kolar et al. 2010).

  The postural role of this part of the diaphragm is evident from the fact that the fibres arise from the second and third lumbar vertebrae (L1-L3 on the right, L1-L2 on the left), descends to the medial arcuate ligaments (connected to the psoas) and the lateral arcuate ligaments (connected to the quadratus lumborum) creating an anatomical structure that helps to support the spine (Quintero 2010).

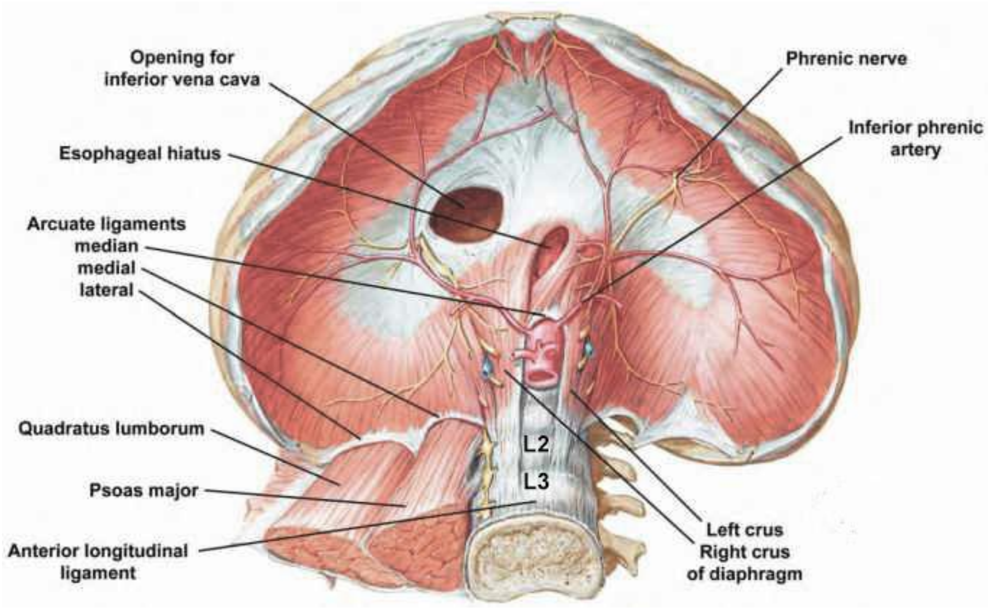

Figure 1- 2. The human diaphragm. During contraction, the diaphragm moves downward into the abdominal cavity, whilst moving the lower ribs upwards and forwards. This increases the volume of the thoracic cavity, creating a negative pressure that is proportional to the extent of diaphragm contraction force. Modified from *Netter F H 2018 in Atlas of human anatomy. Elsevier, United States.*

1.3.2 Intercostal muscles

On each side of the thorax, there are eleven intercostal spaces occupied by muscles, membranes, nerves, and vessels. These muscles are arranged in three layers, named according to their surface relation as external, internal and innermost.

The primary role of the intercostal muscles is to stabilise the chest wall to prevent paradoxical motion[1] (De Troyer et al. 2005). However, the intercostal muscles are also involved in trunk rotation (Rimmer et al. 1995), support upper-limb movements (Anderson et al. 2018) and limit thoracic spinal loading (reducing intervertebral discs pressure) (Watkins et al. 2005).

1.3.3 Scalene muscles

The scalenes consist of four muscle bundles originating from the transverse processes of the lower five cervical vertebras and inserting into the upper surface of the first two ribs (Olinger and Homier 2010). These muscles are divided into scalenus anterior, medius, minimus and posterior.

The scalene muscles are considered as primary muscle of inspiration and help in raising the 1st and 2nd ribs during inhalation (Raper et al. 1966). In addition, superimposed on their respiratory activities, the scalenes have prominent postural functions controlling cervical flexion and rotation (Olinger and Homier 2010).

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[1] Opposite to normal breathing during paradoxical motion the chest wall moves down during inspiration and up during expiration.

1.3.4 Sternocleidomastoids.

The sternocleidomastoid has two heads of origin, the sternal head and the clavicular head, both insert to the lateral surface of the mastoid process of the temporal bone (De Troyer et al. 2005). Their inspiratory action is absent during normal ventilation, but when the respiratory volumes increase the sternocleidomastoid muscles participate in the expansion of the thorax (Han et al. 1993).

1.3.5 Role of inspiratory muscle in supporting the spine and balance

Mounting evidence suggests that the inspiratory muscles (particularly the diaphragm) should be considered as two separate muscles that link the requirements of balance with breathing (Kocjan et al. 2018).

Hodges and Gandevia (Hodges and Gandevia 2000a) showed the diaphragm role in balance proficiency; they reported that during continuous movements of upper limbs (i.e. shoulder abduction and adduction), contraction of the diaphragm is sustained and modulated at the frequencies of both respiratory and upper limb movements. Their results suggested that this diaphragm activation assists spine stabilisation.

Detailed magnetic resonance imaging confirmed that during upper- and lower-limb isometric contractions the diaphragm responses non-uniformly, between the costal and crural portions (Kolar et al. 2010). This segment-specific response may act to attenuate the perturbating forces on the spine during limbs movements and to increase the intra-abdominal pressure (IAP).

When IAP is produced by electrical tetanic stimulation of the phrenic nerves (at 20 Hz for 5 seconds), the lumbar spine stiffness is increased (by 8–31%) with a greater stiffness at L2 - L3, showing a direct mechanical effect of the diaphragm crural fibres on the spine (Hodges et al. 2005).

The diaphragm muscle (above all the other inspiratory muscles) has, therefore, a double function allowing respiration and contributing to balance. The mechanism(s) of the muscle contribution to balance proficiency remains unclear but Kocjan and colleagues (Kocjan et al. 2018) demonstrated that deterioration of diaphragm function is related with decrement in balance maintenance. Similar results were also reported in participants with evident sign of inspiratory muscle weakness (i.e. obstructive pulmonary disease [COPD] patients; (Hakamy et al. 2018).

It is then possible to hypothesise few mechanisms that link inspiratory muscle function with balance:

- Inspiratory muscle strength – assessed with maximal inspiratory pressure measures (see Chapter 2.3.5), has been shown to be related with increment in balance proficiency. In particular a thicker and stronger diaphragm ameliorates balance ability in people with low back pain (Janssens et al. 2015). On the contrary, low diaphragm thickness fraction (i.e. less than 20%) is associated with greater balance deficit (Kocjan et al. 2018).

- Inspiratory muscle shortening velocity - assessed with peak inspiratory flow (see Chapter 2.3.5), can predict the quickness of muscle contraction (i.e. force-velocity muscle relationship) which in turn might have a positive effect on balance stability, especially in situation of sudden balance perturbation. Recently has been reported that a better diaphragm motion during quiet breathing is linked to lower balance instability (Kocjan et al. 2018). It is therefore rational to conceive that a higher peak inspiratory flow can predict a higher balance ability.

- Intraabdominal pressure (IAP) – the diaphragm plays an important role in the modulation of IAP (along with the expiratory muscles), but alteration in diaphragm excursion leads to insufficient IAP. As Koral and colleagues (2010) reported the crural portions of the diaphragm potentially respond to upper and lower muscle contractions by increasing IAP producing higher balance stability.

- $V\dot{O}_2$ dynamic – following inspiratory muscle training Bailey and colleagues (2010) reported an improvement in $V\dot{O}_2$ transportation to the lower limbs with young participants (22 ± 4 years old). The authors speculated that the improvement was a consequence of the effect of the intervention on the metaboreflex. Producing a higher O_2 availability to the lower limbs during the exercises resulted in a lower perception of fatigue and a better performance. It is possible to conclude that a similar mechanism might affect mobility and gait speed also with older adults undertaking inspiratory muscle training.

The relationship between inspiratory muscles and balance require further investigation. However, based on this rationale, since inspiratory muscles participate in maintaining balance, and a decrement in inspiratory muscle strength produces a subsequent decrement in balance ability, it is rational to conceive that improvements in inspiratory muscle strength can elicit increases in balance proficiency, potentially similar to what known in lower limbs training, but through a more complex mechanism(s).

1.4 Age-related changes in the respiratory system

The process of ageing is associated with changes, known as senile emphysema, which directly affect the function of the respiratory pump muscles. This syndrome is present from the age of 50 years (Britto et al. 2009), or earlier, in the presence of obstructive pulmonary conditions (Janssens et al. 1999).

Senile emphysema is characterised by dynamic hyperinflation (Deruelle et al. 2008), increased mechanical ventilatory constraints (deLorey and Babb 1999), rapid shallow breathing, increased ventilatory demand (deLorey and Babb 1999), increased static recoil pressure of the lungs, reduced chest wall compliance (Janssens et al. 1999), as well as increased vascular stiffness and a decreased surface area of alveolar capillaries (Taylor and Johnson 2010).

The inspiratory muscles are also weakened functionally by hyperinflation (McConnell 2013) and affected by sarcopenia (Watsford et al. 2005), Figure 1-3. Indeed, inspiratory muscle strength was found predictive for decline in mobility with older adults (Buchman et al. 2008).

Therefore, age-related physiological changes can reduce respiratory muscle strength and these decline may impair the contribution made by the inspiratory muscles to their secondary role in balance, as seen in patients with COPD (Oliveira et al. 2013).

Inspiratory muscle training (IMT) has been shown to be beneficial in increasing respiratory muscles function with older adults (Mills et al. 2015). Since the inspiratory muscle (particularly the diaphragm) are also involved in balance proficiency, it is conceivable to suppose that IMT may produce an increase in balance ability as a direct consequence of improvements in inspiratory muscles function.

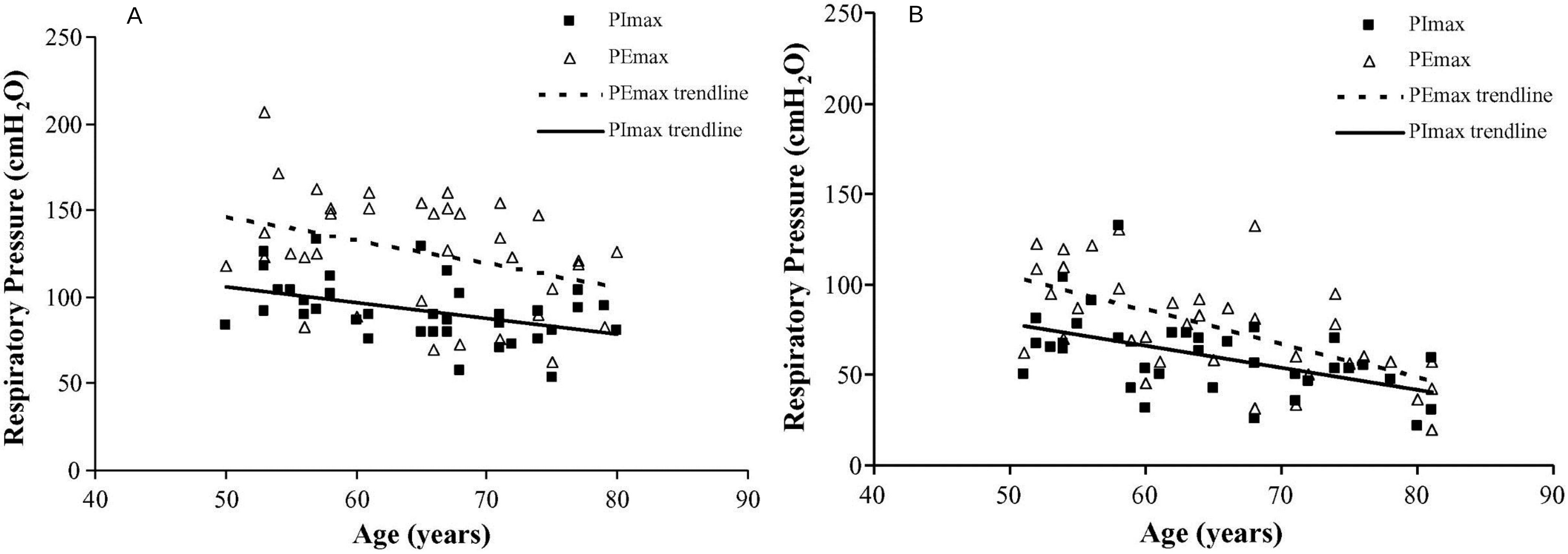


Figure 1- 3 The effects of ageing on respiratory muscle strength in males (A) and female (B).

Data from n = 72 participants aged 50 to 79 years. PImax = maximum inspiratory pressure. PEmax = maximum expiratory pressure. (A) The effect of ageing on respiratory muscle strength in males. Regression equations using solely age to predict respiratory muscle strength were as follows: PImax $r^2 = 0.18$, $p < 0.01$; PEmax $r^2 = 0.13$, $p < 0.05$. (B) The effect of ageing on respiratory muscle strength in females. Regression equations using solely age to predict respiratory muscle strength were as follows: PImax $r^2 = 0.27$, $p < 0.01$; PEmax $r^2 = 0.37$, $p < 0.01$. From *(Watsford et al. 2005), “The effect of ageing on respiratory muscles strength”, JSMS, Elsevier, 2005 United States.*

1.5 Inspiratory muscle training with healthy older adults

Inspiratory muscle training is designed to strengthen the inspiratory muscles by using a pressure threshold device, that produces resistances at any inhalation (refer to Chapter 2.3.9 for more details). The intervention has been reported to improve inspiratory muscle strength, exercises capacity, quality of life and decrease dyspnea in COPD patients (Beaumont et al. 2018). As well as in patients with chronic heart failure for improvements in inspiratory muscle strength and walking distance (Sadek et al. 2018).

Six studies have addressed the effect of IMT with healthy older adults; the main outcomes, relative to this research, can be divided into respiratory function and physical performance. (See Appendix A-1, for a descriptive table that summarised the study`s outcomes).

1.5.1 Respiratory function

Inspiratory muscle training has been reported to produce positive changes in inspiratory muscle strength (measured with maximal inspiratory pressure [MIP] tests). Anzar-Lain and colleagues (Aznar-Lain et al. 2007) reported a 79% improvement in 9 participants performing IMT at 50% and 80% of their (baseline) MIP. Similar findings were also reported in recent studies with 13 participants performing IMT at 40% of (baseline) MIP for 8 weeks (Souza et al. 2014) and 17 participants performing IMT at 50% of (baseline) MIP for 8 weeks (Mills et al. 2015).

For spirometry assessments (i.e. forced vital capacity and forced expiratory volume) there is no agreement on this findings, with only one study reporting a significant improvements (by 4%) in forced vital capacity with 13 participants performing IMT (10 sessions at 10% of [baseline] MIP and 2 sessions at 40% [baseline] MIP for 8 weeks; (Watsford and Murphy 2008).

Inspiratory muscle training has also been found to improve diaphragm mobility (by 9%) and thickness at maximum contraction (by 9%) (Souza et al. 2014), as well as at residual capacity (by 38%) (Mills et al. 2015)

1.5.2 Physical performance

Inspiratory muscle training improves different aspects of physical performance, Alzanar-Lain and colleagues (2007) reported that following IMT there was an improvement by 36% in time fixed load (speed and grade) walking test. Similar improvements in walking ability were reported also by Chien-Hui and colleagues (Chien-Hui et al. 2011). They showed a 12% increment in the 6 meters walking test after undertaking IMT daily for 6 weeks, for four sessions of 6 repetitions at 80% of [baseline] MIP with 24 participants.

Previous research has studied the effect of IMT with older adults, showed that the intervention improves inspiratory muscle strength and walking ability. However, there is a gap of evidence on the feasibility of the intervention and the type of IMT, with different studies using different training intensities and durations.

Moreover, since older adults have a high risk of falls accidents, and because a decrement in inspiratory muscle function can lead to a direct decrement of balance ability, this thesis aims to answer the following question: Can a home-based, unsupervised, inspiratory muscle training be feasible and produce improvements in balance and physical performance with healthy older adults?

Chapter Two

GENERAL METHODS

“Consider well the seed that gave you birth: you were not made to live as brutes, but to follow virtue and knowledge”

Dante Alighieri, Inferno, canto XXVI

2.1 Outline of chapter two

The following sections provide detailed information about the general methods used during the thesis. Table 2.1 indicates which outcome measures were used in each respective study, whilst table 2.2 to 2.6 indicates the rationale behind each assessment. All methods and protocols were approved by Bournemouth University Research Ethics Committee.

Table 2. 1 Representation of the outcome tests used during the three studies.

Measurements	Study 1	Study 2	Study 3
Health questionnaires	✗	✓	✓
Activity balance scale for elderly (ABC)	✓	✓	✓
Physical activity scale for the elderly (PASE)	✓	✗	✗
Oswestry low back pain disability questionnaire (ODI)	✗	✓	✓
Mini-mental state examination (MMSE)	✗	✓	✓
Forced vital capacity (FVC)	✓	✓	✓
Forced expiratory volume (FEV$_1$)	✓	✓	✓
Peak inspiratory flow rate (PIFR)	✓	✓	✓
Maximal inspiratory pressure (MIP)	✓	✓	✓
Maximal expiratory pressure (MEP)	✓	✗	✗
Peak inspiratory power (PIP)	✓	✓	✓
Timed up and go (TUG)	✓	✓	✓
Cognitive timed up and go (TUG$_C$)	✓	✓	✓
Motor timed up and go (TUG$_M$)	✗	✓	✓
Five sit to stand (5STS)	✓	✓	✗
30 seconds sit to stand (30sSTS)	✗	✗	✓
Functional reach (FR)	✓	✗	✗
Mini-BEST	✓	✓	✓
Postural stability index (PSt)	✗	✓	✗
Isometric trunk flexion/extension (ISOM$_F$, ISOM$_E$)	✓	✗	✗
Isometric trunk rotation (ISOM$_R$)	✓	✗	✗
Isotonic trunk flexion/extension (ISOT$_{F,}$ ISOT$_E$)	✓	✗	✗
Sit-up test	✓	✓	✓
Biering-Sørensen test	✓	✓	✓

Table 2. 2 Questionnaires.

Measurements	Rational
Health questionnaires	It was introduced following the Transfer examination to monitor possible confiders (i.e. pilates, yoga or exercise) and to keep a record of conditions that might affect the results (e.g. diabetes, beta-blockers, etc.). It was therefore used as an inclusion/exclusion checkpoint.
ABC	The questionnaire helped to discriminate between fallers and not fallers with a total score below 67% used as cut off to exclude participants with a high risk of falling.
PASE	The questionnaire was used before the introduction of the health questionnaires only in the first study, as it monitors possible sources of bias, related to physical activity (i.e. pilates, yoga or balance exercises).
ODI	It has been introduced following Transfer Examination feedback as back pain produces confounder during balance assessments. Hence a cut off of 20%, which indicates minimal or absence of disability, was used as inclusion criteria.
MMSE	It has been added following Transfer Examination feedback as cognitive impairments can affect the ability to following the training instruction and can be a contributory cause to fall accidents. A cut off > 25 (which indicates the absence of cognitive impairments) was then used as inclusion criteria.

Table 2. 3 Spirometry and respiratory muscle tests.

Measurements	Rational
FVC and FEV_1	Spirometry measures were used as indexes to make sure that participants did not have any respiratory occlusion or obstruction (e.g. asthma or COPD condition) that affect their ability to performer inspiratory muscle training. Therefore a cut off of 0.7 of the Tiffeneau-Pinelli index (i.e. FEV1/FVC) was used inclusion criteria.
PIFR	It is a valid index to monitor shortening velocity of the inspiratory muscles and was necessary also to control that the training was performed correctly (as PIFR has been reported to increase following inspiatory muscle training).
MIP	It is an index on inspiratory muscle strength as was necessary to control that the training was performed correctly.
MEP	It was used only during study 1 as an index of expiratory muscle strength. It was used to monitor possible learning effects concerning MIP measurements.
PIP	It is the product between MIP and PIFR. PIP is an index of the function of the inspiratory muscles. It was introduced to clarify possible mechanism(s) behind the relational between inspiratory muscle and balance.

Table 2. 4 Physical performance tests.

Measurements	Rational
TUG, TUG_C and TUG_M	Gait assessments were introduced as practical clinical tools to monitor physical performance.
5STS	The tests were used in two out of the three studies to monitor whether the intervention would have had any effects of meta-stable tasks.
30sSTS	Similar to the 5STS. However, i) because there was no effect of inspiratory muscle training on 5STS ii) and the 30sSTS has been used in the majority of the studies that involved Otago exercises it was introduced only for the third study.
FR	It is a clinical tool to measure meta-stable balance ability.

Table 2. 5 Balance tests.

Measurements	Rational
Mini-BEST	It was used as the primary outcome during the thesis. The reason this test has been used (among other such as the Tinetti test or Berg Balance Scale) is that it allows analysing different sub-task of balance ability, including static, reactive, sensory and dynamic balance.
PSt	In the absence of improvements in static balance sub-task, the PSt was introduced to detect possible anterior-posterior or medio-lateral perturbations during standing (i.e. analysis of statokinesigram).

Table 2. 6 Trunk muscle tests.

Measurements	Rational
$ISOM_F$, $ISOM_E$, $ISOM_R$, $ISOT_{F,}$ $ISOT_E$), Sit-up and Biering-Sørensen tests	To monitor possible mechanism(s) that would have helped to clarify the relationship between inspiratory muscle and balance outcome, measures of trunk isometric strength, isotonic power and endurance were introduced.

2.2 Pre-test preparation

2.2.1 Participants

Written informed consent to take part in the studies and to use photographs for scientific publication, was obtained from all participants before testing (consent form sample in Appendix A-3). Participants were recruited from the local community through public engagement activities and from retirement homes through direct contact with managers and stakeholders. Recruitment was conducted across Dorset and Hampshire (UK) from September 2016 to August 2018. Participants were familiarised with all test procedures before testing by verbal explanation, with the aid of participant information sheets (Appendix A-4). Health check questionnaires were introduced following the advice received by Dr Jonathan Williams and Dr Simon Dyall of the Faculty of Health and Social Sciences (Bournemouth University) as part of the PhD Transfer Examination (Appendix A-5).

These questionnaires were completed before testing to ensure each participant met the following exclusion criteria: having fallen in the past two years, heart conditions preventing physical activity, receiving beta-blocker medication, vertigo in the past six months and diabetes.

On test days, participants were requested to avoid drinking alcohol or caffeinated beverages and taking any substances known to affect, or may, affect human physiological functions. They were also required to dress in a tracksuit or shorts and t-shirts, with plimsolls or trainers.

2.2.2 Testing Environment

Environmental conditions were standardised; test sessions took place in a temperature-controlled laboratory (20 to 22 °C; humidity < 70%) at the Orthopaedic Research Institute. Testing and re-testing sessions were scheduled at a similar time of the day (between 8:00 and 11:00 am) to minimise potential effects of diurnal variation (Atkinson and Reilly 1996).

2.3 Apparatus and procedures

2.3.1 Procedures

The following sections will address the different outcome measures and testing procedures, explaining how each assessment was conducted. All procedures were sequenced and timed, in order to minimise potential fatigue and boredom effects. To avoid external influence on test performance, the amount of encouragement given to participants, as well as the number of times participants repeated a test, were standardised (Guralnik et al. 1989).

2.3.2 Anthropometry

Age, stature, and body mass index

Demographic information was collected before testing. Free-standing stature was measured to the nearest 0.1 cm with a stadiometer (SECA 217, Birmingham, UK), on which participants stood barefoot with heels together and arms by their sides, with the buttocks and scapulae in contact with the stadiometer. Participants were instructed to look straight ahead and take a deep breath upon measurement. Stature was measured as the maximum distance from the floor to the vertex of the head. The body mass in minimal clothing was recorded using an electronic weighing scale (Mc 780 MA, Tanita Body Composition Analyser, Amsterdam NL).

2.3.3 Questionnaires

Health check questionnaire

An health check questionnaire was introduced after the completion of the study 1 (Table 2.1), following feedback received during Transfer Examination process. The questionnaire was introduced in order to identify inclusion/exclusion criteria (section 2-1.1) and to record potential confounding variables (e.g. moderate physical activities). In addition, the questionnaires focused on medical conditions known to affect balance outcomes (e.g. taking beta-blocker medication and diabetes). A copy of the questionnaire is available in Appendix A-5.

The Activities-Specific Balance Confidence (ABC) Scale – (Powell and Myers 1995)

The ABC questionnaire was included to measure self-confidence in situation-specific activities. It presents 16 items of assessment from vestibular balance (e.g. stand on tiptoes) to functional mobility (e.g. get into or out of a car). Each item is rated on a scale ranging from 0% “no confidence” to 100% “complete confidence”. The overall score is calculated by adding each item score and then dividing it by the total number of items (Powell and Myers 1995).

The ABC scale shows good discriminative abilities between participants with or without balance disorders, regardless of age (Whitney et al.

2005) with a total score below 67% indicates that participants are at risk of falling (Lajoie and Gallagher 2004). The ABC also shows excellent test-retest reliability (r = 0.92, p < 0.001) (Powell and Myers 1995). The time required to administer the test was between 5 and 10 minutes.

The Physical Activity Scale for the Elderly (PASE) – (Washburn et al. 1999)

The PASE questionnaire was used to note participants' physical activity levels and record confounding variables (such as moderate physical activities). The questionnaire consists of 12 questions regarding the frequency and duration of leisure activities (e.g. jogging), household activities (e.g. cleaning the dishes), and work-related activities during a seven days period (Washburn et al. 1999*)*.

The score ranges from 0 to 793, with higher scores indicating greater physical activity. The ODI also shows a good test-retest reliability over 3 to 7 weeks (r = 0.84; (Washburn et al. 1999) and required 10 to 15 minutes to administer it.

Oswestry Disability Index (ODI) 2.0 – (Fairbank and Pynsent, 2000()

The low back pain and disability questionnaire was included in the light of recent findings of an association between inspiratory muscle training, and balance ability in individuals with low back pain (Janssens et al. 2015). In addition, moderate and severe back pain may influence the ability to perform outcome tests and particularly the balance assessments (da Silva et al. 2018).

The questionnaire consist of 10 items divided into pain intensity during movement, personal care (e.g. getting dress), lifting, walking, sitting, standing, sleeping, sex life, social life, and travelling. Each item consists of six statements correlating to scores of 0 (lower disability) to 5 (greatest disability). Test-retest reliability has also been shown to be high. ($0.83 < r \leq 0.99$) (Vianin 2008).

Scores are calculated as follows: if the participant completes all the questions then the final score is calculated from equation (1), but if the participant decides not to answer one question (e.g. sex life) or if the question is not applicable then the score is calculated with equation (2). Score interpretation is reported in Table 2.7.

$$(1) \qquad \left(\frac{\text{Total Score}}{50} \text{ x number of questions answered } \right) \text{ x } 100$$

$$(2) \qquad \left(\frac{\text{Total Score}}{45} \text{ x number of questions answered } \right) \text{ x } 100$$

Table 2. 7 Score interpretation of the Oswestry Low Back Pain Disability Questionnaire.

Score	Interpretation
0 to 20%	Minimal disability
21 to 40%	Moderate disability
41 to 60%	Severe disability
61 to 80%	Crippled
81 to 100%	Exaggeration of symptoms

For the purpose of this thesis, the upper limit for inclusion was 20%, which indicates minimal or absence of disability. The time required to administer the questionnaire was between 5 and 10 minutes. Modified from (Fairbank and Pynsent 2000).

*The Mini-Mental State Examination (MMSE) – (*Folstein et al. 1975)

The MMSE includes 11 questions divided into two sections, the first requiring vocal responses, covering orientation, memory and attention; the second requiring the ability to name things, follow verbal and written commands, write a sentence spontaneously and copy a complex polygon (similar to a Bender-Gestalt figure; (Folstein et al. 1975). The questionnaire had been founded with moderate test-retest reliability (r = 0.38 - 0.99) (Tombaugh and McIntyre 1992).

Several sources of bias are known to influence MMSE, including age, education, cultural and socioeconomic background (Mungas et al. 1996). However, in the context of this thesis, the risk of bias was considered minimal, as participants were of similar age, educational level, and cultural and socioeconomic background.

Score interpretation is reported as follows: absence of cognitive impairment (total score between 25–30); mild impairment (total score between 20–25); moderate impairment (total score between 10–20); severe impairment (total score between 0–10). For the purpose of this thesis, only participants with absence of cognitive impairment were recruited (using a total score of 25 as cutoff). The time required to administer the questionnaire was between 5 and 10 minutes.

2.3.4 Pulmonary Function

Forced vital capacity (FVC) and Forced expiratory volume (FEV_1) - (Miller et al. 2005)

Forced respiratory measures were conducted using either a hand-held spirometer MicroLab (ML3500S, Micro Medical Ltd, Rochester, Kent, UK) with Spida software (during the 1st study), and a hand-held spirometer SpiroUSB (Care Fusion, Wokingham, Berkshire, UK) with Care Fusion software (during 2nd and 3rd studies), following the guidelines of the American Thoracic Society (Miller et al. 2005). Participants performed forced breathing manoeuvres at least five and no more than eight times, until variability was within 5% in three consecutive manoeuvres, from which the higher score was collected. All measurements were made with participants in a seated position wearing a nose-clip (Figure 2-1). The correct technique was explained and demonstrated before testing. Sufficient time for resting was allowed between measurements (1 to 2 minutes) and verbal encouragement was provided during maximal effort as following:

> “*Breathe forcefully and without hesitation with the nose-clip on, inhale until your lungs are as full as they can possibly be and then blow out through the mouthpiece as hard and fast as you can…keep going, out, out, squeeze out, then breathe in as fast as you can...big deep breath, keep going.*”

At the end of every single forced expiration-inspiration cycle, participants were able to view their spirometry trace via the computer monitor, which helped them to improve the technique. The time required to administer the test was between 10 and 15 minutes.

The spirometry test was completed as the first assessments, in order to record any sign of asthma, COPD or other conditions that could have exclude participants for taking part (inclusion/exclusion criteria are included in the relevant experimental chapters). The conditions were monitored trough the Tiffeneau-Pinelli index (i.e. FEV_1/FVC) and only participant with a ration $\geq$ 0.7 were included in the research.

Figure 2- 1 Participant is performing spirometry testing.

Peak Inspiratory Flow Rate (PIFR) – (Depledge 1985)

Peak inspiratory flow rate is an index of maximal inspiratory muscle shortening velocity. The PIFR was measured using the Powerbreathe® K5 (POWERbreathe International Ltd. Southam, UK) and the Breathe-Link 2.0 software (Langer et al. 2013). Participants were instructed to perform between 15 and 30 maximal inspirations, as fast and deep as they could, starting from complete exhalation, with 30 seconds rest between each (Figure 2-2). All measurements were made in a seated position and with nose-clip attached. The measurements were repeated until three values were obtained that differed by no more than 0.10 l s^{-1}. The time required to administer the test was between 10 and 15 minutes.

Figure 2- 2 Participant is performing peak inspiratory flow tests.

2.3.5 Respiratory Muscle Function

Maximal Static Respiratory Muscle Function – (Black and Hyatt 1969)

A hand-held mouth pressure meter MicroRPM (Micro Medical Ltd, Rochester, Kent, UK) was used for the determination of maximal inspiratory (MIP) and expiratory (MEP) pressures during a quasi-static effort (i.e. Mueller or Valsalva manoeuvres, respectively), in conjunction with Micro Medical PUMA software (Micro Medical Ltd, Rochester, Kent, UK) for recording the measurements. The pressure meter incorporates a small air vent, which prevents the production of artificially high pressures generated by the muscles of the buccal cavity when the glottis is closed (Black and Hyatt 1969). The vent was small enough

(~1 cm) that it did not significantly affect lung volumes during maximum efforts. Participants breathed via a flanged mouthpiece, while wearing a nose-clip. The device was capable of measuring differential pressure between $\pm$300 cmH_2O. Since MIP and MEP measurements are dependent on lung volume, each effort was initiated from residual volume or total lung capacity, respectively.

The test manoeuvre consisted of isolated concentric muscle contractions to avoid the variability that is caused by the stretch-shortening cycle of the respiratory muscles. All manoeuvres were sustained for 3 to 4 seconds while seated, and participants were instructed to exert efforts rapidly and maximally (Figure 2-3). In addition, participants were provided with strong verbal encouragement in support.

For MIP, participants were instructed to:

"*Breathe in hard - pull, pull, pull*";

For MEP, participants were instructed to:

"*Breathe out hard - push, push, push.*"

Before testing, all participants practised the Müller and Valsalva manoeuvres three times, and measurements were repeated at least five, but no more than eight times, until variability was < 10% in three consecutive manoeuvres, from which the best was recorded. The required time to administer the test was between 10 and 15 minutes.

Figure 2- 3 Participant is performing maximal inspiratory pressure tests. The principal investigator is indicating that the 4 seconds have elapsed, and that he can stop.

Peak Inspiratory Muscle Power (PIP) – (Romer and McConnell 2003)

Using the POWERbreathe® K5 with Breathe-Link 2.0 software (Langer et al. 2013) participants inhaled with maximal effort against six discrete load settings: 40%, 50%, 55%, 60%, 70% and 80% of their [baseline] MIP (Figure 2-4).

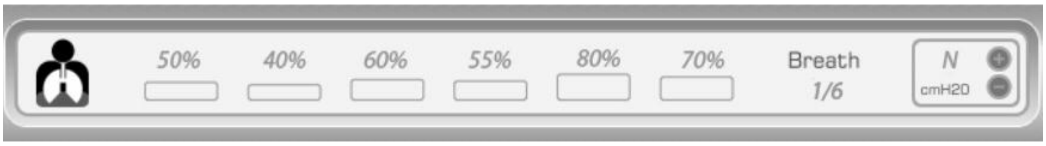


Figure 2- 4 Representation of Breathe-Link 2.0 visual feedback screen. Each rectangle is shaped proportionally different to represent different pressures that were calculated from participant`s [baseline] MIP. The order of the rectangles was randomised during every PIP test.

Three trials were performed for each of the loading intensities with 30 seconds rest intervals between efforts, for a total of 18 maximal inspiratory manoeuvres. All loads were assigned randomly using free software available on randomizer.org. All manoeuvres were performed seated, wearing the nose-clip and within a 20 minutes period. Participants received visual feedback of pressure from the Breathe-Link 2.0 software to prepare them for the magnitude of the ensuing inspiratory efforts and were instructed to inhale with maximal effort as rapidly as possible (Figure 2-5).

Figure 2- 5 Participant is preparing for peak inspiratory power tests. During the 30 seconds rest intervals, participants were able to look at their performance and prepare themselves for the following load.

2.3.6 Balance

Mini-balance evaluation systems test (mini-BEST) – (Franchignoni et al. 2010)

The mini-BEST is a clinical balance measure that contains 14 items, divided into four domains: i) anticipatory postural adjustments (Figure 2-6), ii) postural responses, iii) sensory orientation and iv) stability in gait (Franchignoni et al. 2010). Each task is scored on a three-point scale from zero to two, where zero indicates that the participant is unable to perform the task whereas two means that the participant is able to complete the task without difficulties. The maximum score is 28 points. A cut-off score of 16 has been suggested to define people with balance disorders (Yingyongyudha et al. 2016). The mini-BEST takes between 15 to 20 minutes to complete and has been shown to have a minimal detectable change of 3.5/28 and standard error of measurement of 1.26

(Godi et al. 2013). For the purpose of this thesis the latest version, freely downloaded on www.BESTest.us, was used.

Figure 2- 6 Participant is performing one of the anticipatory tasks of the mini-BEST (i.e. standing on tiptoes)

Biodex Balance Postural Stability Test (PSt) – (Arnold and Schmitz 1998)

The PSt measures static balance in anterior-posterior and medial-lateral axes computing the statokinesigram around a zero point, established prior to testing (Arnold and Schmitz 1998). Software analysis of the statokinesigram provides the Overall Stability index (OSi), with a low OSi indicating minor fluctuation hence better balance performance. The PSt required participants to maintain a static position for a duration of 20 seconds, three times for each, separated by 60 seconds rest (Parraca et al. 2011).

The test was performed in two conditions that were assigned randomly: one on a stable-firm surface, the other on an unstable-foam surface. During both conditions, participants were blindfolded, barefoot and were instructed to keep their hands at their sides (Figure 2-7). Participants were also instructed not to talk during the tests, as changes in respiratory panthers during speaking action produce postural perturbation (Dault et al. 2003). Time to administer the test was between 10 to 15 minutes.

Figure 2- 7 Participant is performing the postural stability test.

2.3.7 Physical performance Indices

Functional Reach Test (FR) – (Duncan et al. 1990)

The functional reach (FR) test evaluates the maximum limits of stable stance. The FR assesses the maximal distance a participant can reach forward beyond arm's length, whilst standing in a fixed position (Duncan et al. 1990). Aware of the different test variants of the FR (e.g. seated and lateral FR), the one-arm FR test was chosen, as it has been reported to be less affected by the knee-hip balance strategy and assess the centre of pressure (CoP) excursion more effectively (Kage et al. 2009).

Participants were instructed to stand comfortably next to, but not touching, a measuring tape pasted to a wall at the height of participants` acromion process. They were asked to position their dominant arm, at 90° of shoulder flexion with the complete extension of the arm and closed fist. The third metacarpal head was measured in the starting position. Then participants were asked to reach as far forward as they could without taking a step, bending their knees or compensate the movement with the other hand (e.g. moving it backwards). The position of the end of the third metacarpal reached along the measuring tape was recorded (Brian et al. 2017) (Figure 2-8).

Scores were determined by assessing the difference between the start and end positions of the reach distance. For the purpose of this thesis, the guidelines of Duncan and colleagues (Duncan et al. 1990) were used, and familiarisation was provided before testing. The test shows excellent test-retest reliability (ICC = 0.92) with community dwelling older people (Duncan et al. 1990). Three trials were then performed from which the average was reported.

Figure 2- 8 Participant is performing the functional reach test.

Five Times Sit to Stand Test (FSTS) – (Watt et al. 2018)

The procedure involved measuring the time taken to stand from a seated position five consecutive times. To facilitate reproducibility and standardisation, a standard armless chair, with 46 cm seat height was used, aware that this approach fails to accommodate for the variety of heights of participants resulting in greater or lesser knee flexion angles (Watt et al. 2018).

Participants performed the test with arms across their chest, sitting at the chair edge with hips in neutral abduction and rotation, not touching the seatback. Participants were blindfolded during the test, to minimise potential effects of vision on the performance (Mourey et al. 2000). For participants safety the chair was placed next to the wall, to block it from slipping during the test. After 15 seconds of usual sitting, they were instructed to rise, and then become seated as fast as possible and with a full range of motion, five times, with both feet maintaining contact with the floor. Timing commenced on the command "*3, 2, 1 and go*". The principal investigator (FF) was standing nearby the participant to prevent actual falls, and no practice trial or verbal encouragements were provided. The time required to administer the test was between 10 and 15 minutes. The 5STS shows high test-retest reliability for frail people (ICC = 0.96) (Bohannon 2011), and good reliability between trials (Silva et al. 2014).

30 second Sit to Stand Test (30sSTS) – (Watt et al. 2018)

The most significant limitation of the FSTS test is its floor effect, as participants might not be able to complete the task, limiting the FSTS`s sensitivity, as Guralnik and colleagues (Guralnik et al. 1994) reported from a sample of 5174 older adults, finding that 22% participants could not complete the FSTS.

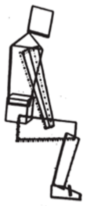
Therefore, the 30 seconds sit to stand (30sSTS) variant was used in study 3. It involves counting the number of sit to stand transitions that a participant can complete in 30 seconds. The procedures for the 30sSTS were consistent with that used for the FSTS test (see above).

Sit to Stand Test motion analysis

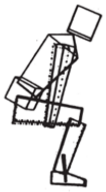
To gain insight into movement dynamics during the sit to stand tests, the motion was analysed, reproducing methods introduced by

Scnekman and colleagues (Schenkman et al. 1990). The assessments were divided into four momentous: flexion (Phase I), transfer (Phase II), extension (Phase III) and stabilisation (Phase IV).

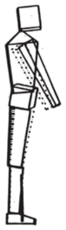
Phase I. The upper body rotates forward about the pelvis and hips, and the centre of motion (CoM) moves forward and slightly downward. This phase ends with the initiation of weight transfer from the chair to the feet.



Phase II. Starts at seat-off to maximum ankle dorsiflexion, with the CoM moving beyond the COP applied through the feet. During this phase, the momentum from the upper body part is transferred to the total body.



Phase III. Lasts until the hips are extended to a standing position. This point approximates the most forward excursion of the CoM.



Phase IV. Is defined as the end of the transfer. It occurs when the CoP is vertical to the standing position.

To quantify the duration of the four momentous (Figure 2-9), two accelerometers were used (BPMpro V1; Chilbolton, UK), with a resolution of 0.001 g (1g = 9.81 m s^{-1}) and sampling frequency 105 Hz.

One accelerometer was positioned on the lateral aspect of the right thigh aligned with the femur, whilst the other was positioned above the manubriosternal junction (Figure 2-10) reproducing method introduced by Doheny and colleagues (Doheny et al. 2013).

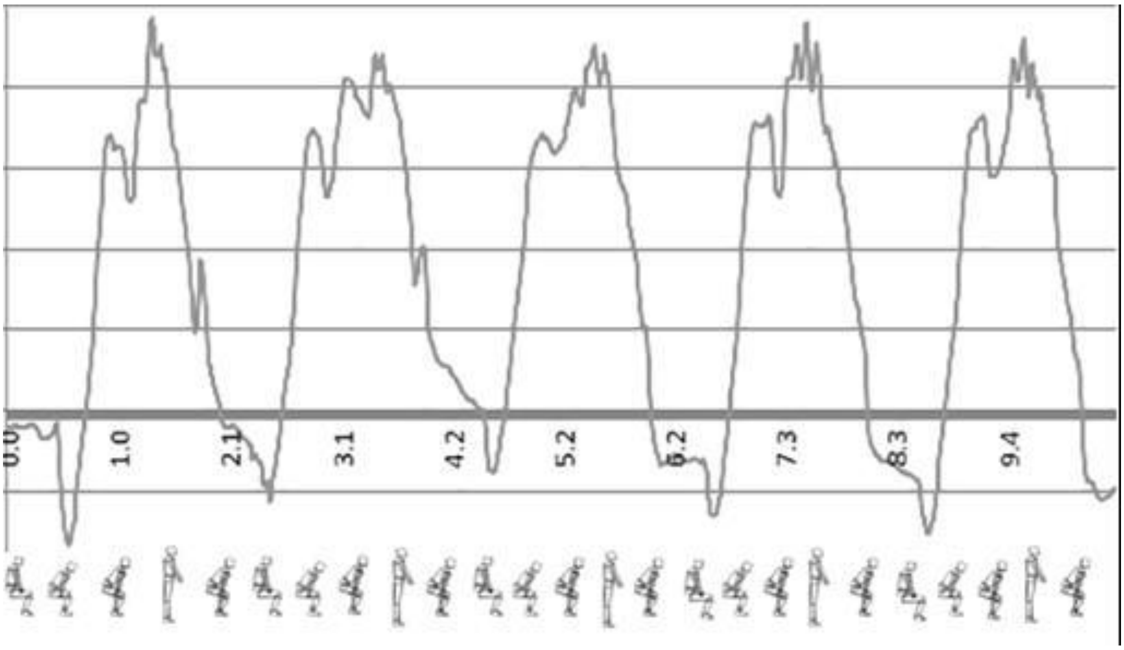


Figure 2- 9 Trunk angle variations during the STS momentous plotted versus time (from 0.0 seconds to ~10.0 seconds) obtained from BPMsport software. The figure shows how the changes in the curves are relative to a specific STS momentum. This analysis allows to measure the time needed in each STS momentum.

Figure 2- 10 The principal investigator is preparing the participant for the sit to stand tests.

Timed Up and Go test (TUG) – (Barry et al. 2014)

The TUG consists of measuring the time required to stand up from a chair, walk 3 meters, turn around, walk back to the chair and sit down again; with a lower time-to-completion indicates better performance/mobility. However, the TUG has limited ability to discriminate between fallers and non-fallers in community-dwelling older adults (Barry et al. 2014), hence it was used as an index of overall mobility and dynamic balance through the thesis.

A standard armless chair (46 cm of height) was used. Participants sat, at the command "*3, 2, 1 and go*", they were instructed to stand up, walk a distance of 3 meters at a comfortable and safe pace, turn around a cone, walk back to the chair, and sit down again. No walking aid or assistance was provided during the test (Figure 2-10). All participants performed the test once, before measurement, for familiarisation. The time was recorded in seconds with digital stopwatches, and the test required between 10 and 15 minutes to complete.

Figure 2- 9 Participant is performing the TUG task.

Divided attention task (dual-task)

The purpose of adding another task, whilst focussing on walking, is to increase participants’ attentional demand by adding a cognitive or motor task, thereby competing for the attentional and mobility resources needed to walk. The premise is that gait performance will decline under dual-task conditions (Alexander and Hausdorff 2008). For the purpose of this thesis, two dual-task variants (cognitive and motor) were introduced to the TUG test. The time to administer the test was between 10 and 15 minutes. The procedures are described below.

Cognitive Timed Up and Go (TUG_C) – (Shumway-Cook et al., 2000)

Participants were asked to perform the same task previously explained for TUG, while being instructed to count down backwards aloud in threes, from a random number between 80 and 100. The number was announced by the principal investigator (FF) immediately before the instruction to commence the test (i.e. “*3, 2, 1, the number is 100 and go*”). The starting number was not repeated and the first number spoken was the result of the first calculation. The time was recorded with a digital stopwatch, from when participant`s buttocks left the back of the chair and ended when the participant`s buttocks touched the seat of the chair.

Motor Timed Up and Go (TUG_M) – (Shumway-Cook et al., 2000)

Participants were asked to perform the same task previously explained for TUG, whilst holding a 70 cm wide tray, atop of which was a glass (diameter 8 cm, height 9.5 cm) filled with water (1 cm away from the top of glass). Time was recorded using a digital stopwatch from when participant`s buttocks left the back of the chair and ended when the participant`s buttocks touched the seat of the chair. In addition, participants did not know the results until all three tests were completed to avoid any influence on performance.

2.3.8 Trunk Muscle Function

In this thesis the trunk muscle function was studied under three different conditions: isometric contraction, isotonic contraction and isometric endurance.

A BTE-Primus dynamometer (BTE Technologies, Maryland USA) with maximum measure speed of $4500^{\circ}\ s^{-1}$ (± 1% error) was used along with a three-dimensional cable attachment (22.9 cm lever length), a chop-lift bar and a waist belt trap. Calibration of the BTE-Primus was performed every two weeks according to the manufacturer’s recommendations (manual 1999). In addition, to limit injury risk and to facilitate maximal performance, prior to testing all participants performed a standardised warm-up for 5 minutes, familiarising with the required tasks (Kumar 1997).

Isometric and isotonic tests were then presented in a randomised order. Within each test, before each measurement, all participants practised the specific movements (i.e. trunk flexion, extension or rotation) until they felt confident to proceed without any discomfort (Roussel et al. 2008).

Isometric Contraction (ISOM)

The ISOM was performed in three different conditions during trunk flexion ($ISOM_F$) rotation ($ISOM_R$) and extension ($ISOM_E$) randomly presented. In each condition, the BTE-Primus provided tailored resistance to generate an isometric contraction. Each time a participant pulled the cable, to which they were attached, the BTE-Primus recorded the real-time index, reported in Newton on the display connected to the testing device. Visual feedbacks were not provided to the participants, to no modified their positions and alter their performance.

For all ISOM tests the participants were instructed not to jerk, but to develop force in the first 3 seconds and then hold it for the remaining 2. This procedure is known to prevent large spikes in the torque output that can occur when the attempt is performed with high acceleration force (Gomez et al. 1991). No external encouragement was provided during testing. Each measurement was performed until three values were in 10% variation range and the highest was recorded.

Trunk Flexion ($ISOM_F$) – (Suri et al. 2009)

Participants sat on a treatment table with their back straight, feet flat on the floor, and with 90° knee angle. Their pelvis was positioned in anteversion, and they were instructed to keep facing forward, with the neck in-line with the back. Participants were secured by the waist, via a belt-strap, that was linked to a hook directly to the BTE-Primus. The principal investigator verified that for each flexion test, the angle between the hook and participant’s back was 60°. When ready, participants were instructed to keep their feet flat on the ground and hold their hands crossed to their chest, then to flex at the hip joint, by concentrically contracting the abdominal muscles and move their chest towards their knees (Figure 2-12).

Figure 2- 10 Participant is performing ISOM$_{F}$, while the principal investigator (FF) is monitoring the results.

Trunk Rotation (ISOM$_{R}$) – *(Torén and Öberg 1999)*

Participants were instructed to sit on a treatment table, adjusted to diminish pelvis twist, with a straight back (spine in neutral lordosis), and legs securely blocked with straps to the table. Their hands were shoulder width placed on a chop-lift bar positioned approximately between C6 - T1 and attached to BTE-Primus, with an angle of 60°. Three maximum voluntary contractions were then performed at five different angles (-40°, -20°, 0°, 20°, 40°; Figure 2-13) presented randomly. For each testing angle participants performed three, maximal 5 seconds isometric trunk ration followed by 5 seconds rest (Figure 2-14)

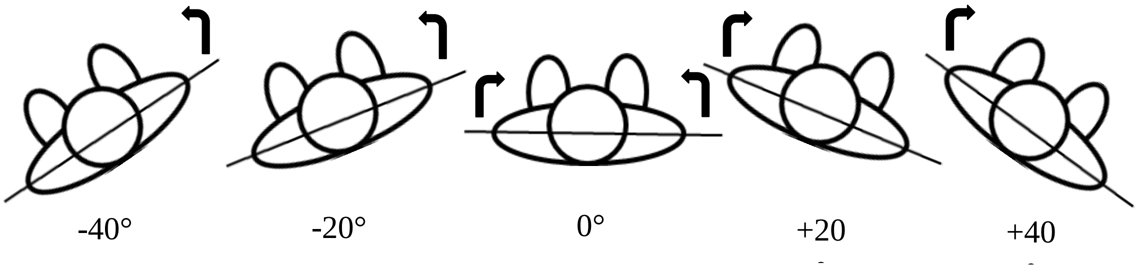


Figure 2- 11 The different angles used as a starting position in the ISOM$_{R}$. The negative and positive values indicating a right and left pre-rotated positions and the arrows indicate the direction of the rotation.

Figure 2- 12 The principal investigator (FF) is positioning the chop-lift bar on participant`s shoulders, ensuring that the orientation of the bar is correct.

Trunk Extension (ISOM$_E$) – *(De Ridder et al. 2015)*

Participants sat on a treatment table adjusted to restrict pelvic twisting, with feet off the floor, to avoid any contribution from the lower limbs (Shirado et al. 1995). Participants were instructed to hold a flexed position (approximately 60° flexion), keep their eyes looking forward, with the neck in-line with the back. A waist belt trap was tied at participant’s chest linked with a hook directly BTE-Primus. The principal investigator verified that for each extension test, the angle between the hook and the participant’s chest was 120° (Figure 2-14). When ready, participants were instructed to hold their hands on their shoulders, then start contracting their back muscles and try to move their trunk backsword to reach an upright, seated position.

Figure 2- 13 The principal investigator (FF) is preparing the participant for ISOM$_E$.

Isotonic Contractions (ISOT)

The ISOT were performed in two different conditions during trunk flexion (ISOT$_F$) and extension (ISOT$_E$). Starting positions were the same as ISOM$_F$ and ISOM$_E$. However, for the ISOT, the BTE-Primus provided a 50% resistance, tailored to each participant, based on participant`s average peak force. Therefore, participants were instructed to perform repeated efforts for at least 80 seconds, as fast as they could. They were instructed to stop and report to the principal investigator (FF) for any sign of dizziness or discomfort. The 80 seconds duration was necessary for the dynamometer to record the force trace. Then, the best of the three values in a 10% range were recorded in Joules.

Trunk Endurance Tests

Isometric Sit-Up test – *(McGill et al., 1999)*

An isometric sit-up was employed to assess anterior trunk muscle endurance. Following the guidelines of McGill and colleagues (1999), participants required to sit on an examination bench and place the upper body against a support with a 60° angle from the test bed. Both the knees and hips were flexed to 90°. The arms were folded across the chest and feet were secured with straps. Participants were instructed to contract their abdominal muscles and maintain the position while the support was pulled back of approximately 10 cm at the command "*3, 2, 1 and go*" (McGill et al. 1999). Time to the limit of tolerance was recorded. The test ended if participants experienced discomfort, or could no longer hold the starting position. No encouragement was provided during the measurement.

Biering-Sørensen test – *(Demoulin, 2006)*

The procedure requires participants to lie prone on an examination table with the iliac crest on the edge of the table. The lower body was fixed to the table by two straps around the pelvis and the knees, while the principal investigator (FF) held the participant`s ankles. Before the beginning of the test, the participants were allowed to rest the upper body on the treatment table. Then, they were asked to lift the upper body, with arms behind their head and maintain the trunk in neutral alignment for as long as possible. The time to the limit of tolerance was recorded for subsequent analysis (Muller et al. 2010). During the test, small perturbations may occur naturally while maintaining the required position and this could produce a false assumption of fatigue (Latimer et al. 1999). Thus, the test was terminated if participants were in discomfort, or if there were a > 10° variation from the neutral alignment (Jørgensen and Nicolaisen 1986). No encouragement was provided during the measurement.

2.3.9 Training interventions

Inspiratory Muscle Training (IMT)

For the purposes of this thesis, the guidelines from the books: '*Breathe strong perform better*' and '*Respiratory muscle training: theory and practice*', were used (McConnell 2011, 2013). Participants performing unsupervised, home-based IMT received a pressure-threshold device (POWERbreathe® Medic Plus, POWERbreathe Ltd. Southam, UK). The training device requires individuals to produce a negative pressure sufficient to overcome the load imposed by the inspiratory valve, to initiate inspiration (Caine et al. 2001).

An accurate training load was tailored for each participant, by computing 50% of their [baseline] MIP achieved during maximal inspiratory pressure test. Participants were instructed to inhale forcefully and quickly through the device, to facilitate inspiratory muscle fibre recruitment, whilst using a nose-clip, in a sitting position. Whereas, the exhalation was performed slowly to avoid hypercapnia due to hyperventilation.

Participants were instructed to exercise twice daily (once in the morning [between 7:00 and 12:00 am] and once in the evening [between 16:00 and 21:00 pm]), for 8 consecutive weeks. Explanation on how to increase the resistance was given, so that inspiratory muscle overload was maintained throughout the training period and ensuring the training stimulus remained progressively challenging. Participants were instructed to complete at least 30 forceful quick inhalations followed by an equal number of slowly protracted expiration manoeuvres. If they were able to exceed 30 breaths by 5 to 10 reps, then the load was increased by one unit (Table 2.8). Participants practised the breathing manoeuvre during baseline testing with the principal investigator (Figure 2-16)

Table 2. 8 Overview of load values on the POWERbreathe® Medic Plus and corresponding pressures (cmH_2O).

Load	0	1	2	3	4	5	6	7	8	9	10
cmH_2O	9	16	23	29	36	43	50	57	64	71	78

Precise load setting may vary marginally as reported by (Caine et al. 2001).

Figure 2- 14 The principal investigator (FF) is coaching how to use the POWERbreathe® to two participants.

Sham Inspiratory Muscle Training (Sham-IMT)

A sham-IMT was used in study 2 with a double-blind placebo randomise design to evaluate the effects of IMT on balance and physical performance in healthy older adults. The sham-IMT group received the same training device of the IMT group, but the ability to adjust the training load was prevented using a sticky tape applied to the device’s load adjuster.

The sham-IMT consisted of 60 slow, protracted breaths once daily in the morning (once in the morning [between 7:00 and 12:00 am]) at a load setting of 0 (Table 2-3). This protocol is known to elicit negligible changes in inspiratory muscle function in a cohort of healthy adults (30 ± 4 years old) (Romer et al. 2002).

Inspiratory Muscle Pre-Activation ($_{PA}$)

Inspiratory muscle pre-activation was used to determine the effect of acute, pre-inspiratory muscle activation (Volianitis et al. 2001) on physical performance (i.e. FR, FSTS, 30sSTS) and balance (i.e. PSt) assessments.

Briefly, participants were asked to breathe at different percentage of [baseline] MIP (~40 and ~80%) until repetition failure via Powerbreathe® K5. When participants were unable to inhale forcefully for three consecutive attempts, they were instructed to stop the forced inspiration and to perform the assessments (Volianitis et al. 2001). The later tests are reported as FR_{PA}, $FSTS_{PA}$, $30sSTS_{PA}$, PSt_{PA}. Details about the specific pre-activation procedures are reported within the relevant Chapters, 3, 4, 5.

The pre-activation tasks have been introduced in light to the recent funding that shows an ergogenic “warm-up effect” upon the inspiratory muscles with young adults (Lomax and McConnell 2009). Volianitis and colleagues (1999) reported that the ‘warm-up’ phenomenon is similar to the one present in locomotory muscles; thus, it can help in identifing possible mechanism(s) behind the relationship between inspiratory muscles and balance.

Training adherence

Adherence to the prescribed training regimes was monitored using a self-report training diary (Appendix A-6)**.** The use of specially prepared training diaries ensured participants were reminded of the requirements of their training schedule, as well as recording feedback about their experiences (McConnell 2005).

EXPERIMENTAL CHAPTERS

“Homo sum, humani nihil a me alienum puto”

“I am human, and I think nothing human is alien to me”

Terence, Heautontimorùmenos, v. 77

Chapter Three

THE INFLUENCE OF 8 WEEKS OF INSPIRATORY MUSCLE TRAINING UPON PHYSIOLOGICAL AND BALANCE OUTCOMES WITH HEALTHY OLDER ADULTS [2]

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[2] The following research has been presented at the Young Life Scientific Symposium: Frontiers in Musculoskeletal Health Ageing and Disease on the 25th November 2017 in Derby (UK). Poster communication included in Appendix A-7

3.1 Abstract

Purpose. Evaluate the feasibility and effects of inspiratory muscle training (IMT) with healthy, community-dwelling older adults. Specifically, to determine i) if unsupervised, home-based IMT is feasible, ii) whether IMT improves inspiratory muscle function, and iii) whether selected functional outcomes are sensitive to IMT.

Methods. Thirty-three participants (aged 72 ± 7 years) underwent 8 weeks of unsupervised, pressure threshold IMT using an uncontrolled repeated measures design. The IMT consisted of 30 breaths, twice daily, at 50% of participants` maximal inspiratory pressure (MIP). Pulmonary and respiratory muscle functions were compared pre- and post-intervention, including forced vital capacity, forced expiratory volume, peak inspiratory flow rate (PIFR), MIP, maximal expiratory pressure, peak inspiratory power (PIP). Physical performance measures (e.g. time up and go and five sit to stand), trunk muscle strength, endurance (e.g. Biering-Sørensen tests) and balance (i.e. Mini-Balance Evaluation Systems Test [mini-BEST]) outcomes were also compared pre- and post-intervention.

Results. Following IMT there were significant improvements in PIFR (by 12.8 ± 1.2%; $P < 0.001$), MIP (by 30.3 ± 25%; $P < 0.001$), the mini-BEST (by 13.7 ± 3.9%; $P < 0.01$) and the Biering-Sørensen test (by 68.6 ± 30.6%, $P < 0.05$).

Conclusion. Data suggest that IMT is feasible and effective to improve inspiratory muscle functions, as well as potentially improves balance and posterior trunk muscle endurance. These findings justify a follow-up

study to evaluate the effects of IMT using a more robust protocol (i.e. a double-blind placebo control design).

3.2 Introduction

Researchers have not adequately explored the postural role of inspiratory muscles and their contribution to balance proficiency. The non-respiratory role of inspiratory muscles has been characterised and discussed by Hodges and colleagues, with the conclusion that the main inspiratory muscle, the diaphragm, is involved in postural control during actions that destabilise the trunk (Hodges and Gandevia 2000b).

In particular, Hodges and colleagues reported that during continuous movement of the upper limbs (i.e. repeated shoulder abduction-adduction), the activity of the diaphragm is modulated at both the respiratory and limb movement frequencies. They suggested that the observed, feed-forward activation of the diaphragm (measured with EMG), assists the mechanical stabilisation of the trunk (Hodges and Gandevia 2000b).

In addition, it has been established that the diaphragm plays an important role in the development of intra-abdominal pressure, to help stabilise the lumbar section of the spine, assisting both dynamic and static balance (Hodges and Gandevia 2000c). Janssens and colleagues (Janssens et al. 2015) reported that inspiratory muscles may have a role in balance control, providing evidence that inspiratory muscle training (IMT) improves static balance performance in participants with low back pain.

Recent interventions of falls prevention focus on balance training (Howe et al. 2011) associated with good breathing technique (e.g. yoga, Tai Chi and Pilates). However, only a small number of studies have assessed the effects of inspiratory muscle training (IMT) upon physical activity (Mills et al. 2015) with older adults, with no assessments related to either static or dynamic balance.

Thus, the purpose of this pilot study was to evaluate the effects of IMT upon respiratory muscle function, balance and physical performance with older adults, in order to determine i) if unsupervised, home-based IMT is feasible with healthy older adults, ii) whether IMT improves inspiratory muscle function, and iii) whether selected outcomes are sensitive to IMT intervention.

The study hypothesis is that home based, unsupervised IMT would be feasible with healthy older adults in improving respiratory muscle function, balance ability and physical performance.

3.3 Methods

3.3.1 Participants' characteristics

Thirty-three (13 male) community-dwelling older adults (72 ± 7 years old) volunteered to take part in the study. Exclusion criteria comprised: aged under 65 years, chronic lung condition (e.g. asthma, obstructive pulmonary disease), fear of falling (Activities Balance Confidence [ABC] scale lower than 67%), having fallen in the previous 24 months, vertigo in the past 6 months, currently undertaking exercise balance training (including Tai Chi and Pilates) and any experience of IMT.

Recruitment occurred via Bournemouth University public engagement events, and participants gave written, informed consent before taking part. The study started on the 12th August 2016 and was completed by the 17th January 2017. Participants met with the principal investigator (FF) on two occasions: first, at baseline (week 1), and secondly, post-intervention (week 8). The study protocol was approved by Bournemouth University Research Ethics Committee (Reference ID: 12379).

3.3.2 General Design

A repeated measures design was used (pre- vs post-intervention); participants were asked to perform IMT for 8 weeks, using a pressure threshold device (POWERbreathe® International Ltd. Southam, UK). Chapter 2-3.9 provides details of the training protocol. All measurement were performed at the Orthopaedic Research Institute (Bournemouth University) under standardised conditions, in a temperature-controlled laboratory (20 to 22 °C; humidity < 70%). Testing and re-testing sessions were scheduled at a similar time of the day (between 9:00 and 11:00 am) to minimise potential effects of diurnal variation (Atkinson and Reilly 1996). Participants were advised not to consume caffeine, alcohol or to perform strenuous exercise two hours before measurements. All assessments and procedures are described briefly below (full details are provided in Chapter 2). Figure 3.1 presents details of screening, sample size, group allocation and withdrawals.

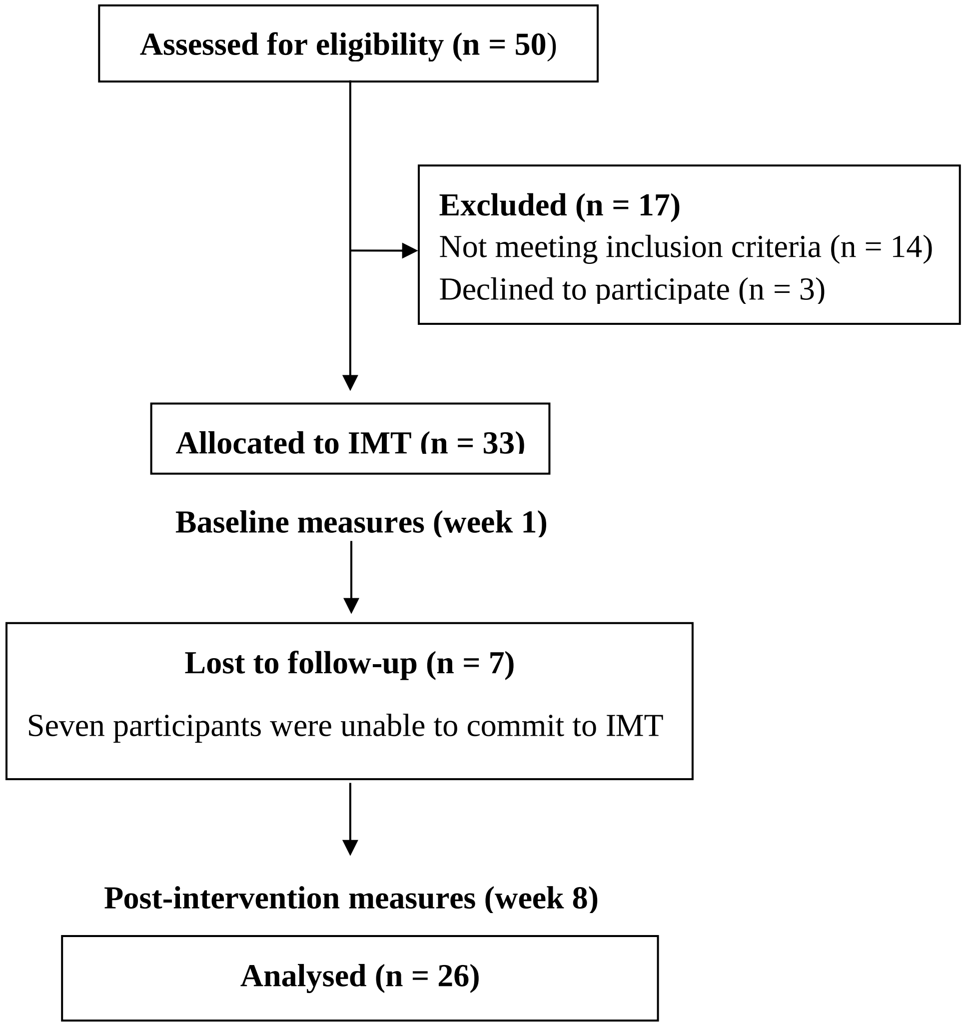

Figure 3- 1 CONSORT flow diagram displaying participants' pathways through the study. IMT = inspiratory muscle training.

3.3.3 Procedures

Questionnaires

The Activities-Specific Balance Confidence Scale (ABC) was used to observe participants fear of falling perception, whilst the Physical Activity Scale for the Elderly (PASE) was chosen as a measure of their level of physical activity. A completed description of both questionnaires is available in Chapter 2-3.3.

Pulmonary Function

A spirometer (ML3500S, Micro Medical Ltd, Rochester, Kent, UK) was used to measure forced vital capacity (FVC) and forced expiratory volume in 1 s (FEV_1), following the guidelines of the American Thoracic Society (Miller et al. 2005). Peak inspiratory flow rate (PIFR) was measured using the POWERbreathe® K5, with Breathe-Link 2.0 software (POWERbreathe® International Ltd, Southam, UK). All pulmonary function measurements were made according to the procedure detailed in Chapter 2.3-4.

Respiratory Muscle Function

A hand-held mouth pressure meter MicroRPM (Micro Medical Ltd, Rochester, Kent. UK) was used to measure maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP). Peak inspiratory power (PIP) was measured using the POWERbreathe® K5 (POWERbreathe International Ltd. Southam, UK) and Breathe-Link 2.0 software. All inspiratory muscle function assessments were made according to the procedure detailed in Chapter 2.3-5.

Physical performance

The timed up and go (TUG), TUG with cognitive dual-task (TUG_C), five sit to stand (FSTS) and functional reach (FR), tests were used to measure physical performance. A detailed description is available in Chapter 2.3-7. In addition, the pre-activation five sit to stand ($FSTS_{PA}$) and pre-activation functional reach (FR_{PA}) were used to determine the effect of acute, muscle pre-activation (Volianitis et al. 2001) on the physical performance tasks.

Briefly, participants were asked to rest before the prior-activation tasks (for 2 to 5 minutes), when ready participants performed a series of forceful inspirations at 80% of their MIP until repetition failure, via Powerbreathe® K5. When participants were unable to inhale forcefully for three consecutive attempts, they were instructed to stop the forced inspiration and to perform the assessments.

Balance

Static and dynamic balance ability was assessed using the Mini-Balance Evaluation Systems Test (mini-BEST). The full procedures are detailed in Chapter 2.3-6.

Trunk Muscle functions

Trunk muscle functions were assessed using a dynamometer (Primus BTE, Hanover, USA) as described fully in Chapter 2.3-8. The assessments include: isometric trunk muscle flexion, rotation and extension, isotonic trunk muscle flexion and extension, and trunk muscle anterior-posterior endurance (i.e. sit-up and Biering-Sørensen).

Intervention

After completion of the baseline measurements, each participant performed IMT twice per day, every day, for 8 weeks, following the protocol described in Chapter 2.3-9. Briefly, the POWERbreathe® Medic Plus was set to a personalised load equivalent to 50% of participant's MIP. The first training session was supervised to ensure that the inspiratory manoeuvres were performed correctly. Participants were instructed to increase the training load if they were able to exceed 30 breaths by 5 to 10 reps. Adherence to the prescribed training regime was monitored using a training dairy (sample available in Appendix A-6).

3.4 Data analysis

Normal distribution was determined with Shapiro-Wilk tests and z-score calculated from skewness and kurtosis. Because improvements were anticipated and the purpose of the pilot study was to detect changes post-intervention a one-tailed paired t-test was used to analyse changes (pre *vs* post) in normally distributed data.

For data that were not normally distributed (i.e. FVC and FEV_1) a Wilcoxon signed ranks test was used. Results are expressed as mean ± standard deviation (SD), statistical significance was determined *a priori* as $P \leq 0.05$, and effects size as Cohen's *d* is reported with the following magnitude ranges: small $d \leq 0.2$; medium $0.2 < d \leq 0.8$; large $d > 0.8$ (Victoria 1978).

3.5 Results

Twenty-six participants out of 33 (79%) completed the study. The reasons for withdrawal were: lack of time for four participants and lack of motivation. During the study, no adverse events (i.e. falls accident and breathing difficulties) were reported. Descriptive characteristics of participants are available in Table 3.1.

3.5.1 Questionnaires

Neither the ABC or PASE questionnaire results showed significant changes across the intervention; participants were found to be extremely confident in their balance, and fairly active in their daily life (Table 3.1).

3.5.2 Pulmonary function and respiratory muscle function

Pulmonary function tests (FVC and FEV_1) were no-significantly different from baseline following 8 weeks of IMT. Whereas, significant improvements ($P < 0.001$) were observed in PIFR, which increased by 12.8 ± 0.0 %, ($d = 0.5$).

Following IMT, MIP increased significantly (30.3 ± 33.2%; P < 0,001; $d = 1.1$; Table 3.1). Significant increase occurred also in PIP ($P \leq 0.01$) measured at 40% (by 40.4 ± 45.8% $d = 0.9$), 50% (by 25.8 ± 50.0% $d = 0.5$), 55% (by 42.6 ± 42.4% $d = 0.8$) and 60% of participants' MIP (by 20.9 ± 36.6% $d = 0.5$; Table 3.2). The overall improvements in PIP (i.e. highest PIP at baseline vs highest PIP post-intervention) was 2.3 W (28.1 ± 0.5, $P = 0.08$ $d = 0.5$). The inter-relationships of inspiratory load, peak inspiratory power, and peak inspiratory flow rates are shown in Figure 3-2.

Table 3. 1 Participants’ characteristics. Pulmonary and inspiratory muscle function tests at baseline (week 1) and post-intervention (week 8).

		IMT n = 26		P-Values
Outcomes	Baseline	Post-intervention	% change	
Gender (M/F)		13/20		N/A
Age (years)		72 ± 7		N/A
BMI (kg m^{-2})		25.8 ± 3.4		N/A
ABC	90.0 ± 8.7	91.1 ± 9.5	1.2 ± 9.2	NS
PASE	166.0 ± 43.7	165.5 ± 55.2	-0.3 ± 26.3	NS
FVC (l)	3.2 ± 0.7	3.2 ± 0.8	0	NS
FEV$_1$ (l s^{-1})	2.4 ± 0.7	2.4 ± 0.6	0	NS
PIFR (l s^{-1})	4.7 ± 1.2	5.3 ± 1.2 **	12.8 ± 0.0	< 0.001
MIP (cmH$_2$O)	83.6 ± 25.0	108.9 ± 33.3 **	30.3 ± 33.2	< 0.001
MEP (cmH$_2$O)	96.8 ± 37.5	98.7 ± 39.1	2.0 ± 4.3	NS

BMI = body mass index. ABC = activities specific balance confidence scale. PASE = physical activity scale for the elderly. FVC = forced vital capacity. FEV$_1$ = forced expiratory volume in 1 second. PIFR = peak inspiratory flow rate. MIP = maximal inspiratory pressure. MEP = maximal expiratory pressure. N/A = not applicable. NS = no-significant. ****** significantly different from baseline ($P \leq 0.01$).

Table 3. 2 Peak inspiratory power at different percentages of load at baseline (week 1) and post-intervention (week 8).

	IMT n = 26.			P-Values
Outcomes	Baseline	Post-intervention	% change	
PIP at 40% MIP (W)	5.2 ± 2.4	7.3 ± 3.5 **	40.4 ± 45.8	<0.01
PIP at 50% MIP (W)	6.2 ± 3.2	7.8 ± 4.8 **	25.8 ± 50.0	<0.01
PIP at 55% MIP (W)	6.1 ± 3.3	8.7 ± 4.7 **	42.6 ± 42.4	<0.01
PIP at 60% MIP (W)	6.7 ± 3.0	8.1 ± 4.1 **	20.9 ± 36.7	<0.01
PIP at 70% MIP (W)	6.4 ± 3.3	7.2 ± 5.2	12.5 ± 57.6	NS
PIP at 80% MIP (W)	6.1 ± 3.8	6.4 ± 5.0	4.9 ± 31.6	NS

PIP = peak inspiratory power, MIP = maximal inspiratory pressure. W = Watts. NS = no-significant. ****** Significantly different from baseline ($P \leq 0.01$).

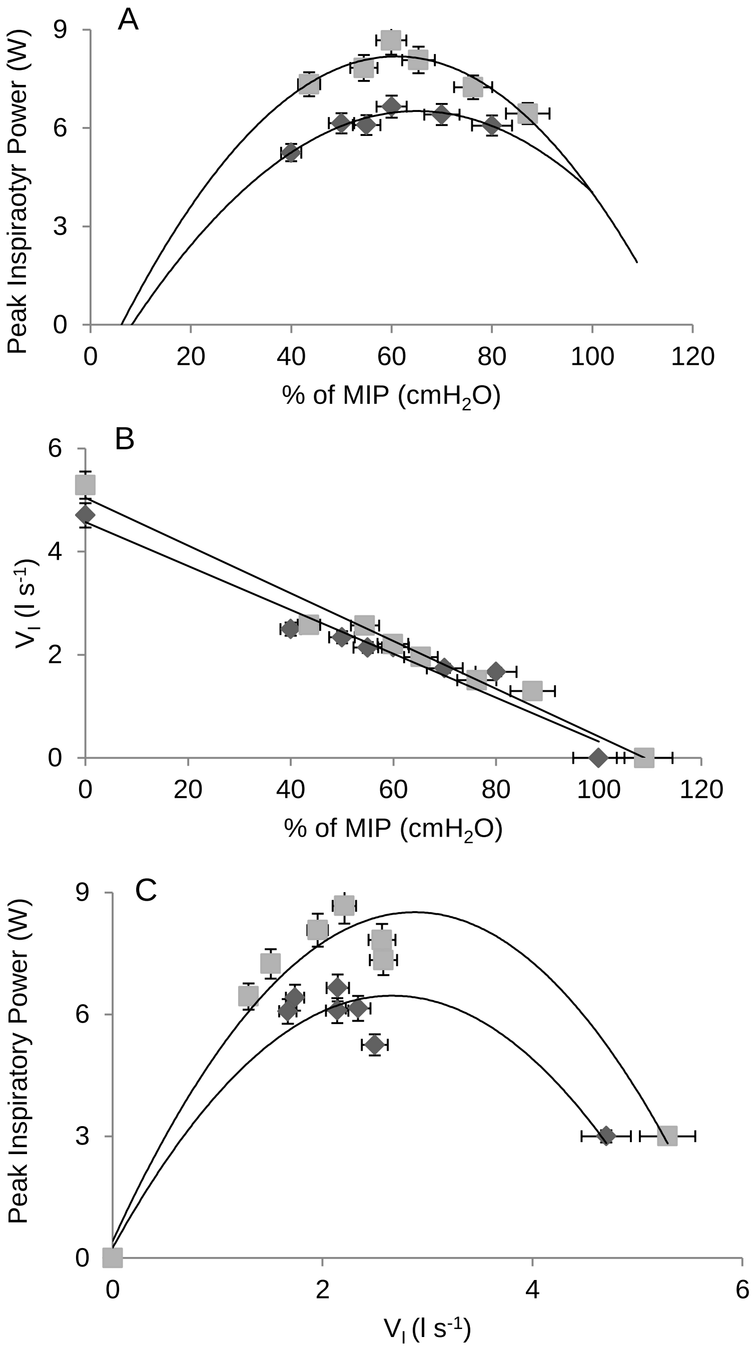

Figure 3- 2 (A) Peak inspiratory power (Watts) vs load as a percentage of maximal inspiratory pressure (MIP; cmH_2O). (B) Peak inspiratory flow rate V_I (l s^{-1}) vs load as a percentage of maximal inspiratory pressure (MIP; cmH_2O). (C) Peak inspiratory power (Watts) vs peak inspiratory flow rate V_I (l s^{-1}). Before (◆) and after (■) 8 weeks of inspiratory muscle training. Data are represented in both axes as mean ± percentage error.

3.5.3 Physical performance

Following IMT there were no-significant changes in any of the physical performance tests (Table 3-3). However, analysis between single and dual-task conditions at baseline and post-intervention showed that TUG_C was significantly higher ($P < 0.001$) than TUG at baseline (2.1 s, 37.5 ± 86.7%, $d = 0.9$) and post-intervention (2.6 s, 46.4 ± 46.4%, $d = 1$) indicating that participants needed more time to complete the TUG_C task. In addition, after 8 weeks of IMT participants were significantly ($P = 0.04$; $d = 0.1$) faster in the $FSTA_{PA}$ than in FSTS.

Table 3. 3 Baseline (week 1) and post-intervention (week 8) physical performance values.

	IMT n = 26			P-Values
Outcomes	Baseline	Post-intervention	% change	
TUG (s)	5.6 ± 1.5	5.6 ± 1.3	0.0 ± 13.3	NS
TUG_C (s)	7.7 ± 2.8 $^{\#\#}$	8.2 ± 3.5 ††	6.5 ± 25.0	NS
FSTS (s)	10.6 ± 4.8	11.4 ± 4.7	7.5 ± 2.1	NS
$FSTS_{PA}$ (s)	10.3 ± 3.4	10.8 ± 4.2 §	4.9 ± 23.5	NS
FR (cm)	36.4 ± 6.1	34.6 ± 4.8	- 4.9 ± 21.3	NS
FR_{PA} (cm)	35.9 ± 5.4	34.8 ± 4.1	- 3.1 ± 24.1	NS

TUG = timed up and go, TUG_C = cognitive TUG, FSTS = five sit to stand, $FSTS_{PA}$ = FSTS with prior inspiratory muscle activation, FR = functional reach, FR_{PA} = FR with prior inspiratory muscles activation. s = seconds. NS = not significant. § Significantly different from no pre-inspiratory muscle activation condition ($P \leq 0.05$). $^{\#\#}$ Significantly different from TUG condition at baseline ($P \leq 0.01$). †† Significantly different from TUG condition post-intervention ($P \leq 0.01$). *The* analyses between *TUG vs TUG_C* were conducted with a single pair t-tests, refer to 3.4 Data Analysis section.

3.5.4 Balance

There was a significant improvement in mini-BEST score (by 13.7 ± 46.2%, *d* = 0.8). In particular, there were significant improvements in reactive (by 38.2 ± 23.5%) and dynamic (by 14.5 ± 47.4%) tasks (P ≤ 0.01; *d* = 0.9 and *d* = 0.7, respectively), Table 3.4.

Table 3. 4 Baseline (week 1) and post-intervention (week 8) values for the mini-BEST and its four domains of balance.

	IMT n = 26			P-Values
Outcomes	Baseline	Post-intervention	% change	
mini-BEST	21.2 ± 3.9	24.1 ± 2.1 **	13.7 ± 46.2	≤ 0.01
Anticipatory	4.9 ± 1.1	5.4 ± 0.6	10.2 ± 45.4	NS
Reactive	3.4 ± 1.7	4.7 ± 1.3 **	38.2 ± 23.5	≤ 0.01
Sensory	5.1± 0.9	5.1 ± 0.5	0.0 ± 44.4	NS
Dynamic	7.6 ± 1.9	8.7 ± 1.0 **	14.5 ± 47.4	≤ 0.01

***** Significantly different from baseline (P ≤ 0.05), ****** significantly different from baseline (P ≤ 0.01) NS = no-significant

3.5.5 Trunk Muscle functions

Following IMT participants showed significant improvements in the Biering-Sørensen test (by 68.6%; P ≤0.05; *d* = 0.6), whereas none of the other trunk muscle tests differenced significantly. Baseline and post-intervention scores are reported in Table 3.5 and Table 3.6

Table 3. 5 Baseline and post-intervention in trunk muscle function values.

	IMT n = 26			P-Values
Outcomes	Baseline	Post-intervention	% change	
$ISOM_F$ (N)	267.4 ± 85.5	305.0 ± 111.1	14.1 ± 29.9	NS
$ISOM_E$ (N)	309.8 ± 140.9	365.8 ± 166.0	18.1 ± 17.8	NS
$ISOT_F$ (J)	259.6 ±165.6	169.4 ± 59.2	-34.7 ± 64.2	NS
$ISOT_E$ (J)	169.2 ± 83.6	187.9 ± 88.9	11.1 ± 6.3	NS
Sit-Up Test (s)	26.9 ± 31.9	30.6 ± 32.9	13.8 ± 3.1	NS
Biering-Sørensen (s)	27.1 ± 30.6	45.7 ± 39.6 *	68.6 ± 29.4	≤ 0.05

$ISOM_F$ = Isometric trunk muscle flexion. $ISOM_E$ = isometric trunk muscle extension. $ISOT_F$ = Isotonic trunk muscle flexion. $ISOT_E$ = Isotonic trunk muscle extension. N = Newton. J = Joules. s = seconds. ***** Significantly different from baseline (P ≤ 0.05). NS = no-significant.

Table 3. 6 Baseline and post-intervention in trunk muscle rotation values.

	IMT n = 26			P-Values
Outcomes	Baseline	Post-intervention	% change	
	Right (θ)			
ISOM$_R$ 0° (N)	40.8 ± 19.0	37.8 ± 22.0	-7.4 ± 15.8	NS
ISOM$_R$ 20° (N)	37.8 ± 19.3	34.2 ± 23.2	-9.5 ± 20.2	NS
ISOM$_R$ 40° (N)	34.9 ± 20.3	31.4 ± 19.9	-10.0 ± 1.8	NS
ISOM$_R$ -20° (N)	39.8 ± 18.4	38.1 ± 19.9	-4.3 ± 8.2	NS
ISOM$_R$ -40° (N)	39.6 ± 19.4	43.4 ± 20.3	9.6 ± 4.6	NS
	Left (θ)			
ISOM$_R$ 0° (N)	41.7 ± 20.3	40.4 ± 23.6	-3.1 ± 16.2	NS
ISOM$_R$ 20° (N)	40.7 ± 20.7	40.6 ± 20.0	-0.2 ± 1.9	NS
ISOM$_R$ 40° (N)	44.7 ± 26.1	44.7 ± 26.5	0.0 ± 1.5	NS
ISOM$_R$ -20° (N)	39.1 ± 21.9	35.4 ± 19.2	-9.5 ± 12.3	NS
ISOM$_R$ -40° (N)	33.8 ± 18.1	32.6 ± 18.8	-3.6 ± 3.9	NS

ISOM$_R$ = Isometric trunk rotation. N = Newtown. NS = no-significant.

3.6 Discussion

3.6.1 Main findings

The results support the proof-of-concept that 8 weeks of unsupervised, home-based IMT is feasible with healthy community-dwelling, older adults (79% completed the intervention). In addition, IMT produced positive changes in inspiratory shorten velocity (measured with PIFR), inspiratory muscle strength (measured with MIP) and inspiratory muscle power (measured with PIP), reactive and dynamic balance outcomes (measured with the mini-BEST test) and back muscle endurance (measured with Biering-Sørensen test).

Additionally information about the overall experience was reported by few participants who declare verbally (to the principal investigator) as extremely positive the training experience was:

D.G. - *After the 8 weeks, it felt easier for me to get up to the hills in Lyme Regis*.

P.N. - *At the beginning it was difficult, but I find it easy to do (it NA) after the first two weeks*.

The thesis purpose is not to analyse the effect of IMT with qualitative methods. However, these aspects are further investigated in section 6.4.8.

3.6.2 Effects of IMT on pulmonary and respiratory muscle function

The PIFR findings are in accordance with Romer and McConnell with a younger cohort (24 ± 2 years old) (2003), as well as with recent publication with older adults (68 ± 3 years old) (Mills et al. 2015).

A significant increment in MIP (by 30.3%), without changes in MEP, was also present. This is consistent with previous findings in healthy older adults (68 ± 3 years old) where similar increase was reported (by 34%) after 8 weeks of IMT (Mills et al. 2015), and with COPD patients (64 ± 8 years old) who increased their MIP (by 18%) after 5 weeks of IMT (Susana et al. 2008).

These results support two conclusions: i) that unsupervised, home-based IMT is effective for older people in improving pulmonary and inspiratory muscle functions, and ii) that the improvements in MIP were due predominantly to improvement in inspiratory muscle adaptions induced by IMT, since MEP showed no significant improvements.

The peak inspiratory flow showed that the training protocol produced improvements in shortening velocity, as well as strength. Significant improvements by 2.1 W, 1.6 W, 2.6 W and 1.4 W (at 40, 50, 55 and 60% of participant MIP, respectively) support the effectiveness of an unsupervised, home-based IMT intervention with healthy older adults. In addition, the greatest increase (2.6 W) occurred in the range loads used during the training (50% of participants` MIP), reflecting the influence of training specificity.

3.6.3 Effects of IMT on physical performance

After IMT TUG and TUG_C were no-significant. At baseline and post-intervention participants needed significantly more time to complete the $TUG_{C,}$ than TUG (baseline: *d* = 0.9; post-intervention *d* = 1). These findings reinforce the concept that a dual-task condition produces difficulties upon gait proficiency (Commandeur et al. 2018).

The FSTS tasks appeared to be unaffected by IMT. However, when combining IMT and inspiratory muscle pre-activation, participants were able to perform significantly faster the $FSTS_{PA}$ than the FSTS post-intervention by 0.6 s (*d* = 0.1). These results may indicate the presence of a inspiratory muscle “warm-up” phenomenon, as reported with healthy younger adults (~20 years) during rowing performance (Volianitis et al. 2001).

3.6.4 Effects of IMT on balance

The intervention significantly improved the mini-BEST score (by 2.9 units). In addition, the improvements occurred during reactive (i.e. compensatory stepping correction) and dynamic (e.g. walking at different speeds) tasks, suggesting that IMT may have a beneficial influence in situations where the trunk musculature is engaged in compensatory adjustments to perturbation (e.g. compensatory stepping correction backward).

These improvements in dynamic and reactive balance outcomes reinforce the theory of Hodges and Gandevia (2000a), suggesting that inspiratory muscles help to maintain balance when sudden destabilising forces perturb the postural stability (e.g. during rapid upper limb movements). In contrast, the absence of changes in sensory tasks (e.g. stand with eyes closed for 30 s) may have occurred because this task is related to the central nervous system function (Rogers et al. 2005), and so it may not be affected directly by IMT. Similarly, the additional recruitment of inspiratory muscles may be unnecessary in anticipatory tasks (e.g. stand on one leg for 20 s), which produce less demand upon postural stability in healthy moderately active individuals, who have no neurological or physical impairment (Horak 1987).

3.6.5 Effects of IMT on trunk Muscle Functions

The Biering-Sørensen test was the only trunk muscle test to exhibit significant changes post-IMT, with an improvement of 18.6 s (d = 0.6). However, based on the results it is not possible to identify the mechanism(s) that caused this improvement.

3.7 Conclusion

The study supports the proof of concept that IMT is feasible with unsupervised healthy older adults, producing improvements in both inspiratory muscle function and dynamic balance proficiency. The findings, along with the amendments introduced from the transfer examination, justified to proceed to an uncontrolled, repeated measures design study to:

1. Understand the magnitude of effects on balance outcomes produced by IMT
2. Report the effectiveness of an IMT intervention in community-dwelling older adults
3. Decrease the possible presence of bias with a more robust approach.

3.8 Limitations

The main limitation of this study is the absence of a control group and more specific exclusion criteria. For example pathology (e.g. diabetes) or the use of medicine (e.g. beta-blockers) can affect the balance results, introducing potential bias.

The peak inspiratory power test was not measured at the same absolute load (i.e. MIP at baseline), but during post-intervention assessments it was modified to the new absolute load (i.e. MIP post-intervention). Hence, the outcomes fail to show the real improvement in peak inspiratory power. For further analysis we recommend not to modify the absolute value between baseline and post-intervention.

Some tests used may not be sensitive to changes elicited by IMT. In particular, the FR, trunk isometric and isotonic tests appeared insensitive to the intervention. In addition, the pre-activation condition (used during $FSTS_{PA}$ and FR_{PA}) was not ideal for the specific population, for further research it is recommend progressing with another approach: 30 breathes at ~40% of MIP followed by forced inspiration at ~80% MIP until exhaustion.

3.9 Acknowledgements

The authors would like to thank all the participants who contributed their time to help with the study and to the visiting PGR and Nuffield students who helped during the tests. We would also like to express great appreciation to Dr Jonathan Williams and Dr Simon Dyall for their feedback during the transfer examination that helped to improve the quality and rigour of the future studies within the thesis.

Chapter Four

THE EFFECTS OF EIGHT WEEKS OF INSPIRATORY MUSCLE TRAINING ON THE BALANCE AND PHYSICAL PERFORMANCE OF HEALTHY OLDER PEOPLE: A RANDOMISED, DOUBLE-BLIND, CONTROLLED STUDY[3]

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[3] The following research has been presented at the British Association Sport Exercise (BASES) student conference on the 12th – 13th April 2018 in Newcastle upon Tyne (UK) and at the BASES conference on the 27th – 28th November 2018 in Harrogate (UK). The research chapter has been published by Physiological Reports (DOI: https://doi.org/10.14814/phy2.14076). Poster communication included in Appendix A-8 and A-9.

4.1 Abstract

Purpose. To examine the effects of 8 weeks home-based inspiratory muscle training (IMT) on the balance and physical performance of healthy older adults.

Method. Fifty-nine participants (74 ± 6 years) were assigned randomly in a double-blinded fashion to either IMT or sham-IMT, using a pressure threshold loading device. The IMT group performed 30 breaths twice daily at 50% of maximal inspiratory pressure (MIP). The sham-IMT group performed 60 breaths once daily at ~15% MIP; training was home-based and unsupervised. Respiratory outcomes were assessed pre- and post-intervention, including forced vital capacity, forced expiratory volume in one second, peak inspiratory flow rate (PIFR), MIP, and inspiratory peak power. Balance and physical performance outcomes were measured using the shortened version of the Mini-Balance Evaluation System test (mini-BEST), Biodex® postural stability, timed up and go, five sit to stand, isometric 'sit-up' and Biering-Sørensen tests. Between-group effects were examined using two-way repeated measures ANOVA, with Bonferroni correction.

Results. After 8 weeks, the IMT group demonstrated greater improvements ($P \leq 0.05$) in: PIFR (IMT = 0.9 ± 0.3 l s^{-1}; sham-IMT = 0.3 l s^{-1}); mini-BEST (IMT = 3.7 ± 1.3; sham-IMT = 0.5 ± 0.9) and Biering-Sørensen (IMT = 62.9 ± 6.4 s; sham-IMT = 24.3 ± 1.4 s) tests.

Conclusions. Twice daily unsupervised, home-based IMT is feasible and enhances inspiratory muscle function and balance for community-dwelling older adults.

4.2 Introduction

Accidental falls are the leading cause of fatal and non-fatal injuries amongst older adults in the Western world (CDCP 2016). According to the UK's National Institute for Health and Care Excellence, 30% of people over 65 years will fall at least once a year in the UK, whereas 50% of people over 80 years will fall annually (NICE 2013). There is an urgent need for effective interventions that are low cost and low risk to reduce falls.

The majority of current exercise programs to improve balance focus on lower limb muscle strength, with the addition of supervised multi-dimensional movements, including Tai Chi, and dance (Sherrington 2016). Recently, it has been suggested that trunk muscle training (i.e. abdominal strength training and Pilates exercises training) may improve balance and thus be used as a falls prevention intervention for older adults (Granacher et al. 2013). However, the contribution of the trunk muscles to balance is unclear.

Hodges and colleagues investigated the stabilising action of the diaphragm muscle, proposing that it works both indirectly, by increasing intra-abdominal pressure to support the spine (Hodges et al. 2005), and directly, by continuous co-contraction contributing in postural stabilisation (Hodges and Gandevia 2000b). Ageing is associated with biological changes (e.g. senile emphysema) that compromise inspiratory muscle function (Britto et al. 2009) and lung structure (Martin 2010).

In particular, the strength of the inspiratory muscles has been reported to decline gradually from 65 years of age onwards (Enright et al. 1994). These age-related declines in respiratory function may directly, and indirectly, alter the contribution of the inspiratory muscles to balance, in accordance with Hodges' theory.

In support of this concept, recent evidence suggests that inspiratory muscle weakness may contribute to balance deficits during daily activities, such as chair rising (Janssens et al. 2014). Therefore, this raises the question as to whether inspiratory muscle training (IMT), which consists of breathing exercises using a pressure threshold device, can reduce the physiological effect of ageing on inspiratory muscle function, thereby improving balance ability for older adults.

The purpose of this study was to evaluate the effectiveness of 8 weeks IMT on the inspiratory muscle function, balance and physical performance of community-dwelling older adults. Based on the aforementioned findings of Hodges and colleagues, we hypothesise that 8 weeks of twice daily home-based IMT will improve inspiratory muscle function and balance performance, without any adverse events (i.e. falls accidents while performing the unsupervised exercises).

4.3 Methods

4.3.1 Participants' characteristics

Fifty-nine (18 male) community-dwelling older adults (74 ± 6 years old) volunteered to take part in the study. Exclusion criteria comprised: aged under 65 years, chronic lung condition (e.g. asthma, obstructive pulmonary disease), moderate or severe low back pain (Oswestry low back pain [ODI] questionnaire higher than 21%) (Fairbank and Pynsent 2000), cognitive impairments (Mini–Mental State Examination [MMSE] score lower than 24) (Folstein et al. 1983), fear of falling (Activities Balance Confidence [ABC] scale lower than 67%) (Powell and Myers 1995), having fallen in the previous 24 months, diabetes (Allet et al. 2008), heart conditions preventing physical activity, taking beta-blocker medication, vertigo in the past 6 months, currently undertaking exercise balance training (including Tai Chi and Pilates) and any experience of IMT (as participants would have been be able to recognise the sham-IMT).

Recruitment occurred via Bournemouth University public engagement events, and participants gave written informed consent before taking part. Participants met with the principal investigator (FF) on two occasions: firstly, at baseline (week 1), and secondly, post-intervention (week 8). The research protocol was approved by Bournemouth University Research Ethics Committee (Reference ID: 15352).

4.3.2 General design

A double-blind, randomised placebo controlled design was used, with participants allocated randomly to undergo either IMT or sham-IMT. An equal number of POWERbreathe® Medic Plus devices were prepared and assigned to each participant randomly, using a pseudo-random number generator (randomizer.org). Figure 4-1 presents details of screening, sample size, group allocation and withdrawals.

All measurements were performed between June 2017 and February 2018 at the Orthopaedic Research Institute (Bournemouth, UK) under standardised conditions, in a temperature-controlled laboratory (20 to 22 °C; humidity < 70%). Testing and re-testing sessions were scheduled at a similar time of the day (between 9:00 and 11:00 am) to minimise potential effects of diurnal variation (Atkinson and Reilly 1996).

Participants were advised not to consume caffeine, alcohol or to perform strenuous exercise two hours before measurements. Assessments of forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), peak inspiratory flow rate (PIFR), maximal inspiratory pressure (MIP), peak inspiratory power (PIP), balance proficiency measured with the shortened version of the Mini-Balance Evaluation System test (mini-BEST) and Biodex® postural stability tests, physical performance (five sit to stand and timed up and go tests) and trunk muscle endurance (sit-up and Biering-Sørensen tests) were performed pre- and post-intervention, by one researcher (FF) blinded to group allocation.

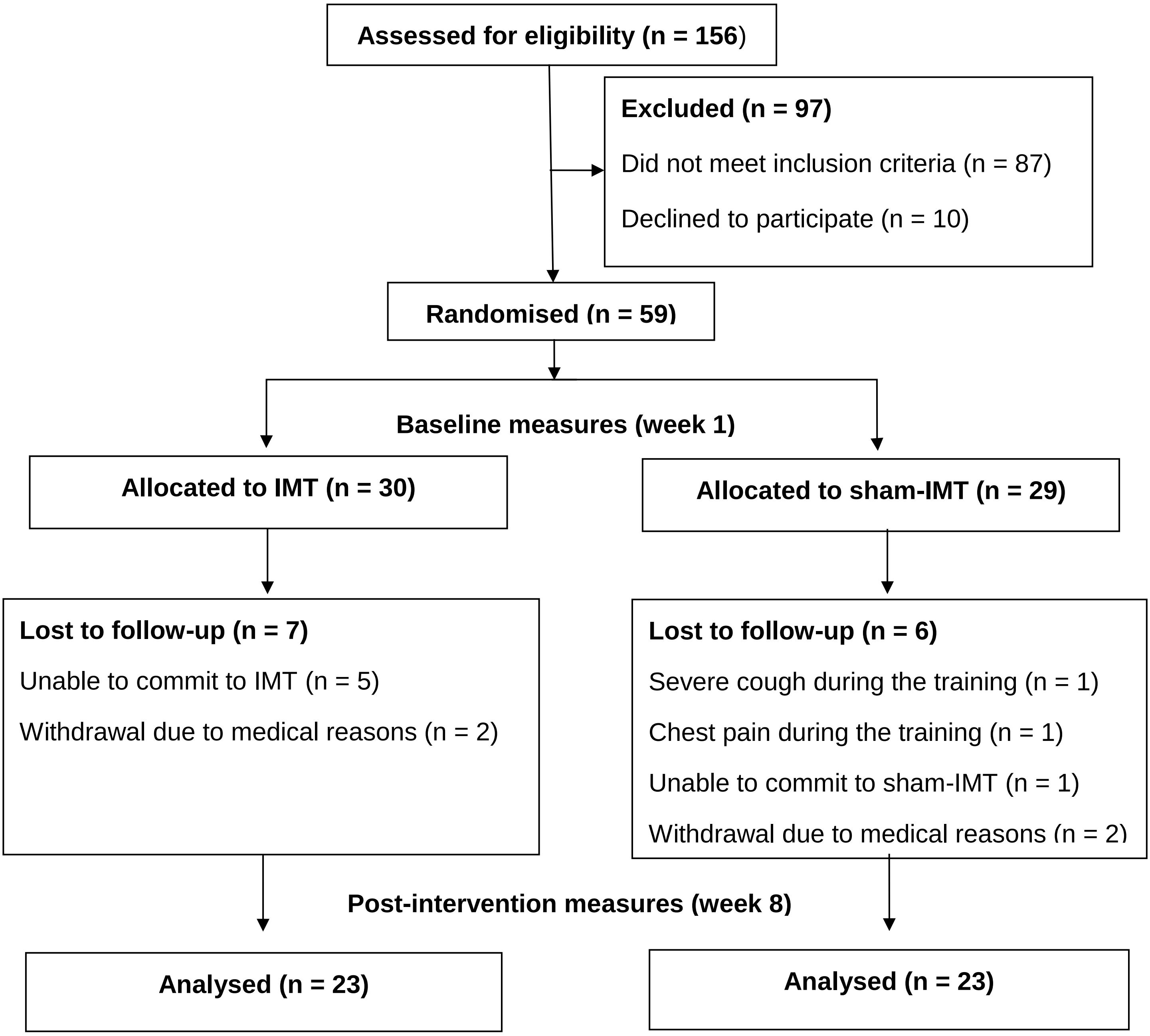

Figure 4- 1 CONSORT flow diagram displaying participant pathways through the study. IMT = inspiratory muscle training.

4.3.3 Pulmonary function

A spirometer (SpiroUSB, Care Fusion, Wokingham, Berkshire, UK) was used to measure FVC and FEV_1, following the guidelines of the American Thoracic Society (Miller et al. 2005), whilst PIFR was measured using the POWERbreathe® K5, with Breathe-Link 2.0 software (POWERbreathe® International Ltd, Southam, UK) (Langer et al. 2013). Participants performed forced breathing manoeuvres, while wearing a nose clip, at least five, and no more than eight times, until variability was within 5% for three consecutive manoeuvres. The highest score was then recorded.

4.3.4 Respiratory muscle function

A hand-held mouth pressure meter (MicroRPM, Micro Medical Ltd, Rochester, Kent, UK) was used to determine MIP. The pressure meter was fitted with a side port opening of 1 mm internal diameter, to maintain glottis opening. All participants practised the Müller manoeuvre three times before testing, and MIP measurements were repeated, at least five, and no more than eight times, until variability was within 10% for three consecutive manoeuvres.

Peak inspiratory power (PIP) was measured using the POWERbreathe® K5 with Breathe-Link 2.0 software (Langer et al. 2013). Inspiratory muscle power analysis was undertaken at six different loads (40, 50, 55, 60, 70 and 80% of participants` [baseline] MIP) and data were fitted in a polynomial curve, replicating methods reported elsewhere (Romer and McConnell 2003). Participants were requested to inhale with maximal effort against the six loads, the order of which was randomly assigned. Three trials were performed for each of the loading intensities with 30 seconds rest between efforts, making a total of 18 forced inspiratory manoeuvres. For all pulmonary and respiratory muscle tests, a nose-clip was worn, and verbal encouragement was provided to promote maximal efforts. In each of the two respiratory muscle function measurements, the highest score was then recorded.

4.3.5 Physical performance

The five sit-to-stand test

The five sit-to-stand test (FSTS) involved measuring the time taken to stand from a seated position five consecutive times (Watt et al. 2018). Briefly, participants were asked to sit on the edge of an armless chair (sitting height 46 cm, seat length 45 cm) with their arms folded across their chest. They were instructed to rise, and then become seated as fast as possible, five times, with both feet maintaining contact with the floor. Timing commenced on the command “3, 2, 1 and go”.

The pre-activation five sit-to-stand ($FSTS_{PA}$) was used to determine the effect of acute, pre-inspiratory muscle activation (Volianitis et al. 2001) on the FSTS task. Briefly, rest intervals between FSTS and $FSTS_{PA}$ were provided (2 to 5 minutes), when ready, participants performed 30 repetitions of forceful inhalations against a load equivalent to ~40% of their [baseline] MIP, followed by forceful inhalation at 80% of [baseline] MIP until repetition failure. Verbal encouragement was provided during the 80% loading phase. When participants were unable to inhale forcefully for three consecutive attempts, they were instructed to stop the forced inspiration and to perform the $FSTS_{PA}$. During both FSTS and $FSTS_{PA}$ tests, participants were blindfolded, to minimise a potential effect of vision on the performance (Mourey et al. 2000).

The timed up and go test

The timed up and go test (TUG) was undertaken to assess mobility and gait speed, in single and dual-task condition, i.e. cognitive timed up and go (TUG_C) and motor timed up and go (TUG_M). For all TUG conditions, participants were asked to sit on the edge of an armless chair (sitting height 46 cm). On the command “3, 2, 1 and go” they were instructed to stand up, walk at habitual pace to a line on the floor 3 m away, turn around, walk back and sit down (Podsiadlo and Richardson 1991). During the TUG_C participants were instructed to perform the same task while counting aloud, backwards in threes from a randomly selected number between 80 and 100. During the TUG_M participants completed the same tasks, as in the TUG, while holding a drinking glass (diameter 8 cm, height 9.5 cm) filled with water (1 cm away from the edge of glass). Before testing, a familiarisation trial of the TUG task was performed. The three tasks were undertaken in a random order, with no physical assistance provided.

4.3.6 Balance

Mini-BEST test

Static and dynamic balance were assessed using the Min-Balance Evaluation Systems Test (mini-BEST), which included 14 different tasks, divided into: anticipatory (e.g. toe rise for 3 seconds), reactive postural control (e.g. compensatory stepping forward), sensory orientation (e.g. stand on a foam surface with eyes closed for 30 seconds) and dynamic gait (e.g. walk with horizontal head turns; (O'Hoski et al. 2015).

Biodex® postural stability test

Static balance was further investigated using the Biodex® postural stability test (PSt) (Biodex, Shirley, NY; (Parraca et al. 2011). The PSt measured participants' ability to maintain their centre of pressure within their base of support, with a lower score indicating a better balance. Participants were asked to step blindfolded onto a firm, stable surface, as well as an unstable foam surface, three times, each for 20 seconds. This test was also repeated after inspiratory muscle pre-activation following the same protocol described for the $FSTS_{PA}$. The latter tests are reported as stable PSt_{PA} and unstable PSt_{PA}, respectively.

4.3.7 Trunk muscle endurance

Anterior trunk muscle endurance was assessed using an isometric 'sit-up' task, adopting a bent knee sit-up, with feet secured by a strap, arms folded across the chest and trunk forming an angle with the horizontal of 60° (McGill et al. 1999). Posterior trunk muscle endurance was assessed using the Biering-Sørensen test, where participants were asked to maintain a prone position, facing the floor, with their torso unsupported over the edge of a test bench. A strap secured their legs and hips. With hands placed behind their head (Biering-Sørensen 1984) participants were instructed to hold the static positions until volitional exhaustion, without verbal encouragement. Time was recorded using a stopwatch.

4.3.8 Interventions

Inspiratory muscle training

Participants performed home-based IMT twice daily [once in the morning (between 7:00 and 12:00 am) and once in the evening (between 16:00 and 21:00 pm)], for 8 consecutive weeks, using a mechanical pressure threshold loading device (POWERbreathe Plus, POWERbreathe® International Ltd, Southam, UK). Participants followed an established training protocol known to improve inspiratory muscle function, consisting of 30 quick breaths twice daily at an adjustable resistance (equivalent to ~50% of [baseline] MIP). In addition, participants in this group were able to increase the inspiratory resistance when they felt that 30 breaths were achievable with ease or if they could reach 35 consecutive breathes (McConnell 2013).

Sham – inspiratory muscle training

Participants performed 60 slow breaths once daily at a load setting of 0 (corresponding to ~15% [baseline] MIP), using the same device as the IMT group. For the sham group, the ability to adjust the training load was prevented using sticky tape applied to the device's load adjuster. This protocol has been shown previously to elicit negligible changes in inspiratory muscle function in healthy young adults (Romer et al. 2002) and in those with chronic obstructive pulmonary disease (Charususin et al. 2018).

Both the researcher and participants were blinded to group allocation, and participants were unaware of the predicted outcomes of the two interventions. To preserve intervention blinding, motivational telephone calls were not provided during either intervention. Adherence to the prescribed training was self-reported through weekly training diaries, which were presented to the researcher post-training.

4.4 Data analysis

Sample size estimation was made using G*Power software (Faul et al. 2007), using data from a pilot study involving 26 participants (73 ± 6 years) (unpublished). Following the recent guidelines for clinical trials, that recommend to use a power $\geq$ 80% (Tushar Vijay 2010), the sample size was estimated with an α error = 0.05 and 1-β = 0.95.

Briefly, In the pilot study (Chapter 3) 26 participants completed 8 weeks of unsupervised, home-based IMT. Measured of balance (assessed with the mini-BEST) pre and post intervention showed a significant improvement (by 13.7%) from baseline: 21.2/28.0 ± 3.8 to post-intervention: 24.1/28.0 ± 2.1 ($P < 0.01$, $d = 0.8$).

To assess the hypothesis that IMT improves dynamic balance performance (measured with the mini-BEST) a total sample of 46 participants were required to demonstrate an improved of 10%. The protocol analysis was used to examine between-group intervention (IMT vs sham-IMT), pre- vs post-intervention. Further within-group effects were explored using a paired t-test and a Wilcoxon signed ranks test for not normally distributed data.

Between-group comparisons were made using a two-way repeated-measures ANOVA, with Bonferroni. Data are reported as mean, standard deviation (SD) and percentage change. Statistical significance between-group (intervention x time interaction) was determined a priori as $P \leq 0.05$ and Cohen's d effect sizes were calculated to determine the effect magnitude (small $d \leq 0.2$; medium $0.2 < d \leq 0.8$; large $d > 0.8$).

4.5 Results

Forty-six participants completed the study; training adherence was 76% and 79% for IMT and sham-IMT, respectively. Following the interventions, there were no adverse events in the IMT group, whereas two participants reported severe cough and chest discomfort during sham-IMT. Reasons for withdrawing are reported in Figure 4-1. Groups were similar in gender, age, BMI, pulmonary function (FVC and FEV_1), balance confidence (ABC), perception of back pain (ODI) and cognitive capacity (MMSE) before training ($P > 0.05$). See Table 4.1.

4.5.1 Pulmonary function

FVC and FEV_1 were not significantly different following either intervention (Table 4.1), whereas both groups improved PIFR post-intervention, with a significant effect between-groups ($P = 0.02$). Specifically, within-participants analysis showed that IMT increased PIFR by 19.7% ($d = 1.2$; $P < 0.01$), whilst sham-IMT increased PIFR by 7.5% ($d = 0.2$; $P = 0.05$).

4.5.2 Inspiratory muscle function

Both groups showed significant improvements in MIP post-intervention (Table 4.1), with no significant changes between groups. The IMT group increased MIP by 45.9% (*d* = 1.4; $P \leq 0.01$), and the sham-IMT group increased by 18.0% (*d* = 0.3; $P = 0.02$). Changes in inspiratory peak inspiratory power (PIP) were not significant between-groups (Table 4.2). However, within-participants analysis revealed significant improvements in PIP at all loads for the IMT group, with the highest inspiratory power improvement (80.6%; *d* = 0.8; $P = 0.008$) at the 80% [baseline] MIP. In contrast, following sham-IMT, inspiratory peak power increased significantly only at the 80% [baseline] MIP (16.3%; *d* = 0.02; $P = 0.03$). Figure 4-2 presents the inter-relationships of the inspiratory loads applied, inspiratory peak power, and peak inspiratory flow rate.

Table 4. 1 Participants' characteristics. Pulmonary and inspiratory muscle function tests at baseline and post-intervention.

	IMT (n = 23)			Sham-IMT (n = 23)			*P*-values
Outcomes	Baseline	Post-intervention	%change	Baseline	Post-intervention	% change	Between-groups
Gender (M/F)	9/14			9/14			N/A
Age (years)	75 ± 6			72 ± 5			N/A
BMI (kg m^{-2})	27 ± 3.1			26 ± 3.5			N/A
ABC	90.5 ± 7.2	91.7 ± 9.5	1.3	84.9 ± 12.8	86.7 ± 10.4	2.1	NS
ODI	3.5 ± 5.7	3.3 ± 5.1	-5.7	4.6 ± 5.7	3.8 ± 4.1	-17.4	NS
MMSE	28 ± 1.6	29 ± 0.9	3.5	28 ± 0.8	29 ± 0.9	3.5	NS
FVC (l)	3.4 ± 0.9	3.5 ± 0.7	2.9	3.2 ± 0.8	3.3 ± 0.8	3.1	NS
FEV_1 (l s^{-1})	2.6 ± 0.7	2.6 ± 0.9	0	2.3 ± 0.6	2.3 ± 0.6	0	NS
PIFR (l s^{-1})	4.6 ± 0.9	5.5 ± 0.6**	19.7	4.0 ± 1.4	4.3 ± 1.4 *	7.5	P = 0.02
MIP (cmH_2O)	76.0 ± 27.4	110.9 ± 21.3 **	45.9	72.8 ± 40.9	85.9 ±28.8*	18.0	NS

BMI = body mass index, ABC = activities specific balance confidence scale, ODI = oswestry low back pain disability questionnaire, MMSE = mini-mental examination test, FVC = forced vital capacity, FEV_1 = forced expiratory volume in 1 second, PIFR = peak inspiratory flow rate, MIP = maximal inspiratory pressure. N/A = not applicable. NS = no-significant.***** Significantly different from baseline ($P \leq 0.05$), ****** significantly different from baseline ($P \leq 0.01$).

Table 4. 2 Baseline and post-intervention values for peak inspiratory power at different percentages of load.

	IMT (n = 21)			Sham-IMT (n = 22)			*P*-values
Outcomes	Baseline	Post-intervention	% change	Baseline	Post-intervention	% change	Between-groups
PIP at 40% MIP (W)	5.0 ± 2.0	6.7 ± 3.1 *	34.0	4.7 ± 3.5	5.1 ± 3.9	8.5	NS
PIP at 50% MIP (W)	4.7 ± 2.7	5.7 ± 2.7 *	21.3	3.6 ± 3.1	4.9 ± 3.7	36.1	NS
PIP at 55% MIP (W)	5.3 ± 3.1	7.0 ± 3.2 *	32.1	4.9 ± 3.9	5.2 ± 3.4	6.1	NS
PIP at 60% MIP (W)	4.8 ± 2.4	7.1 ± 3.7 **	47.9	4.1 ± 3.5	4.9 ± 2.9	19.5	NS
PIP at 70% MIP (W)	5.3 ± 3.4	7.3 ± 3.9 *	37.7	4.5 ± 4.1	5.3 ± 3.5	17.8	NS
PIP at 80% MIP (W)	3.6 ± 2.4	6.5 ± 4.3 **	80.6	4.3 ± 3.1	5.0 ± 4.4 *****	16.3	NS

PIP = peak inspiratory power, MIP = maximal inspiratory pressure. W = Watts. NS = no-significant.* Significantly different from baseline (P ≤ 0.05). ** Significantly different from baseline (P ≤ 0.01).

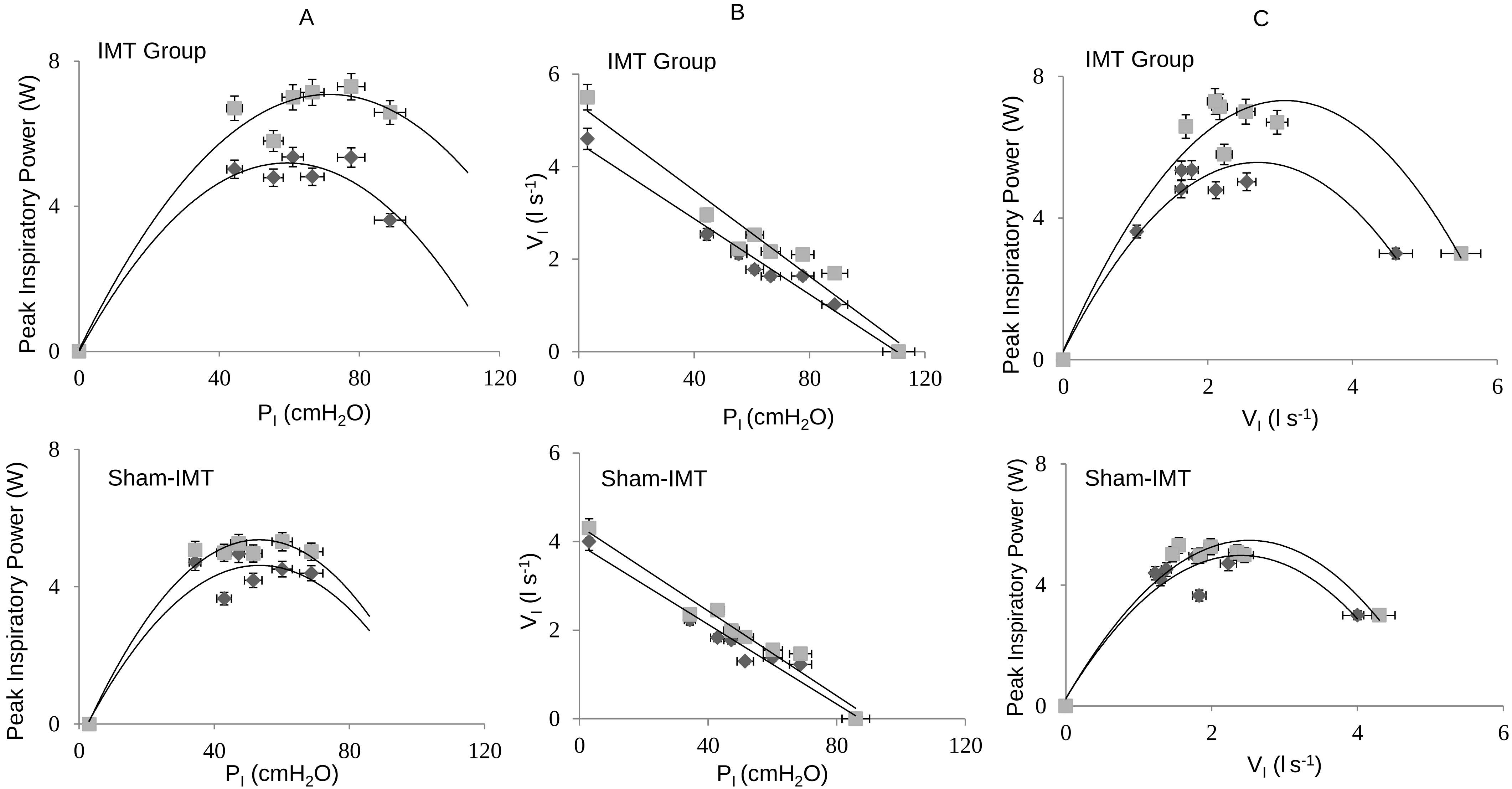

Figure 4- 2 (A) Peak inspiratory power (Watts) vs inspiratory load pressure P_I (cmH$_2$O). (B) Inspiratory flow rate V_I (l s^{-1}) vs Inspiratory mouth pressure P_I (cmH$_2$O). (C) Inspiratory peak power (Watts) vs inspiratory flow rate V_I (l s^{-1}). Before (■) and after (◆) 8 weeks of inspiratory muscle training (IMT) and sham-IMT. Data are represented in both axes as mean ± percentage error.

4.5.3 Physical performance

For the FSTS and $FSTS_{PA}$ tasks (Table 4.3), there were no-significant between-group differences following the interventions. However, there were significant within participants changes for $FSTS_{PA}$ in the sham-IMT group, which needed 20.5% more time to complete the task (*d* = 0.5; P = 0.03).

Post-intervention, both groups were significantly faster in the $FSTS_{PA,}$ than the FSTS test. In particular, time decreased by 10.7% in IMT group (*d* = 0.2; P ≤ 0.01) and by 10.0% in sham-IMT (*d* = 0.2; P ≤ 0.01). The post-intervention changes in TUG, TUG_C and TUG_M, were significantly different between the groups (P = 0.03; P = 0.02; P = 0.02, respectively).

The TUG was also significantly different within the IMT participants, who needed 5.3% less time to complete the task (*d* = 0.2; P = 0.04). Further analysis between single and dual-task conditions at baseline and post-intervention showed that cognitive (TUG_C) and motor (TUG_M) dual-tasks were both significantly different (P ≤ 0.01) from the single-task (TUG) condition at baseline and post-intervention in IMT, and sham-IMT groups.

However, the data also showed that changes in motor dual-task were significantly different from changes in cognitive dual-task (*d* = 0.4; P ≤ 0.01) post-intervention in sham-IMT group and not in the IMT group.

4.5.4 Balance

The mini-BEST score differed within-participants and between-groups (P = 0.05) post-intervention (Table 4.4). The IMT group improved by

18.1% (*d* = 1.3; $P \leq 0.01$), specifically in reactive (by 39.4%; *d* = 0.8; $P \leq 0.01$) and dynamic tasks (by 21.1%; *d* = 0.8; $P \leq 0.01$). The PSt and PSt_{PA} tests showed no significant difference between- or within-groups. See Table 4.3.

4.5.5 Trunk muscle endurance

There were significant between-group differences in anterior (sit-up, $P = 0.02$) and posterior (Biering-Sørensen, $P \leq 0.01$) trunk endurance tests (Table 4.3). However, within-group analysis showed that the IMT group exhibited significant improvements in the Biering-Sørensen test performance (by 63%; *d* = 3.7; $P < 0.01$).

Table 4. 3 Baseline and post-intervention values for physical performance, Biodex® postural stability index and trunk endurance tests.

	IMT (n = 23)			Sham-IMT (n = 23)			*P*-values
Outcomes	Baseline	Post-intervention	% change	Baseline	Post-intervention	% change	Between-groups
FSTS (s)	15.5 ± 5.9	16.8 ± 8.1	8.4	18.6 ± 11.5	20.9 ± 8.9	12.4	NS
FSTS$_{PA}$ (s)	15.1 ± 5.9	15.0 ± 5.8 ††	-0.7	15.6 ± 4.9	18.8 ± 7.5 ^{A} ††	20.5	NS
TUG (s)	7.6 ± 1.6	7.2 ± 1.8 ^{A}	-5.3	9.0 ± 2.4	9.3 ± 3.6	3.3	P = 0.03
TUG$_{C}$ (s)	10.0 ± 3.0**	10.3 ±5.1 $^{\#\#}$	3.0	12.3 ± 3.8**	13.5 ± 4.7 $^{\#\#}$	1.6	P = 0.02
TUG$_{M}$ (s)	10.3 ± 2.2**	9.2 ± 2.2 $^{\#\#}$	-10.7	11.7 ± 3.5**	11.8 ± 3.3 $^{\#\# §§}$	0.9	P = 0.02
Stable PSt	2.8 ± 0.8	2.0 ± 0.7	-27.8	2.7 ± 0.9	1.7 ± 0.7	-35.7	NS
Stable PSt$_{PA}$	2.6 ± 0.9	2.4 ± 0.8	-9.5	2.6 ± 0.8	2.2 ± 0.7	-13.2	NS
Unstable PSt	3.1 ± 1.4	2.7 ± 1.2	-11.7	3.2 ± 1.4	1.9 ± 1.4	-10.5	NS
Unstable PSt$_{PA}$	2.6 ± 1.2	2.8 ± 1.2	6.5	3.0 ± 1.4	2.8 ± 1.4	-7.6	NS
Sit-up (s)	59.9 ± 14.5	87.2 ± 17.9	45.6	31.8 ± 5.5	39.3 ± 9.8	23.6	P = 0.02
Biering-Sørensen (s)	64.7 ± 7.3 (n=22)	105.4 ± 13.7 ^{AA}	62.9	37.1 ± 6.7 (n=17)	46.1 ± 8.1	24.3	P = 0.001

TUG = timed up and go, TUG$_{C}$ = cognitive TUG, TUG$_{M}$ = motor TUG, FSTS = five sit to stand, FSTS$_{PA}$ = FSTS pre inspiratory muscles activation, PSt = postural stability index, PSt$_{PA}$ = PSt prior inspiratory muscles activation. s = seconds. NS = no-significant. ^{A} Significantly different from baseline ($P \leq 0.05$), ^{AA} significantly different from baseline ($P \leq 0.01$). †† significantly different from no pre inspiratory muscle activation condition ($P \leq 0.01$). ** Significantly different from TUG condition at baseline ($P \leq 0.01$). $^{\#\#}$ Significantly different from TUG condition post-intervention ($P \leq 0.01$). §§ Significantly different from TUG$_{C}$ condition post-intervention ($P \leq 0.01$).

Table 4. 4 Baseline and post-intervention values for the mini-BEST and its four domains of balance.

	IMT (n = 23)			Sham-IMT (n = 23)			*P*-values
Outcomes	Baseline	Post-intervention	% change	Baseline	Post-intervention	% change	Between-groups
Mini-BEST	20.4 ± 3.5	24.1 ± 2.2**	18.1	20.8 ± 3.3	21.3 ± 2.9	2.4	P = 0.05
Anticipatory	5.0 ± 0.9	5.5 ± 0.6**	10.0	5.2 ± 1.2	4.9 ± 0.9	-5.8	NS
Reactive	3.3 ± 1.7	4.6 ± 1.2**	39.4	3.0 ± 1.7	4.0 ± 1.3	33.3	NS
Sensory	4.9 ± 0.6	5.4 ± 0.6**	10.2	5.1 ± 0.8	5.1 ± 0.6	0	NS
Dynamic	7.1 ± 1.5	8.6 ± 0.9**	21.1	7.3 ± 1.6	7.3 ± 1.6	0	NS

The mini-BEST test has a maximum score (MS) of 28, and it is composed of four component Anticipatory MS 6; Reactive postural control MS 6; Sensory orientation MS 6; Dynamic gait MS 10. ***** Significantly different from baseline (P ≤ 0.05), ****** significantly different from baseline (P ≤ 0.01) NS = no-significant.

4.6 Discussion

This is the first study to investigate the effects of unsupervised, home-based IMT on measures of balance and physical performance in community-dwelling, older adults. Using a double-blind, placebo controlled design, our findings support the study hypothesis that IMT enhances dynamic balance performance, as evidenced by improvements in the mini-BEST test.

In addition, we have found that healthy older adults can undertake IMT safely at home, unsupervised for 8 weeks. Drop-out was relatively low in both groups (24% for IMT; 21% for sham-IMT), particularly given that: i) motivational calls were not provided and, ii) participants performed the exercises unsupervised during the study.

4.6.1 Effects of IMT on pulmonary and inspiratory muscle function

Pulmonary function (FVC and FEV_1) remained unchanged after 8 weeks of training in both groups. In accordance with Mills and colleagues (2015), we propose that improvements in spirometry measurements following IMT are mostly related to task-learning effects, rather than physiological improvements.

Following IMT, inspiratory muscle shortening velocity (PIFR) moderately increased (by 19.7%), whereas sham-IMT increased to a lesser extent (by 7.5%). These findings are similar to those observed by Mills and colleagues (Mills et al. 2015) with healthy older adults (68 ± 3 years).

Our participants improved inspiratory muscle strength (MIP) significantly following IMT, which supports previous research with older women (aged 68 ± 5 years) (Souza et al. 2014). However, we also observed improvements in MIP following sham-IMT that are similar to those reported with older (70 ± 8 years old) heart failure patients (Bosnak-Guclu et al. 2011) and with young (18 ± 2 years old) elite swimmers (Mickleborough et al. 2008).

The improvements in MIP and PIFR following sham-training may reflect enhanced neural activation, rather than respiratory muscle remodelling *per se* (Eastwood et al. 1998). Accordingly, we must conclude that at least part of the improvements in MIP observed in the IMT group also reflects an improvement in neural activation.

The peak inspiratory power generated during inspiratory loading (Table 4.2 and Figure 4-2) assesses the ability of the inspiratory muscles to shorten under different loads. A greater flow at any given load is indicative of a higher inspiratory power output resulting in faster muscle shortening.

Following 8 weeks of IMT, participants significantly improved the peak inspiratory power at all loads, with the greatest improvement at 80% of their [baseline] MIP (peak inspiratory power increased by 80.6% or 2.9 W). Conversely, in the sham-IMT group, participants showed significant improvements only at 80% of [baseline] MIP (peak power increased by 16.3% or 0.7 W).

Our results concur with those observed by Romer and colleagues with young adults (25 ± 2.8 years) (Romer and McConnell 2003). Overall, our findings support the effectiveness of IMT, which can be undertaken by community-dwelling older adults in their own homes without supervision, to enhance pulmonary and inspiratory muscle function. For future research, we recommend decreasing or removing the loading resistance to reduce potential task-learning effects, for control groups.

4.6.2 Effects of IMT on physical performance

Following both interventions, the FSTS did not improve, but the sham-IMT group showed a significant decrease in FSTS_{PA} performance (-3.2 s) from baseline. This may be attributed to impairment in postural control caused by inspiratory muscle fatigue. In addition, the FSTS has deemed a reasonable choice for clinical and research assessments (Zhang et al. 2018), however it may not be an ideal test to address changes induced by IMT.

Firstly, because the FSTS results mostly correlate to quadriceps strength (Lord et al. 2002), thus potentially the test is insensitive to changes in the trunk musculoskeletal system.

Secondly, the FSTS presents a floor effect that can reduce the validity of the measurement in older adults (Guralnik et al. 1994). For further investigation, we recommended using variants of the sit-to-stand test that presents a lower ceiling effect and can produce more stress to the musculoskeletal system (e.g. 30 s sit-to-stand). After 8 weeks the IMT group was able to complete the TUG significantly faster (-5.3%)

compared to baseline. Analysis between single and dual-tasks revealed that the dual-tasks (TUGc and TUG_M) were significantly different from the single-task (TUG), in both groups at baseline and post-intervention. However, only in the sham-IMT group did the TUG_C and the TUG_M differ significantly from each other post-intervention (by 1.7 s).

These changes show that the sham-IMT group experienced greater difficulty in the cognitive dual-task, than in the motor dual-task, when compared to IMT group. This may indicate a possible decrement in gait ability for the sham-IMT group. These finding are in accordance with reported amelioration in walking ability, measured through the shuttle walking test, with patients with COPD following IMT (Ahmed Saad et al. 2016).

Our results on the TUG test are also similar, in magnitude, from those observed following 12 weeks of OTAGO exercise program with 27 healthy home residents older adults (aged 78 ± 8 years) (Kocic et al. 2018). However, it is not possible to conclude what mechanism(s) contributed to the improvements in gait proficiency.

We believe that an increase in gait ability can be the result of either: improved VO_2 uptake, that reduced the feeling of fatigue in the lower limbs (Bailey et al. 2010), or an increase in inspiratory muscle strength, that produced enforcements to the upper and lower body segment linkage, similar to that observed in other trunk muscle exercises (Granacher et al. 2013). Further investigation is required to understand the potential mechanism(s) by which IMT may enhance walking ability in older adults.

4.6.3 Effects of IMT on balance performance

This is the first study to describe the effects of IMT upon balance performance. The mini-BEST score improved significantly following IMT (18.1%), whilst sham-IMT did not differ significantly. Our results are similar in magnitude to those seen after 12 weeks of therapeutic yoga, with community-dwelling older adults (Kelley et al. 2014). Subsequent analysis of the different mini-BEST`s components showed that the greatest improvements were in reactive (by 39.4%) and dynamic (by 21.1%) tasks, Table 4.4.

Hodges and colleagues (2000) established that diaphragm phasic contractions assist in maintaining postural stability in situations whereby external forces (i.e. rapid movement of upper limb) destabilise the spine. We believe that a similar mechanism occurs during reactive (i.e. compensatory stepping correction) and dynamic (e.g. walking at different speeds) tasks, and that improved inspiratory muscle strength resulted in a subsequent improvement in dynamic balance abilities.

We also noted a significant improvement (by ~10%) in anticipatory (e.g. standing on one leg for 20 s) and sensory (e.g. standing with eyes closed on an inclined ramp) tasks following IMT. The positive changes may be related to the participants’ ability to increase intra-abdominal pressure that supports the spine (i.e. Valsalva manoeuvre) (Hodges et al. 2005).

The absence of significant influence of IMT on PSt is likely to relate with the specific postural challenges created by the PSt (i.e. standing blindfolded on a stable surface) do not require recruitment of the trunk musculature. Furthermore, it appears that an ankle-driven strategy (as opposed to hip strategy) dominates the compensatory response to balance perturbation in similar tasks (Horak 1987).

In addition, the improvements in balance observed for the IMT group (measured with the mini-BEST) were greater than those observed following 12 weeks of OTAGO exercise training (measured with Berg Balance scale) for healthy older adults (n = 27; aged 78 ± 8 years; IMT *d* = 1.3; OTAGO *d* = 0.6) (Kocic et al. 2018). We can conclude that following 8 weeks of IMT participants increased balance performance, in particular in dynamic balance, which is relevant for falls risk.

Balance improvements may be related to positive changes in inspiratory muscle strength (measured with MIP, PIFR and PIP) that caused positive changes in diaphragmatic phasic contractions, and in the ability to increase intra-abdominal pressure. We recommend further investigation in the possible mechanism(s) by which IMT improves balance proficiency.

4.6.4 Effects of IMT on trunk muscle endurance

The posterior trunk muscle endurance tests (Biering-Sørensen) was completed by 39 participants out of 46. The reason because 7 participants did not perform the assessment was due to discomfort while performing it. Participants in the IMT group showed significant improvements (by 63%) in the posterior trunk endurance test (Biering-Sørensen), whilst the sham-IMT group were no different after 8 weeks.

Our findings agree with previous research reporting that IMT enhances endurance plank performance in young recreational runners (Tong et al. 2014). However, it remains unclear as to how IMT may mechanistically contribute to improved trunk muscle endurance for older adults.

4.6.5 Effects of pre-activation of the inspiratory muscles

Studies with young participants (~20 years) reported that pre-activation of the inspiratory muscles significantly improves rowing performance (Volianitis et al. 2001). Volianitis et al. concluded that a ‘warm-up’ phenomenon, similar to the one present in locomotor muscles, occurs for the inspiratory muscles (Volianitis et al. 1999).

Our results support Voliantis' supposition of a respiratory ‘warm-up’ effect, since both our groups improved $FSTS_{PA}$ time to a greater extent than FSTS (IMT by 10.7%; sham-IMT by 10.0%). We also noticed that the IMT group had minor changes between baseline and post-intervention in $FSTS_{PA,}$ whilst the sham-IMT group showed significant changes, needing more time to complete the $FSTS_{PA}$ (by 20.5%).

These results indicate that combining IMT and inspiratory muscle pre-activation can lead to improvements in FSTS tasks. We can then conclude that a ’warm-up’ effect of inspiratory muscles can improve physical performance outcomes and that IMT can help in maintaining this performance in older adults.

4.7 Conclusion

Using a double-blind, randomised placebo-controlled design, we investigated the effectiveness of 8 weeks of unsupervised, home-based IMT with healthy older adults. After 8 weeks the IMT group showed improvements in inspiratory muscle function (PIFR, MIP and PIP), as well as dynamic balance ability, as shown by increased mini-BEST score. Therefore, our study demonstrated that IMT can be feasible and effective for healthy older adults when delivered at home and unsupervised, to improve respiratory function and dynamic balance.

Inspiratory muscle function improvements in the placebo group suggest that compared to younger adults, healthy older adults may rely more greatly on neural systems. Further research is required to determine the potential mechanism(s) by which inspiratory muscles contribute to dynamic and static balance, as well as the role that IMT may play in reducing the risk of falling compared to other balance interventions (e.g. OTAGO exercise program).

4.8 Limitations

The main limitation of this study was that PSt may have been insensitive to detecting changes elicited by IMT. We believe that, in the absence of external perturbation, participants used primarily an ankle-driven strategy as opposed to a hip strategy (Horak 1987). The ankle strategy has been shown to be adopted for more than 90% of the time to cope with task demand in similar assessments for young adults (23 ± 3.6 years) (Blenkinsop et al. 2017). Therefore, without the necessary hip and trunk muscle recruitment, the effect of IMT on balance was not detectable. Future research should investigate the role that IMT may play in increasing balance proficiency for frailer adults (i.e. care home residents).

4.9 Acknowledgements

The authors would like to express great appreciation to all the participants who contributed their time to help and to thank all the students that collaborate during their placements.

Chapter Five

COMPARISON OF CHANGES IN BALANCE AND FUNCTIONAL MOBILITY FOLLOWING INSPIRATORY MUSCLE TRAINING AND OTAGO EXERCISE TRAINING FOR HEALTHY OLDER ADULTS[4]

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[4] The following Chapter is currently under review by Plos One.

5.1 Abstract

Aim. The inspiratory muscles contribute to balance via diaphragmatic co-contraction and by increasing intra-abdominal pressure. We have shown previously that inspiratory muscle training (IMT) is feasible for community-dwelling older adults, improving balance significantly. However, the relative magnitude of improvements following IMT and traditional balance enhancement interventions is unknown. This study compared the effects of 8 weeks of IMT for community-dwelling adults, to 8 weeks of Otago exercise program (OEP) for care home-dwelling adults, on balance and physical performance outcomes.

Methods. Nineteen community-dwelling adults (74 ± 4 years) were assigned to unsupervised self-administered IMT. Eighteen care home residents (82 ± 4 years) were assigned to supervised instructor-led OEP. The IMT involved 30 breathes twice-daily at 50% of maximal inspiratory pressure (MIP). The OEP group undertook resistance and mobility classes for ~60 minutes, twice-weekly. Balance and physical performance were assessed using the Mini-balance evaluation systems test (mini-BEST), time up and go (TUG) and 30 sec sit to stand tests.

Results. After 8 weeks, both groups significantly improved balance ability (mini-BEST: IMT by 24 ± 34%; OEP = 34 ± 28%). Particularly, the dynamic balance sub-task improved significantly more for the IMT group (P = 0.04) than the OEP group. The IMT group also improved MIP (by 66 ± 97%), peak inspiratory power (by 31 ± 12%) and TUG (by -11 ± 27%); whilst significant changes were not present for the OEP group.

Conclusion. Inspiratory muscle training and OEP improved balance ability similarly but in slightly different areas of balance, IMT produces positive changes in dynamic whilst OEP in static balance aspects. Furthermore, IMT conferred additional benefits for inspiratory muscle function and TUG performance.

5.2 Introduction

Physical activities have been shown to ameliorate age-related risk factors associated with falls accidents (Sherrington 2016). In particular, multidirectional exercises (e.g. Tai Chi, Pilates or dance) have become popular to target balance deficiencies for older adults. Among these, the Otago exercise program (OEP) is an evidence-based intervention that is effective in reducing falls in older adults (Campbell et al. 1999), as well as improving balance performance for both older community-dwelling (Thomas et al. 2010) and care home-dwelling adults (Kocic et al. 2018).

The OEP involves group-based, lower-limb resistance (e.g. knee extension-flexion and hip abduction) and mobility exercises (e.g. tandem stance and walking) tailored to older adults who are at high risk of falling (Campbell et al. 1997). Kocic and colleagues (Kocic et al. 2018) recently found that performing OEP three times a week, for 6 months, can improve dynamic balance (measured with the Berg Balance Scale) and physical performance (timed up and go and chair rising tests) in nursing home residents (aged between 70 - 86 years old). Although such multidirectional exercises may improve lower limb strength and balance ability with elderly participants, they required supervision, trained instructors and specific facilities, and are therefore impractical for the majority of community-dwellers.

In the last decade, alternative physical interventions have emerged, including those targeting the upper-body and trunk musculature (Granacher et al. 2013) and in particular, inspiratory muscles (i.e.

diaphragm and intercostal muscles), which have been shown to contribute to balance performance. During rapid limb movements, designed to perturb balance (i.e. shoulder abduction and adduction), the diaphragm is activated in a feedforward manner, and assists in the mechanical stabilisation of the spine (Hodges and Gandevia 2000b). In addition, the inspiratory muscle contraction increases intra-abdominal pressure, which helps to stabilise the lumbar part of the spine during static (e.g. standing on tiptoes) and dynamic (e.g. walking with head turns) balance perturbations (W Hodges et al. 2005).

In a previous study with community-dwelling older adults (73 ± 6 years) (Ferraro et al. 2019), we have shown that 8 weeks of individual, unsupervised, home-based inspiratory muscle training (IMT) is not only feasible, but also elicits significant improvements in dynamic and reactive balance, gait speed and inspiratory muscle function for healthy older adults.

However, it is unknown whether this novel and adaptable intervention, *viz.* IMT, is as effective as established interventions, such as OEP. Therefore, this pragmatic study aimed to compare the influence of 8 weeks of either, i) daily, self-administered, unsupervised IMT with community-dwelling older adults and ii) instructor-led, group-based OEP with residential care home-dwelling older adults, upon balance ability and functional performance. We hypothesised that, despite the differing physical characteristics of the two groups, 8 weeks of home-based IMT would improve balance ability similarly to OEP.

5.3 Methods

5.3.1 Participants' characteristics

Thirty-seven older adults (79 ± 7 years) participated in the study. Exclusion criteria comprised: aged under 70 years, acute respiratory tract infection or chronic lung disease (e.g. asthma and obstructive pulmonary disease), having fallen in the previous 24 months, diabetes, heart conditions preventing physical activity, taking beta-blocker medication, vertigo in the past 6 months, currently undertaking balance exercise training (including Tai Chi and Pilates) and previous experience of IMT.

Individuals with the following characteristics were also excluded: low balance confidence (activities balance confidence scale [ABC] lower than 67%) (Powell and Myers 1995), moderate low back pain (Oswestry low back pain questionnaire [ODI] higher than 20%) (Fairbank and Pynsent 2000), cognitive impairments (Mini-mental examination test [MMSE] lower than 24) (Folstein et al.1983).

Participants were recruited through Bournemouth University public engagement events and residential care home managers in Dorset and Hampshire (from April to August 2018). Written informed consent was obtained by the principal investigator (FF) before baseline measurements, and the research protocol was approved by Bournemouth University Research Ethics Committee (Reference ID: 19458).

5.3.2 General design

A non-randomised repeated measures, pragmatic, parallel study design was used to investigate whether community-dwelling older adults undertaking 8 weeks of unsupervised, home-based IMT would improve balance and physical performance outcomes, similarly to care home residents undertaking 8 weeks of instructor-led, group-based OEP. Nineteen (15 female) community-dwelling older adults were allocated to IMT, and 18 (14 female) care home-dwelling residents were assigned to OEP group classes.

This pragmatic non-randomised approach was selected for the following reasons:

- The interventions were delivered according to the settings in which they were validated, to preserve internal validity. For example, IMT is effective as an unsupervised, individual home-based programme, to improve balance and physical performance for older adults (Ferraro et al. 2019). In addition, IMT does not require supervision and takes between 10 and 15 minutes per session. Whereas, the OEP is most effective as a group-based class (Kyrdalen et al. 2014). The OEP involves supervision, as participants must perform resistance and balance exercises that require safety and technique monitoring. The training requires between 40 and 50 minutes per session.

- To enhance external validity, the investigators aimed to reproduce a similar OEP group-based intervention as adopted in Geriatric

Medicine (i.e. NHS Christchurch Hospital, Fairmile Road, Christchurch, UK), whilst minimising financial and logistical costs for the participants. Residential homes having appropriate facilities, staff and equipment to perform the group-based OEP safely were recruited. Group allocation and participant pathways through the pragmatic study are illustrated in Figure 5-1.

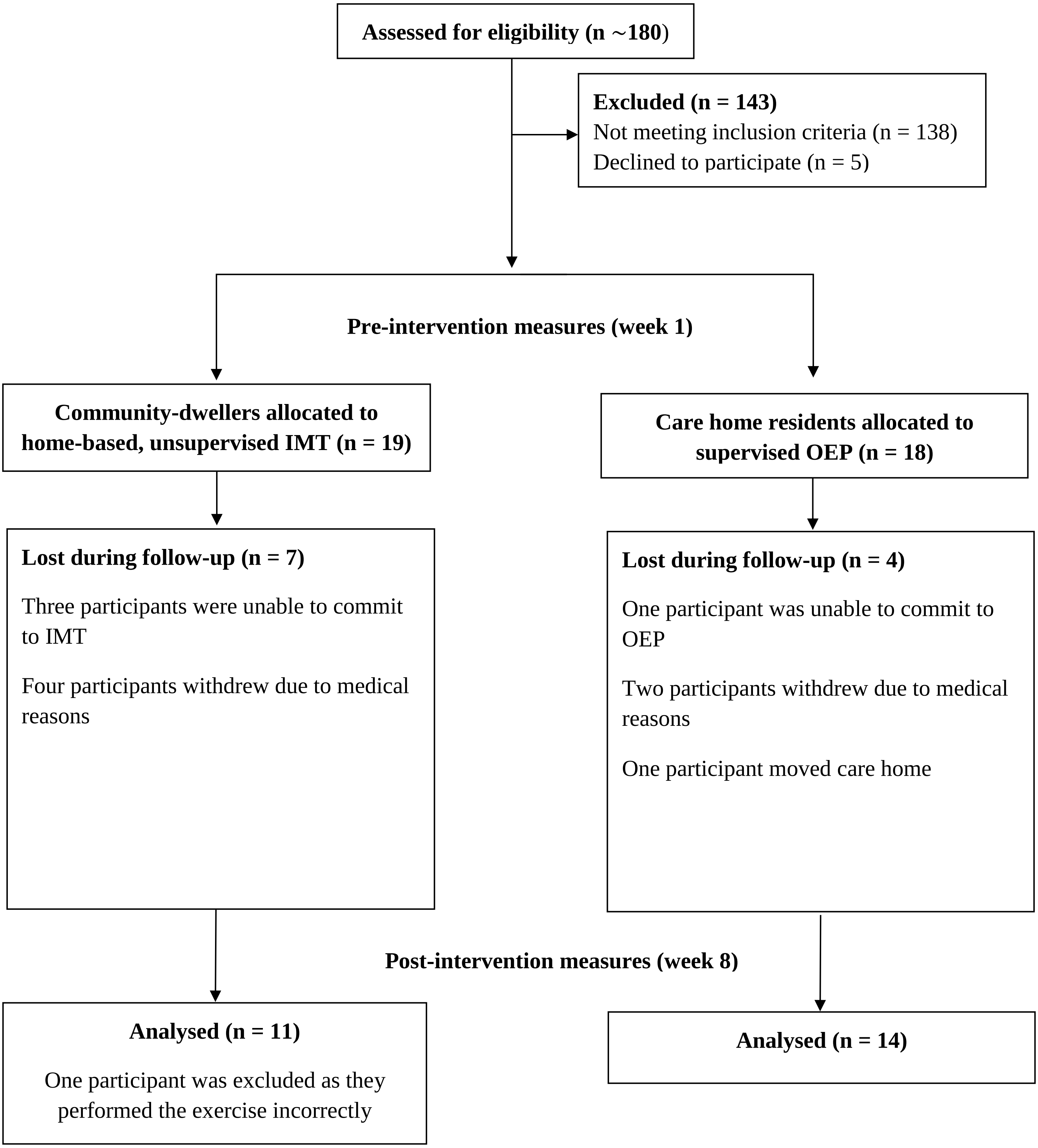

Figure 5- 1. CONSORT flow diagram displaying participant pathways through the 8 weeks non-randomised comparison study. IMT = inspiratory muscle training, OEP = Otago exercise program.

Outcome measures were collected at the University premises for IMT participants, and at the care homes (six homes in total) of OEP participants. Testing and re-testing sessions were scheduled at a similar time of the day (between 8:00 and 11:00 am) to minimise potential effects of diurnal variation (Atkinson and Reilly 1996).

Participants were requested not to consume caffeine, alcohol or to perform physical activities (e.g. gardening, hiking or other activities that can produce fatigue) 2 hours before testing sessions. Assessments of forced vital capacity (FVC), forced expiratory volume (FEV_1), peak inspiratory flow rate (PIFR), peak inspiratory power (PIP), maximal inspiratory pressure (MIP), balance (mini-BEST), timed up and go (TUG), and 30 seconds sit to stand (30sSTS) were made at baseline (week 1) and post-intervention (week 8) by the principal investigator (FF).

5.3.3 Pulmonary function

A spirometer (SpiroUSB, Care Fusion, Wokingham, Berkshire, UK) was used to measure FVC and FEV_1 according to the American Thoracic Society guidelines (Miller et al. 2005). Whereas PIFR was measured using the POWERbreathe® K5, with Breathe-Link 2.0 software (POWERbreathe® International Ltd, Southam, UK) using a technique validated by Langer and colleagues (Langer et al. 2013). Participants performed the forced breathing manoeuvres, at least five, and no more than eight times until variability was within 5% for three consecutive manoeuvres.

5.3.4 Respiratory muscle function

A hand-held mouth pressure meter (MicroRPM, Micro Medical Ltd, Rochester, Kent, UK) was used to determine MIP. The pressure meter was fitted with a side port opening of 1 mm internal diameter, to maintain glottis opening. All participants practised the Müller manoeuvre three times before testing, and MIP measurements were repeated, at least five, and no more than eight times, until variability was within 10% for three consecutive manoeuvres.

Peak inspiratory power was measured using the POWERbreathe® K5 with Breathe-Link 2.0 software (Langer et al. 2013). Inspiratory muscle power analysis was undertaken at six different loads (40, 50, 55, 60, 70 and 80% of participants` [baseline] MIP) and data were fitted with a polynomial curve, replicating methods reported elsewhere (Romer and McConnell 2003). Participants were requested to inhale with maximal effort against the six loads, each of which was performed in random order (using randomizer.org software). Three trials were performed for each of the loading intensities, with 30 seconds rest intervals, making a total of 18 forced inspiratory manoeuvres.

Nose-clip were worn for all pulmonary and respiratory muscle tests, and verbal encouragement was provided to promote maximal efforts. In each of the two respiratory muscle function measurements, the highest score was recorded.

5.3.5 Physical performance and trunk muscle endurance

The timed up and go tests

The timed up and go test (TUG) was used to assess mobility and gait speed. Two TUG variants were also used (i.e. the dual-task cognitive timed up and go [TUG_C] and motor timed up and go [TUG_M]) to measure the effect of dual-task on walking proficiency (Commandeur et al. 2018).

In all TUG assessments, participants were asked to sit on the edge of an armless chair (seat height 46 cm). On the command "3, 2, 1 and go" they were instructed to stand up, walk at their self-selected pace to a line on the floor 3 m away, turn around, walk back and sit down (Podsiadlo and Richardson 1991).

During the TUG_C, participants were instructed to perform the same task, whilst counting aloud backwards in threes, from a randomly selected number between 80 and 100. During the TUG_M, participants completed the same tasks, as in the TUG, whilst holding a drinking glass (diameter 8 cm, height 9.5 cm) filled with water (1 cm away from the edge of glass). Before testing, a familiarisation trial of the TUG task was performed. The three tasks were undertaken in random order, with no physical assistance provided. Analysis to look at the added 'cost' of dual tasks is reported as the difference [Δ] between the dual-task and single task conditions.

Sit to stand tests

The 30 seconds sit to stand test (30sSTS) involved measuring the number of times participants were able to stand from a seated position, and then become seated again in 30 second period (Jones et al. 1999). Briefly, participants were asked to sit on the edge of an armless chair (sitting height 46 cm, seat length 45 cm) with their arms folded across their chest. They were instructed to rise, and then become seated as fast as possible, and as many times as possible in 30 seconds, with both feet maintaining contact with the floor at all times. Timing commenced on the command “3, 2, 1 and go”.

The pre-activation 30 seconds sit-to-stand ($30sSTS_{PA}$) was used to determine the effect of acute, pre-inspiratory muscle activation (Volianitis et al. 2001) on the 30sSTS task. Briefly, adequate rest intervals between 30sSTS and $30sSTS_{PA}$ were provided (2 to 5 minutes), participants then performed 30 repetitions of forceful inhalations against a load equivalent to 50% of their [baseline] MIP, followed by forceful inhalation at 80% of [baseline] MIP until repetition failure. Verbal encouragement was provided during the 80% loading phase. When participants were unable to inhale forcefully for three consecutive attempts, they were instructed to stop the forced inspiration and to perform the $30sSTS_{PA}$. During both 30sSTS and $30sSTS_{PA}$ tests, participants were blindfolded to minimise a potential effect of vision on performance (Mourey et al. 2000). To further analyse the magnitude changes between sit to stand tasks the difference [Δ] between the standard condition and pre-activation condition are reported for both groups as 30sSTS vs $30sSTS_{PA}$.

Trunk muscle endurance

Anterior and posterior trunk muscle endurance were measured only in the IMT group due to concerns about ensuring the participants' safety during this test in the residential care homes.

Anterior trunk muscle endurance was assessed using an isometric 'sit-up' task, by adopting a bent knee (~75°) sit-up. A strap secured participants' feet, their arms were folded across the chest, while their back was placed against a support (60° angle from the test bed), and knees and hips were flexed to 90°. Participants were instructed to contract their abdominal muscles and maintain the position, whilst the support was manually pulled 10 cm back by the principal investigator (McGill et al. 1999).

Posterior trunk muscle endurance was assessed using the Biering-Sørensen test, where participants were asked to maintain a prone position, facing the floor, with their torso unsupported over the edge of the test bench. A strap secured their legs and hips, and hands were placed behind their head (Biering-Sørensen 1984). Participants were instructed to hold the static positions until the limit of tolerance, without verbal encouragement. Time was recorded using a digital stopwatch.

5.3.6 Balance

Static and dynamic balance were assessed using the Mini-balance evaluation systems (mini-BEST), which included 14 different tasks, divided into anticipatory (e.g. rising on the toes for 3 seconds), reactive postural control (e.g. compensatory stepping forward), sensory orientation (e.g. standing on a foam surface with eyes closed for 30 seconds) and dynamic tasks (e.g. walking with horizontal head turns) (O'Hoski et al. 2015).

5.3.7 Interventions

The interventions are described according to the Template for Intervention Description and Replication (TIDieR) (Hoffmann et al. 2014).

Inspiratory muscle training (IMT)

Participants performed individual home-based, unsupervised IMT for 8 consecutive weeks, using a mechanical pressure threshold loading device (POWERbreathe Plus, POWERbreathe$^{®}$ International Ltd, Southam, UK). Participants followed an established training protocol known to improve inspiratory muscle function, which consisted of 30 breaths, twice-daily (once in the morning [between 7:00 and 12:00] and once in the evening [between 16:00 and 21:00]) at an adjustable resistance (equivalent to 50% of participants' [baseline] MIP). The IMT group's participants were instructed to increase the inspiratory resistance when they felt that 30 breaths were achievable with ease, or if they could reach 35 consecutive breaths (McConnell 2013).

Otago exercise program (OEP)

The OEP consisted of a warm-up (10 - 15 minutes), resistance exercises with ankle weights (~20 minutes), balance activities (~20 minutes), and then a cool-down (5 - 10 minutes). The resistance exercises were tailored to the lower-limbs, including knee extension-flexion, hip abduction and ankle plantarflexion-dorsiflexion movements. The OEP also involved exercises for the upper-body, including head and trunk rotations and posterior neck hyperextension. The balance training exercises involved knee bends, backwards-, sideways-, stair-, heel and toe walking, tandem stance, the figure of eight, single-leg standing and sit to stand tasks. The classes were delivered by the principal investigator (FF) in the residential home twice a week for 8 consecutive weeks, following guidelines of the Geriatric Medicine Department, NHS Christchurch Hospital (Fairmile Road, Christchurch, UK) (see Appendix A-2 for the specific exercise regimen).

The group classes involved a minimum of two participants and a maximum of seven participants per class. The number of repetitions and the level of resistance were tailored to participants` physical fitness and progressively increased (by 0.5 kg if they were able to increase the number of repetitions by two). The resistance of each exercise was increased through ankle weights (ranging from 0.5 - 5 kg). Exercise sessions were conducted between 10:00 am and 12:00 am. Participants were also instructed to walk for a minimum of 30 minutes at least twice a week, on the days in which the OEP was not performed. Attendance at the exercises classes was recorded by the principal investigator (FF); participants were also instructed to cease exercising if they experienced any physical or mental discomfort.

5.4 Data analysis

Sample size estimation was made using G*Power software (Faul et al. 2007) and data from our previous study involving 46 participants (73 ± 6 years) (Ferraro et al. 2019), using α error = 0.05 and 1-β = 0.95 (Tushar Vijay 2010). To test the hypothesis that community-dwelling older adults undertaking 8 weeks of unsupervised home-based IMT would improve balance outcomes, to a similar magnitude to care home-dwelling older adults undertaking 8 weeks of instructor-led group-based OEP, a total sample of 26 participants were required.

Comparisons were made using a repeated-measures ANOVA, with Bonferroni corrections to examine between-group magnitude effect (i.e. % change in IMT vs % change in OEP), pre- vs post-intervention. Within-group effects were examined using paired t-tests. Data are reported as mean, standard deviation (SD) and percentage change. The threshold for statistical significance was determined a priori as $P \leq 0.05$ and Cohen's d effect sizes were calculated to determine the effect magnitude (small $d \leq 0.2$; medium $0.2 < d \leq 0.8$; large $d > 0.8$). Additionally, medium to large effect sizes were used to classify non-significant tendency.

5.5 Results

Twenty-six participants out of 37 completed the study: adherence was 63% (12/19) for IMT and 78% (14/18) for OEP. In addition, all OEP participants reported having walked at least twice a week (3.9 ± 1.8 days) for a minimum of 30 minutes. During the 8 weeks interventions, no-participant reported adverse events (i.e. fall accident or chest pain), and reasons for withdrawal were not related to the interventions. One IMT participant was excluded from data analysis, as they performed the exercise incorrectly (i.e. they forgot to increase the training load).

Both groups were similar at baseline for gender, body composition (BMI), cognition (MMSE > 24) and lower back health (ODI < 20%). However, the IMT group was significantly younger (IMT: 74 ± 4 years; OEP: 82 ± 7 years; $P = 0.03$) and more functionally mobile ($P \leq 0.01$), than the care home-dwelling OEP group (Table 5.1, Table 5.3 and Table 5.4). After 8 weeks the ODI score increased for the IMT group (by 0.6 score points, $d = 0.1$; $P = 0.008$), but remained below the minimal disability threshold (Table 5.1). This increase appeared in Section 8 (i.e. *sex life*) for one participant only and is unlikely to be attributable to the effect of IMT.

5.5.1 Pulmonary function and inspiratory muscle function

After 8 weeks, MIP was significantly different between groups (P = 0.001; Table 5.1); the magnitude of the increase (66%; d = 1.4; P = 0.03) was significantly larger for the IMT group (P = 0.001).

Figure 5-2 presents the interrelationships of inspiratory loads applied, inspiratory peak power, and peak inspiratory flow rates. The magnitude of the increase in peak inspiratory power values were significantly different (P < 0.01) between groups after 8 weeks at 50% and 70% of MIP (P = 0.01; P = 0.04, respectively) (Table 5.2). Within-group analysis showed that the IMT group, significantly improved inspiratory power output at 50% of [baseline] MIP (1.79 W; +31%; d = 0.5; P = 0.02). Conversely, the OEP group tended to exhibit lower powers at all loads post-intervention (Table 5. 2 and Figure 5-2), though not significantly.

The maximal peak power (MAX_{PP}) for the IMT group at baseline was 8.9 ± 4.4 W, and occurred at 60% of [baseline] MIP and was 9.8 ± 40 W at 70% of [baseline] MIP post-intervention. Whilst for OEP group it was 4.1 ± 4.1 W at baseline and 3.3 ± 2.2 post-intervention and occurred at 70% of [baseline] MIP, without significant magnitude of the change between groups.

Table 5. 1. Participants' characteristics and pulmonary function at baseline (week 1) and post-intervention (week 8).

	IMT n = 11			OEP n= 14			P-values
Outcomes	Baseline	Post-intervention	% change	Baseline	Post-intervention	% change	Between groups changes
Gender (M/F)		4/7			4/10		N/A
Age (years)		74 ± 4			82 ± 7		N/A
BMI (kg m^{-2})		27 ± 4.3			25 ± 5.3		N/A
ABC (%) ^{A}	90.3 ± 9.7	92.0 ± 11.0	2 ± 18	67.1 ± 28.7	72.2 ± 27.9	8 ± 3	NS
ODI (%)	3.8 ± 6.4	4.4 ± 7.1 **	16 ± 11	7.5 ± 7.5	7.1 ± 8.8	-5 ± 17	NS
MMSE (total score 30)	28.6 ± 1.0	28.6 ± 0.9	0 ± 10	27.9 ± 1.4	28.0 ± 1.4	0 ± 0	NS
FVC (l)	2.9 ± 0.9	3.0 ± 0.9	3 ± 0	2.2 ± 0.8	2.2 ± 0.8	-2 ± 0	NS
FEV$_1$ (l s^{-1}) ^{A}	2.2 ± 0.7	2.2 ± 0.7	0 ± 0	1.6 ± 0.6	1.7 ± 0.7	6 ± 17	NS
PIFR (l s^{-1})	4.9 ± 1.0	5.5 ± 1.1	12 ± 10	3.5 ± 1.3	3.6 ± 1.4	3 ± 8	NS
MIP (cmH$_2$O)	81.0 ± 24.1	134.4 ± 47.4 *	66 ± 97	52.8 ± 31.1	61.0 ± 35.9	16 ± 15	P = 0.001

Data are mean ± standard deviation, BMI = body mass index, ABC = activities specific balance confidence scale, ODI = Oswestry low back pain disability questionnaire, MMSE = mini-mental examination test, FVC = forced vital capacity, FEV$_1$ = forced expiratory volume in 1 second, PIFR = peak inspiratory flow rate, MIP = maximal inspiratory pressure. N/A = not applicable. NS = no-significant.* Significantly different from baseline ($P \leq 0.05$), ** significantly different from baseline ($P \leq 0.01$). ^{A} = group were significantly different at baseline ($P \leq 0.01$).

Table 5. 2. Baseline (week 1) and post-intervention (week 8) values for peak inspiratory power at different percentages of load.

	IMT n= 11			OEP n = 14			P-values
Peak power	Baseline	Post-intervention	% change	Baseline	Post-intervention	% change	Between groups change
40% MIP (W)	6.2 ± 3.6	6.9 ± 3.9	10 ± 8	2.9 ± 2.5	2.3 ± 1.5	-23 ± 40	NS
50% MIP (W)	5.9 ± 4.1	7.7 ± 3.6 **	31± 12	2.4 ± 1.9	2.2 ± 1.4	-7 ± 26	P = 0.01
55% MIP (W)	7.2 ± 4.2	8.0 ±3.4	11 ± 19	3.2 ± 3.5	2.4 ± 1.8	-25 ± 48	NS
60% MIP (W)	6.2 ± 5.2	7.8 ± 3.6	26 ± 30	2.6 ± 2.7	2.2 ± 1.8	-14 ± 33	NS
70% MIP (W)	6.6 ± 4.3	8.5 ± 5.0	30 ± 16	3.5 ± 4.3	2.2 ± 1.8	-36 ± 58	P = 0.04
80% MIP (W)	6.3 ± 4.5	7.4 ± 3.6	17 ± 20	2.7 ± 3.2	1.7 ± 1.5	-35 ± 53	NS
MAX_{PP} (W)	8.9 ± 4.4	9.8 ± 4.0	9 ± 4.6	4.1 ± 4.1	3.3 ± 2.2	20 ± 46	NS

Data are reported as mean ± standard deviation, MAX_{PP} = maximal peak power, MIP = maximal inspiratory pressure. W = Watts. NS = no-significant *. Significantly different from baseline (P ≤ 0.05), ** significantly different from baseline (P ≤ 0.01). NS = no-significant.

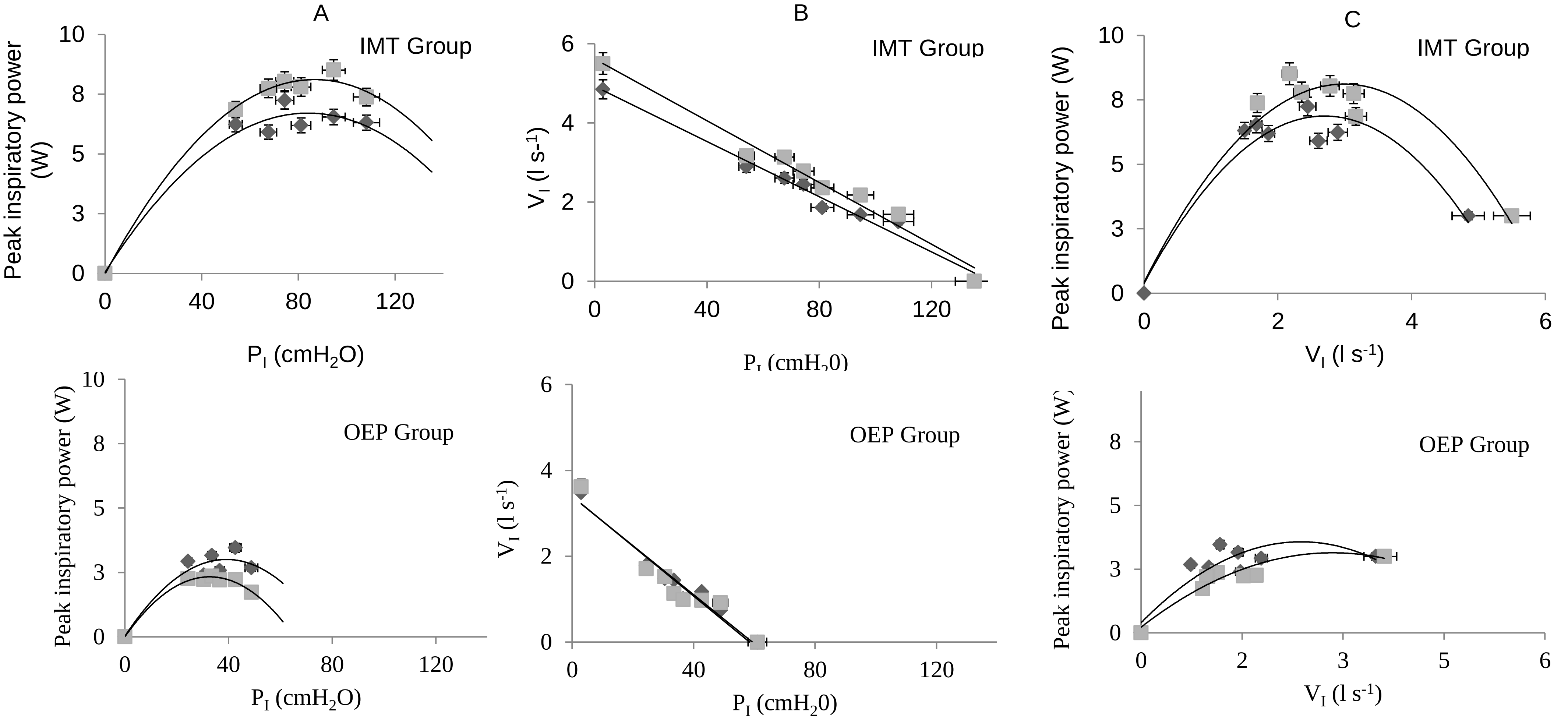

Figure 5- 2 A. Peak power vs inspiratory mouth pressure P_I (cmH_2O). B. Inspiratory mouth pressure P_I (cmH_2O) vs inspiratory flow rate V_I ($l\ s^{-1}$). C. Inspiratory peak power (Watts) vs inspiratory flow rate V_I ($l\ s^{-1}$). Before (◆) and after (■) 8 weeks of inspiratory muscle training (IMT) and Otago exercise program (OEP). Data are represented as mean ± percentage error.

5.5.2 Balance

The mini-BEST was significantly different between group at baseline ($P \leq 0.01$), but following the interventions both groups improved their mini-BEST score IMT by 24 ± 34% (+5 points) and OEP by 19.5 ± 3.5% (+5 points), with no-significant magnitude of change between groups. Further, within-group analysis showed that the OEP group exhibited a significant improvement in the mini-BEST score ($d = 1.2$; $P = 0.008$); specifically in anticipatory tasks ($d = 1.0$; $P = 0.01$) and reactive tasks ($d = 1.3$; $P = 0.02$), (Table 5.3). Whereas, the IMT group showed significant improvement in the mini-BEST score ($d = 1.5$; $P = 0.002$), specifically in reactive ($d = 1.4$; $P = 0.004$) and dynamic tasks ($d = 1.7$; $P = 0.001$). The analysis of the magnitude of change in the dynamic balance tasks appeared significant between groups ($P = 0.04$), where IMT improved by 47 ± 22% whilst OEP by 18 ± 15%.

Table 5. 3 Baseline (week 1) and post-intervention (week 8) values for the mini-BEST test and its four aspects of balance.

	IMT n = 11			OEP n = 14			P-values
Outcomes	Baseline	Post-intervention	% change	Baseline	Post-intervention	% change	Between groups change
Mini-BEST [A]	19.0 ± 4.1	24.2 ± 2.7 **	24 ± 34	14.6 ± 4.9	19.5 ± 3.5 **	34 ± 28	NS
Anticipatory	4.7 ± 1.0	5.3 ± 0.5	13 ± 50	3.6 ± 1.6	4.9 ± 0.9 **	36 ± 80	NS
Reactive	2.8 ± 1.9	5.0 ± 1.3 **	79 ± 31	1.9 ± 1.9	3.7 ± 1.1 **	95 ± 42	NS
Sensory [A]	5.2 ± 0.8	5.5 ± 0.7	6 ± 12	3.6 ± 1.7	4.4 ± 1.2	22 ± 29	NS
Dynamic	5.8 ± 1.8	8.5 ± 1.4 **	47 ± 22	5.5 ± 2.0	6.5 ± 1.7	18 ± 15	P = 0.04

Data are mean ± standard deviation, the mini-BEST test has a maximum score (MS) of 28, and it is composed of four component Anticipatory MS 6; Reactive postural control MS 6; Sensory orientation MS 6; Dynamic gait MS 10. * Significantly different from baseline ($P \leq 0.05$), ** Significantly different from baseline ($P \leq 0.01$), NS = no-significant. [A] = group were significantly different at baseline ($P \leq 0.01$).

5.5.3 Physical performance and trunk muscle endurance

The timed up and go test

At baseline IMT and OEP were significantly different ($P \leq 0.01$), where the IMT group performed significantly better than the OEP in TUG (IMT: 8.9 ± 1.1 s; OEP 16.8 ± 13.7 s), TUG_C (IMT: 14.6 ± 7.2 s; OEP: 23.4 ± 13.9 s) and TUG_M (IMT: 10.8 ± 1.6 s; OEP: 20.0 ± 17.1 s). However, after 8 weeks there were no-significant difference in the magnitude of the change between groups (Table 5.4). Further within-group analysis showed that TUG and TUG_M tests improved significantly with the IMT group (by 11%; $d = 0.7$; $P = 0.02$; by 18%; $d = 1.2$; $P = 0.008$, respectively). For both groups, TUG_C and TUG_M were significantly slower than TUG, both at baseline ($P < 0.01$) and post-intervention ($P < 0.01$). The magnitude of change for the ‘cost’ of the dual tasks was no-significant different between and within groups and did not change as a result of either intervention.

Table 5. 3. Baseline (week 1) and post-intervention (week 8) scores for TUG single and dual-task tests

	IMT n = 11			OEP n = 14			P-values
Outcomes	Baseline	Post-intervention	% change	Baseline	Post-intervention	% change	Between groups change
TUG (s) ^{A}	8.9 ± 1.1	7.9 ± 1.4 *	-11 ± 27	16.8 ± 13.7	14.1 ± 11.0	-16 ± 20	NS
TUG$_{C}$ (s) ^{A}	14.6 ± 7.2 †	10.3 ± 3.2 †	-29 ± 55	23.4 ± 13.9 †	19.9 ± 10.0 †	-15 ± 28	NS
TUG$_{M}$ (s) ^{A}	10.8 ± 1.6 †	8.9 ± 1.5 ** †	-18 ± 6	20.0 ± 17.1 †	17.8 ± 14.2 †	-11 ± 17	NS
TUG vs TUG$_{C}$ (Δ s)	5.7 ± 7.7	2.4 ± 2.5		6.6 ± 6.7	5.8 ± 3.3		NS
TUG vs TUG$_{M}$ (Δ s)	2.0 ± 1.2	1.0 ± 0.9		3.2 ± 4.5	3.7 ± 3.7		NS

Data are mean ± standard deviation TUG = timed up and go, TUG$_{C}$ = cognitive TUG, TUG$_{M}$ = motor TUG, TUG vs TUG$_{C}$ value (Δs) represent the differences between TUG and TUG$_{C}$ before and after intervention expressed in seconds, TUG vs TUG$_{M}$ value (Δ s) represent the differences between TUG and TUG$_{M}$ before and after intervention expressed in seconds. * Significantly different from baseline ($P \leq 0.05$), ** Significantly different from baseline ($P \leq 0.01$) † Significantly different from TUG ($P \leq 0.05$). NS = no-significant. N/A = not applicable. ^{A} = group were significantly different at baseline ($P \leq 0.01$).

Sit to stand tests

Both groups improve in the 30STS with a similar magnitude of change (IMT: 15 ± 16%; OEP: 16 ± 9%), with no-significant differences between groups. After 8 weeks the performance in the $30sSTS_{PA}$ was increased significantly compared to the 30sSTS only in the IMT group (by 15%; d = 0.4; P = 0.03). In addition, the magnitude changes between sit to stand tasks (i.e. 30sSTS vs $30sSTS_{PA}$) was no-significant between and with groups after interventions.

Trunk muscle tests

Anterior and posterior trunk muscle endurance improved post-IMT, but not significantly (Table 5.5; 75%, d = 0.6, P = 0.12 and by 56%, d = 0.7, P = 0.20, respectively). The OEP group did not perform trunk muscle tests (see Methods).

Table 5. 4. Baseline (week 1) and post-intervention (week 8) scores for physical performance tests.

	IMT n = 11			OEP n = 14			P-Values
Outcomes	Baseline	Post-intervention	% change	Baseline	Post-intervention	% change	Between groups change
30sSTS (nSTS)	13.2 ± 4.4	15.2 ± 5.1	15 ± 16	9.3 ± 4.6	10.8 ± 4.2	16 ± 9	NS
30sSTS$_{PA}$ (nSTS)	13.4 ± 5.1	17.5 ± 6.3 [†]	31± 23	10.0 ± 4.6	12.0 ± 5.6	20 ± 22	NS
30sSTS vs 30 sSTS$_{PA}$ (Δ nSTS)	0.2 ± 1.6	0.8 ± 1.6		0.7 ± 1.7	1.2 ± 2.3		NS
Sit-up (s)	32.2 ± 27.2	56.4 ± 48.4	75 ± 78		N/A		N/A
Biering-Sørensen test (s) (n = 9)	69.8 ± 46.1	109.3 ± 66.7	56 ± 137		N/A		N/A

Data are mean ± standard deviation, 30sSTS = 30 seconds sit to stand, 30sSTS$_{PA}$ = 30sSTS prior inspiratory muscles activation, nSTS = number of sit to stand completed. [†] Significantly different from non-pre-inspiratory muscle activation condition ($P \leq 0.05$), NS = no-significant. N/A = not applicable.

5.6 Discussion

This is the first study to compare the effects of 8 weeks of IMT to those of OEP, upon balance and physical performance outcomes. Our data confirm those of our previous study, showing that IMT improves inspiratory muscle function, balance and physical performance with healthy older adults (Ferraro et al. 2019), as well as data with COPD patients (Beaumont et al. 2018). More importantly, our hypothesis that IMT and OEP would generate similar magnitudes of improvement in function was confirmed for mini-BEST, TUG and 30sSTS performances, despite the IMT group possessing superior function at baseline. Analysis of the four sub-components of balance assessed by the mini-BEST tests showed that the IMT group specifically improved in dynamic balance (e.g. walking with head turns) to a greater extent that the OEP group.

The differences in training mode, frequency and dose (IMT: 10 minutes, twice daily for seven days *per* week *vs*. OEP: 40 minutes, once-daily for two days per week) were reflected in adherence, which was 63% (12/19 sessions) for IMT and 78% (14/18 sessions) for OEP. The 15% difference in adherence between groups concurs with the findings of Farrance and colleagues (2016), who reported a mean adherence rate of 70% for group-based exercise programs with community-dwellers. Adherence to IMT was reported via training diaries, in which participants were instructed to record the number of breaths and the level on training load for each session. Adherence was verified with the MIP test which is known to improve following IMT interventions, due to inspiratory muscles adaptation to the overloading training stimulus

(Romer and McConnell 2003). Adherence in the OEP group was recorded by the principal investigator (FF) prior to each training class. Thus, it is possible that the difference in adherence might be even greater, as self-report diary records tend to inflate adherence (Moseley et al., 2006)

5.6.1 Pulmonary function and inspiratory muscle function

After 8 weeks, the IMT group improved MIP (by 66%, d = 1.4), which is an impressive improvement compared to that observed by previous studies (Mills et al. 2015) with healthy older adults (68 ± 3 years) after 8 weeks of IMT (34 ± 43%; d = 0.8). As anticipated, the increase in MIP tended to be accompanied by an increase in peak inspiratory power, which has also been shown previously with young athletes (~ 20 years old) (Romer & McConnell, 2003). The significant increase in power post-IMT occurred at a load of 50% of [baseline] MIP, which corresponds to the training load, emphasising the influence of training specificity upon adaptations to IMT. The OEP group exhibited a slight deterioration in power output at all inspiratory loads, with the result that there were significant between-group differences in the power generated at loads corresponding to 50% and 70% of [baseline] MIP. Thus, as anticipated, IMT improved inspiratory muscle function (force and power), but OEP did not.

5.6.2 Balance

Both groups, reported significantly different balance at baseline, however after 8 weeks they exhibited similar significant improvement in the mini-BEST performance, by around 30%, with no-significant magnitude of change between groups. The balance improvements shown by the OEP group were unsurprising, given that OEP is clinically effective in improving strength and balance (Shubert et al. 2018). The improvements for the IMT group agree with our previous study, in which a younger cohort of community-dwelling older adults (≥ 65 years old), exhibited improvement in the mini-BEST performance (by 18%, d = 1.3) after an identical IMT intervention (Ferraro et al. 2019). Thus, our findings support the hypothesis that 8 weeks of unsupervised, individual home-based IMT for community-dwellers and supervised group-based OEP for older home-dwelling residents, would be similarly effective in improving balance ability. In addition, the mini-BEST sub-tasks demonstrated that the OEP group improved specifically in the anticipatory tasks (e.g. single-leg standing for 20 seconds), whereas the IMT group did not. Conversely, the IMT group improved in the dynamic task (e.g. walking at different speeds), whilst the OEP group did not.

These findings could help in isolating the possible physiological mechanism(s) by which each intervention improves balance. The OEP is known to improve the lower-limb strength of older women (≥ 80 years) (Binns and Taylor 2011), and with participants who have a high risk of falls (Campbell et al. 1997). Therefore, gains in muscle strength and static balance from targeted exercises (e.g. standing on one leg) may underpin the improvements in anticipatory task. As mentioned previously, the diaphragm has been shown to be activated in a feedforward manner (in conjunction with rectus abdominis), presumably to aid balance during rapid, destabilising movements of the upper limbs (Hodges and Gandevia 2000b). Greater inspiratory muscle strength may thus support the co-coordination of the upper- and lower-body segmental linkage, enhancing the ability to increase intra-abdominal pressure by coactivation of the diaphragm and abdominal muscles (Hodges et al. 1997).

5.6.3 Physical performance and trunk muscle endurance

The timed up and go test

The IMT group showed significant positive changes in TUG and TUG_M performance by 11% ($d = 0.8$; $P < 0.05$) and 18% ($d = 1.2$; $P < 0.01$), respectively (Table 5.4). These findings agree with the results of our previous study with a slightly younger sample of older adults (Ferraro et al. 2019), where we found that TUG performance improved by 5.3% ($d = 0.2$). The improvement in TUG following our OEP intervention (16%; $d = 0.2$), though non-significant, is double that observed following a similar intervention by Kocic and colleagues (Kocic et al. 2018), who reported an 8% improvement ($d = 1.0$) after 3 months of OEP with care home residents (≥ 65 years).

It is plausible that the absence of significant improvements in TUG performances for the OEP group were attributable to the wide participants age range (75 to 89 years) and thus, of their gait proficiency. In addition, at baseline, performance in the TUG, TUG_C and TUG_M were different between groups ($P \leq 0.01$), but not after 8 weeks of training, indicating that larger relative improvements occurred for the OEP group.

Further analysis of single (TUG) and dual-task (TUG_C and TUG_M) conditions showed that in both groups the dual-task effort induced deterioration in performance, pre- and post-intervention (Table 5.4).

Analysis of dual-task (TUG *vs*. TUG_C and TUG *vs*. TUG_M) demonstrated that the effort decreased following 8 weeks in both groups, with the exception of the TUG_M, which increased for the OEP group. The reason for this paradoxical deterioration post-intervention is unclear.

Sit to stand tests

After 8 weeks, performance in 30sSTS and $30sSTS_{PA}$ tests improved with similar magnitude of change (Table 5.5) with both IMT and OEP groups (15% and 16%, respectively) with no-significant changes between groups.

Similar to observations in healthy older adults (≥ 65 years old) (Ferraro et al. 2019), we found that combining IMT with pre-activation of the inspiratory muscles enhanced performance in the $30sSTS_{PA,}$ when compared to that of the standard 30sSTS test. After 8 weeks, participants of the IMT group were able to complete an additional two sit to stands in 30 s after pre-activation. The additive effects of IMT, plus inspiratory muscle pre-activation suggest the presence of an ergogenic “warm-up effect” upon the inspiratory muscles with older adults, similar to that reported by Lomax and McConnell (Lomax and McConnell 2009) with young participants (29 ± 6 years).

Trunk muscle tests

Anterior (sit-up test) and posterior (Biering-Sørensen test) trunk muscle endurance were not affected by 8 weeks of IMT. However, the IMT group did show a moderate, though no-significant change post-intervention for both the sit-up (by 75%, d = 0.6) and Biering-Sørensen tests (by 56%, d = 0.7). The absence of significant changes is contrary to our previous study of a slightly younger sample of healthy older adults (sit-up n = 23, 46%, d = 1.6; Biering-Sørensen n = 22, 63%, d = 3.7) after an identical IMT intervention. Accordingly, the absence of a significant change in the present study is most likely due to insufficient statistical power, underpinned by greater heterogeneity of baseline function.

5.7 Conclusion

The findings of this pragmatic parallel study support our hypothesis that 8 weeks of unsupervised, individual, home-based IMT with community-dwelling older adults, improves balance to a similar extent to supervised, group-based OEP with older care home-dwelling residents. In particular, the results showed that IMT improved dynamic balance, whereas the OEP improved static balance for our older participants. Secondary, the IMT group exhibited additional benefits to their walking speed (TUG, TUG_M) and inspiratory muscle function (MIP and PIP). Further research is required to determine the potential mechanism(s) by which inspiratory muscles contribute to dynamic balance, as well as the role that IMT could play in improving balance proficiency as both a stand-alone intervention and as an adjunct to OEP and other falls prevention interventions.

5.8 Limitations

The main limitation was the absence of random allocation, which meant that at baseline the IMT group was younger and had greater functional mobility (e.g., balance confidence and walking ability), when compared to the OEP group. These differences could have introduced an error in the absolute and relative changes observed, especially for the IMT group, where improvements might have been greater if a frailer cohort was recruited. However, to preserve validity (group-based exercises as adopted in current clinical settings practice) and feasibility (i.e. reduce travel and financial burdens) we were required to use care-home facilities for the OEP group. Also, due to difficulties in maintaining participant safety in care homes, we could not perform trunk muscle assessments (i.e. sit-up and Biering-Sørensen tests) with the OEP group. For future studies, we recommend measuring the efficiency and feasibility of IMT on balance outcomes in frailer populations (i.e. care-home residents).

5.9 Acknowledgements

The authors would like to thank all participants who volunteered their time to help with the research. We would also like to express great appreciation to the managers and the staff of Anchor Westmorland Court, Richmondwood residential home, Belvedere Court and Williams Court of Stonewater, and Sunrise in Westbourne for their help and support.

Chapter Six

THE EFFECTS OF INSPIRATORY MUSCLE TRAINING ON HEALTHY OLDER ADULTS: A POOLED ANALYSIS

6.1 Outline of Chapter Six

The chapter investigates whether inspiratory muscle training (IMT) has a greater/lesser effect across different ages and seeks to identify possible correlations between inspiratory muscle functions (e.g. MIP and PIFR), balance (i.e. mini-BEST) and physical performance measures (e.g., TUG and Biering-Sørensen), as well as between changes in these parameters. In addition, the effects of 8 weeks of IMT upon the sit to stand motion analysis and participants` personal experience (qualitative) are reported.

6.2 Introduction and methods

Table 6.1 (extract from Table 2.1 in Chapter 2), summarised the measurements common in the three studies, identifying which significantly changed after 8 weeks of IMT.

Table 6. 1 Representation of the measurements common in the three studies.

Measurements	Study 1	Study 2	Study 3
Activity Balance Scale for elderly (ABC)	✓	✓	✓
Forced Vital Capacity (FVC)	✓	✓	✓
Forced Expiratory Volume (FEV_1)	✓	✓	✓
Peak Inspiratory Flow Rate (PIFR) [A B]	✓	✓	✓
Maximal Inspiratory pressure (MIP) [A B C]	✓	✓	✓
Peak Inspiratory Power (PIP) [A B C]	✓	✓	✓
Timed Up and Go (TUG) [B C]	✓	✓	✓
Cognitive Timed Up and Go (TUG_C)	✓	✓	✓
mini-BEST [A B C]	✓	✓	✓
Sit-Up test	✓	✓	✓
Biering-Sørensen test [A B]	✓	✓	✓

[A] Measurements that showed significant changes ($P \leq 0.05$) post-IMT during study 1 (Chapter 3 [n = 26]).

[B] Measurements that showed significant changes ($P \leq 0.05$) post-IMT during study 2 (Chapter 4 [n = 23]).

[C] Measurements that showed significant changes ($P \leq 0.05$) post-IMT during study 3 (Chapter 5 [n = 11]).

6.2.1 Participants characteristics

Across the three studies within this thesis, a total of 129 participants were recruited from the local community (111) and residential homes (18) in Dorset and Hampshire (UK) between September 2016 and August 2018. Recruitment occurred via Bournemouth University public engagement events and direct contact with residential home managers.

The common criteria of exclusion to the three studies comprised: aged under 65 years, chronic lung condition (e.g. asthma, obstructive pulmonary disease), low balance confidence (Activities Balance Confidence [ABC] scale lower than 67%), having fallen in the previous 24 months, vertigo in the past 6 months, currently undertaking exercise balance training (e.g. Tai Chi and Pilates) and any experience of IMT.

Participants gave written, informed consent before taking part and met with the principal investigator (FF) on two occasions: at baseline (week 1), and post-intervention (week 8). The research protocols were approved by Bournemouth University Research Ethics Committee (Ethics Committee approval letters are in Appendix A-10 and ID in within relevant chapters: 3-3.1, 4-4.1 and 5-5.1).

6.2.2 General Design

The general designs were similar in all three studies and comprised repeated measures; 80/111 participants undertook, unsupervised, home-based IMT for 8 consecutive weeks, using a pressure threshold device (POWERbreathe$^{®}$ International Ltd. Southam, UK). Chapter 2-2.9 provides details about the training protocols. All measurements were performed at the Orthopaedic Research Institute (Bournemouth

University) under standardised conditions as fully descripted in the study chapters. For the purpose of this chapter only the measurements common in the three studies (see Table 6-1) were analyse (qualitative).

6.3 Data analysis

Data were grouped by age (65-70, 71-75, 76-80 and >80 years), normal distribution was determined with Shapiro-Wilk tests and z-score calculated from skewness and kurtosis. A paired t-test was used to analyse baseline and post-intervention changes in normally distributed data. Results are expressed as mean ± standard deviation (SD), statistical significance was determined *a priori* ($P \leq 0.05$), and effects size as Cohen's *d* is reported with the following magnitude ranges: small $d \leq 0.2$; medium $0.2 < d \leq 0.8$; large $d > 0.8$ (Victoria 1978). Pearson correlation is reported with statistical significance determined *a priori* $P \leq 0.05$. The experiences provided by participants are reported verbatim as paraphrased quotations.

6.4 Results

Sixty participants out of 80 (75%) completed IMT, with only one participant excluded from the data analysis, as they did not perform the intervention correctly (i.e. forgot to increase the pressure load). The reasons for withdrawal are reported within respective chapter. During the research studies there were no adverse events related with IMT (i.e. fall accidents, breathing difficulties or chest pain).

6.4.1 Effect of IMT on inspiratory muscle function

Two measurements were used to assess the effect of IMT on inspiratory muscle function. Firstly, MIP increased significantly

(P < 0.001) for participants aged 65 to 70 years (by 33%; *d* = 0.8) and aged 71 to 75 years (by 56%; *d* = 1.6).

With participants aged from 76 to 80 years, MIP showed a trend for change by 39% (P = 0.06, *d* = 1.1) and among participants aged > 80 years, by 49% (P = 0.08, *d* = 1.2); MIP results are reported in Table 6.3

The PIP increased significantly (P ≤ 0.05) at 40% [baseline] MIP load with participants aged 65 to 70 years (*d* = 0.3); at 50 and 60% [baseline] MIP load with participants aged 71 to 75 years (*d* = 0.7, *d* = 0.5, respectively); at 40, 50 and 60% [baseline] MIP load (*d* = 0.4, *d* = 0.5, *d* = 0.4 respectively) among those aged 76 to 80 years (see Table 6.2).

Table 6. 2 Peak inspiratory power before and after 8 weeks for all participants organised by age range.

Outcomes	65-70 years (n = 28)		71-75 years (n = 16)		76-80 years (n = 7)		>80 years (n = 8)	
	Baseline	Post-intervention	Baseline	Post-intervention	Baseline	Post-intervention	Baseline	Post-intervention
PIP 40% MIP (W)	5.8 ± 3.8	7.1 ± 4.3 *	4.6 ± 2.3	5.4 ± 3.1	4.6 ± 3.6	5.9 ± 3.7 *	4.9 ± 2.4	5.8 ± 3.7
PIP 50% MIP (W)	5.5 ± 3.7	7.0 ± 4.3	4.1 ± 2.2	6.1 ± 3.5 *	5.1 ± 3.9	7.5 ± 5.0 *	3.4 ± 2.2	5.9 ± 4.3
PIP 55% MIP (W)	6.4 ± 4.4	7.8 ± 4.4	4.9 ± 2.8	5.5 ± 2.8	5.6 ± 5.0	7.3 ± 3.9	5.1 ± 1.8	8.4 ± 4.7
PIP 60% MIP (W)	6.2 ± 4.4	7.4 ± 3.8	4.4 ± 2.5	5.9 ± 3.2 *	4.8 ± 4.6	6.8 ± 4.1 *	5.3 ± 2.8	6.9 ± 4.4
PIP 70% MIP (W)	5.6 ± 4.6	6.6 ± 4.7	5.0 ± 2.8	6.2 ± 4.1	6.2 ± 4.9	7.0 ± 5.3	5.4 ± 2.3	6.8 ± 5.7
PIP 80% MIP (W)	5.2 ± 3.9	6.0 ± 4.5	5.3 ± 2.8	5.8 ± 3.8	5.4 ± 5.3	6.9 ± 6.3	4.8 ± 3.2	5.0 ± 4.6

PIP = peak inspiratory power. W = Watt. * Indicates significant changes $P \leq 0.05$.

6.4.2 Effect of IMT on peak inspiratory flow rate

Peak inspiratory flow rate improved significantly (P < 0.001) across the age ranges by 15.2% for 65 to 70 year olds (*d* = 0.6), by 15.9% for 71 to 75 year olds (*d* = 0.5), by 17.1% for 76 to 80 year olds (*d* = 1.1); and by 10.2% for those aged > 80 years (*d* = 0.5), Table 6.3.

6.4.3 Effect of IMT on timed up and go

The timed up and go test improved significantly (P = 0.02) in participants aged between 71 to 75 years by 7.9% (*d* = 0.4). Table 6.3.

6.4.4 Effect of IMT on posterior trunk muscle endurance

The Biering-Sørensen test improved significantly (P = 0.007) by 55.6% (*d* = 0.6) for participants aged between 65 to 70 years and by 56.4% (*d* = 0.7; P = 0.002) for those aged 71 to 75 years.

Table 6. 3 Inspiratory muscle function, physical performance and posterior trunk muscle endurance at baseline and after 8 weeks, organised by age range.

Outcomes	65-70 years (n = 28)		71-75 years (n = 16)		76-80 years (n = 7)		>80 years (n = 8)	
	Baseline	Post-intervention	Baseline	Post-intervention	Baseline	Post-intervention	Baseline	Post-intervention
PIFR (l s^{-1})	4.8 ± 1.2	5.5 ± 1.1 *	4.4 ± 0.8	5.1 ± 0.7 *	4.7 ± 0.7	5.6 ± 0.8 *	5.6 ± 1.2	6.2 ± 1.3 *
MIP (cmH$_2$O)	83.3 ± 27.7	111.0 ± 35.1 *	71.9 ± 23.5	111.9 ± 26.2 *	80.3 ± 25.3	111.3 ± 28.5	94.3 ± 19.8	140.7 ± 51.0
TUG (s)	6.1 ± 1.8	6.0 ± 1.9	7.7 ± 1.3	7.1 ± 1.5 *	8.0 ± 2.8	7.4 ± 1.9	8.0 ± 1.9	7.1 ± 1.4
Biering-Sørensen (s)	53.8 ± 38.7	83.6 ± 58.2 *	52.6 ± 31.9	82.2 ± 52.1 *	64.5 ± 63.1	69.1 ± 32.7	70.6 ± 66.7	114.3 ± 114.0

PIFR = peak inspiratory flow, MIP = maximal inspiratory pressure, TUG = timed up and go. * Indicates significant changes $P \leq 0.05$.

6.4.5 Effect of IMT on balance

The mini-BEST test performance improved significantly across all age ranges, with participants aged 65 to 70 years improving by 14.1% ($P < 0.001$, *d* = 1.5), 71 to 75 years by 21.6% (P = 0.001, *d* =1.1), 76 to 80 years by 22.5% (P = 0.004, *d* = 2.4) and among participants over 80 years by 23.3% (P = 0.02, *d* =1.4).

Additional analysis of the domains of balance within the mini-BEST test showed significant improvements in dynamic and reactive tasks (by 33%, P = 0.005, *d* = 0.7; by 10%, P = 0.04, *d* = 0.6, respectively) with participants aged 65 to 70 years; in reactive task (by 60%, P = 0.02, *d* = 0.9) in those aged 71 to 75 years and among participants aged > 80 (by 52%, P = 0.001, *d* = 1.3), Table 6.4.

Table 6. 4 Mini-BEST test and its four balance domain before and after 8 weeks, organised by age range.

Outcomes	65-70 years (n = 28)		71-75 years (n = 16)		76-80 years (n = 7)		>80 years (n = 8)	
	Baseline	Post-intervention	Baseline	Post-intervention	Baseline	Post-intervention	Baseline	Post-intervention
Mini-BEST (N/28)	21.5 ± 3.2	24.5 ± 2.1 *	19.6 ± 5.0	23.8 ± 2.2 *	20.3 ± 2.1	24.9 ± 1.7 *	18.4 ± 3.4	22.7 ± 2.7 *
Anticipatory (N/6)	5.2 ± 0.9	5.4 ± 0.7	5.1 ± 1.6	5.2 ± 0.8	5.3 ± 0.5	5.0 ± 1.0	4.0 ± 1.0	4.7 ± 0.5
Reactive (N/6)	3.3 ± 1.5	4.4 ± 1.5 *	2.9 ± 2.2	4.6 ± 1.3 *	3.1 ± 1.8	3.9 ± 1.3	3.3 ± 1.6	5.0 ± 1.0 *
Sensory (N/6)	5.1 ± 0.9	5.2 ± 0.7	5.2 ± 0.9	5.3 ± 0.5	5.3 ± 1.1	5.3 ± 0.8	5.1 ± 0.7	5.1 ± 0.7
Dynamic (N/10)	7.5 ± 2.0	8.3 ± 1.4 *	6.9 ± 1.9	7.8 ± 1.3	7.1 ± 1.1	8.4 ± 1.9	6.7 ± 2.4	8.1 ± 1.8

* Indicates significant changes P ≤ 0.05. N/28 refers to mini-BEST maximum score. N/6 and N/10 refer to the balance domain maximal scores.

6.4.6 Sit to stand motion analysis

In the absence of information about validity, sensitivity or any published study with BPMpro accelerometers (BPMpro V1; Chilbolton, UK) the following results must be viewed with caution.

Motion analysis of the Sit To Stand (STS) tasks showed that following 8 weeks of IMT participants improved their speed significantly, decreasing the duration of the “sit” phase by 13% ($P = 0.005$, $d = 0.3$). During STS in pre-inspiratory muscles activation condition (i.e. STS_{PA}) participants showed speed improvements in “sit to stand” phase by 20% ($P = 0.001$, $d = 0.3$), Table 6.5.

Table 6. 5 Sit to stand and sit to stand pre-activation motion analysis data at baseline and post-inspiratory muscle training intervention.

STS				
	Baseline	Post-intervention	Δ (%)	P-values
Sit (s)	0.6 ± 0.4	0.5 ± 0.3 *	-13 ± 25	P = 0.005
Sit to stand (s)	0.5 ± 0.3	0.5 ± 0.2	-6 ± 33	P = 0.1
Stand (s)	0.6 ± 0.4	0.6 ± 1.1	7 ± 172	P = 0.6
Stand to sit (s)	0.7 ± 0.3	0.6 ± 0.3	-4 ± 0	P = 0.2

STS_{PA}				
	Baseline	Post-intervention	Δ (%)	P-values
Sit (s)	0.6 ± 0.5	0.6 ± 0.4	-10 ± 20	P = 0.2
Sit to Stand (s)	0.6 ± 0.3	0.5 ± 0.3 *	-20 ± 0	P = 0.001
Stand (s)	0.7 ± 0.4	0.6 ± 0.3	-10 ± 25	P = 0.3
Stand to sit (s)	0.6 ± 0.4	0.6 ± 0.3	-17 ± 25	P = 0.09

Total participant analysed n = 46. STS = sit to stand; STS_{PA} = STS pre-inspiratory muscles activation. Δ (%) = percentage of variation. * significant difference from baseline.

6.4.7 Interrelationships

Correlation analysis between changes in inspiratory muscle functions, and changes in the other functional outcomes (i.e. MIP *vs* mini-BEST, MIP *vs* TUG, MIP *vs* Biering-Sørensen test, PIFR *vs* mini-BEST, PIFR *vs* TUG, PIFR *vs* Biering-Sørensen test) indicated that improvement in inspiratory muscles strength (MIP) are positive correlate ($p = 0.04$) with improvements in balance proficiency (mini-BEST).

In particular, dynamic tasks appeared to be positively correlated with improvements in MIP ($p = 0.02$), whereas reactive tasks appeared negative correlated with improvements in MIP ($p = - 0.05$). Figure 6-1 represents the bivariate plot of the significant correlation from Table 6.6.

Additional correlation analysis of absolute values at baseline (reported in Table 6.7) showed that only reactive task was correlated with MIP ($p = - 0.04$).

Improvements in PIFR were significantly correlated with increments in Biering-Sørensen test ($p = 0.04$). Whereas, improvements in MIP and PIFR and improvements in TUG showed a significant negative correlation ($p = - 0.01$ and $p = - 0.007$, respectively).

Table 6. 6 Correlations between changes in inspiratory muscle functions and changes in the other variables.

Assessments	MIP		PIFR	
Mini-BEST	$p = 0.04$ *****	$R^2 = 0.003$	$p = 0.2$	$R^2 = 0.0025$
Reactive tasks	$p = -0.05$ *	$R^2 = 0.008$	$p = 0.2$	$R^2 = 0.004$
Dynamic tasks	$p = 0.02$ *	$R^2 = 0.0005$	$p = 0.3$	$R^2 = 0.1$
Timed up and go	$p = -0.01$*****	$R^2 = 0.0002$	$p = -0.007$ *	$R^2 = 0.009$
Biering-Sørensen test	$p = 0.1$	$R^2 = 0.013$	$p = 0.04$	$R^2 = 0.004$

MIP = maximal inspiratory pressure, PIFR = peak inspiratory flow rate**. *** Indicates a significant Pearson correlation ($p = 0.05$) between variables.

Table 6. 7 Correlations between baseline absolute values in inspiratory muscle functions and baseline absolute values in the other variables.

Assessments	MIP		PIFR	
Mini-BEST	$p = -0.1$	$R^2 = 0.04$	$p = 0.3$	$R^2 = 0.1$
Reactive tasks	$p = -0.04$*	$R^2 = 0.001$	$p = 0.2$	$R^2 = 0.06$
Dynamic tasks	$p = 0.1$	$R^2 = 0.02$	$p = 0.1$	$R^2 = 0.01$
Timed up and go	$p = -0.2$	$R^2 = 0.03$	$p = -0.1$	$R^2 = 0.02$
Biering-Sørensen test	$p = 0.2$	$R^2 = 0.03$	$p = 0.1$	$R^2 = 0.01$

MIP = maximal inspiratory pressure, PIFR = peak inspiratory flow rate**. *** Indicates a significant Pearson correlation ($p = 0.05$) between variables.

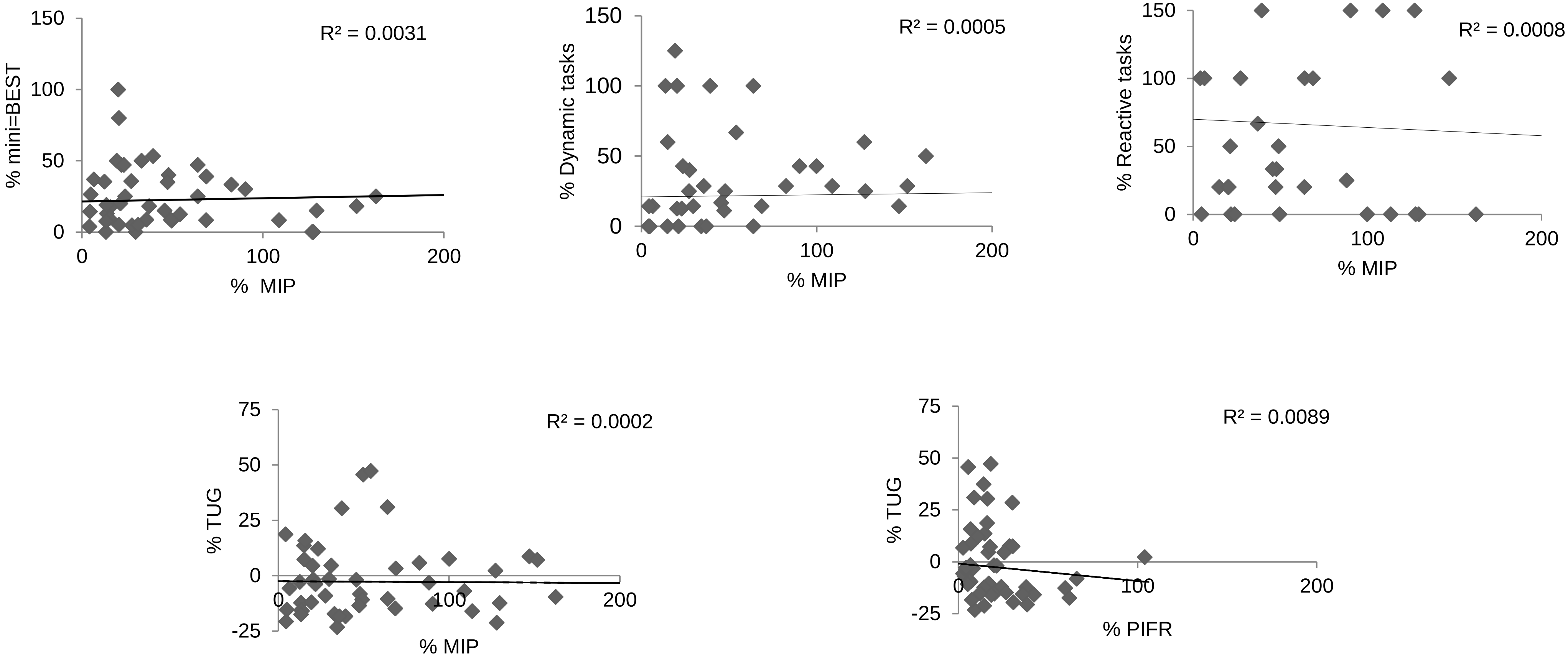

Figure 6- 1. The figures represent the significant correlations from Table 6.6. MIP = maximal inspiratory pressure; PIFR = peak inspiratory flow rate; TUG = timed up and go.

6.4.8 Overall participants experience

Although the purpose of the thesis was to assess the effect of IMT on balance outcomes from a quantitative perspective, this section can add useful information about the transferability of the intervention into people's daily lives.

Positive feedback

Participants reported the overall IMT experience as extremely positive, in relation to their daily errands. After 8 weeks four participants wrote:

"After the 8 weeks, it felt easier for me to get up to the hills in Lyme Regis" (D.G.).

"I felt better when playing with my nephews and going up to the stairs" (L.D.).

"At the beginning it was difficult, but I find it easy to do (*"it = IMT" NA*) *after the first two weeks"* (P.N.).

"I found the overall training extremely satisfying, especially as I had more energy to play the flute" (D.M.).

Negative feedback

Participants reported difficulties with the nose clips ("*too tight"*) and with the excessive production of saliva during the training, to the point that they needed to stop to dry the POWERbreathe. In addition, participants reported difficulties between the 7th and 10th level on the POWERbreathe corresponding to 70% and 100% of their baseline MIP (Table 2. 3 in Chapter 2-3.9).

“*I was struggling a little at level 8, and I needed to stop (before 30 breaths NA), but at the end I still completed it”* (P.N.).

In summary

Participants found the following characteristics most beneficial: the small amount of time needed to practice IMT (~10 minutes per session), the ease of following the training diary, and increasing the training load (following the numbers on the POWERbreathe). However, it is recommended to modify the POWERbreathe nose-clip, as the one provided was not appropriate for older adults, as it appeared to be too tight (since originally design for sports practice). Consequently, during the experimentations, few (~10) nose-clip were broken and needed to be replaced.

6.5 Discussion

6.5.1 Main findings

Balance proficiency improved among different ages range (65 to over 80 years) after IMT in particular in reactive (with participants 65 – 75 and over 80 years) and dynamic (with participants 65 – 70 years) tasks. Additionally, PIFR improved significantly for all age ranges (65 – over 80 years) and MIP for participants aged 65 – 75 years.

Correlation analysis showed a positive relationship between changes in inspiratory muscle strength (MIP) and changes in overall balance (mini-BEST), as well as between changes in MIP and changes in dynamic balance tasks. These results are in accordance with Hodges and

Gandevia’s theory that inspiratory muscles help in maintaing balance when destabilising forces challenge postural stability (e.g. walking with head turns). Consequently, the data suggest that improvements in inspiratory muscle strength can potentially, in turn, support the co-coordination of upper-body and lower-body segmental linkage, similar to that seen for other trunk muscle exercise programmes (Granacher et al. 2013).

However, the significant negative correlation between MIP and physical performance tasks, MIP and TUG, PIFR and TUG indicate that mechanism(s), not directly related to inspiratory muscle strength, may influence balance outcomes, such as the participant’s ability to produce intraabdominal pressure (Hodges and Gandevia 2000c).

It is possible to conclude that IMT may contribute to improving balance and respiratory muscle function after 8 weeks, but the underlying mechanism(s) remain unclear and require further investigation.

Additional quantitative data showed that, due to the convenience of IMT, the overall experience was perceived as positive by the participants.

Effects of IMT on balance

The effect of IMT on balance ability were discussed in the previously chapters, however the separate analysis of the different age ranges suggests greater balance improvements were present in people over 80 years old (by 23.3%, $d = 1.4$). Such an improvement in this very old cohort, reinforces the efficacy (Godi et al. 2013) and safety (Bissett et al. 2012) of IMT and justifying further progression with high risk of falling participants (e.g. care residents).

Effects of IMT on physical performance

The TUG improved significantly only with participants aged from 71 and 75 years (by 7.9%, $d = 0.4$). Gait tasks can potentially be improved by IMT interventions, as shown in COPD patients after 8 weeks of IMT combined with upper and lower limb endurance and strength training (Ahmed Saad et al. 2016). However, the TUG might not be the ideal test to detect changes in healthy, moderately active older adults, as shown in the significant negative correlation between TUG, MIP and PIFR.

Since it has been established that IMT can reduce the rate of fatigue (McConnell and Lomax 2006) and improve lower limb oxygen supply (Bailey et al. 2010), we recommended using gait assessments that require longer distances that 3 meters (e.g. 4 x 10 meters walk test).

After 8 weeks of IMT participants exhibited improvements in speed during “sit” phase of the STS tasks, and in “sit to stand” phase of the STS_{PA}. However, these results must be interpreted with caution due to lack of information on validity and sensitivity of the instruments (as shown by the highly standard deviation). It is recommended to further investigate the potential connection between IMT and STS tasks, with validated equipment (e.g. SenseWear Pro).

Effects of IMT on trunk muscle functions

Posterior trunk muscle endurance (Biering-Sørensen tests) improved for participants age between 65 and 70 years, and 71 and 75 years to similar magnitude (55.6%, $d = 0.6$ and 56.4% $d = 0.7$, respectively). In addition, there was a trend toward significance in the correlation between changes in Biering-Sørensen test and PIFR ($p = 0.04$). These results support the hypothesis that IMT can improve trunk muscle endurance, as previously shown with healthy adults (n = 10, 26 ± 9 years old) performing a load carriage task (i.e. running with 25 kg backpack), which improved by 8% after 6 weeks of IMT (Faghy and Brown 2016).

Effects of IMT on pulmonary and respiratory muscle function

Peak inspiratory flow rate improved for participants across all age ranges. Maximal inspiratory pressure improved significantly for the 65-70 and 71-75 age ranges, with a trend toward significance for the older two cohorts. These findings indicate that IMT increases inspiratory shortening velocity and strength, as a consequence of muscle adaptation to the training, as shown previously with older adults (n = 17 , 68 ± 3 years) after 8 weeks of IMT (Mills et al. 2015) and with COPD patients (Geddes et al. 2008).

In addition, peak inspiratory power increased at loads of 40, 50, 55 and 60% of MIP across different ages, these percentages span the range of training intensity used during IMT (Chapter 2-3.9) and support the specificity of IMT, previously described with younger adults (Romer and McConnell 2003).

Effects of IMT on participants experience

From the qualitative feedback received, it is possible to conclude that the overall experience was perceived as positive. However, we recommend using more comfortable nose-clip, and identify possible solution to contain the production of saliva (e.g. changing to mouthpiece)

6.6 Conclusion

Combining the results of the experimental chapters and grouping data by age ranges, it is possible to conclude that 8 weeks of unsupervised, home-based IMT, is a safe and effective intervention to improve balance, and inspiratory muscle functions with older adults. In particular, the results suggest that the oldest cohort (over 80 years old) received the greatest benefits from the intervention.

Lack in significant results in TUG tests and significant negative correlations, between changes in inspiratory muscle function and physical performance tasks, indicate the complexity of the potential mechanism(s) linking IMT with balance improvement. Therefore, subsequent studies should investigate the physiological adaptations (e.g. changes in intrabdominal pressure during functional tasks) produced by IMT alongside pulmonary and functional balance tasks.

Chapter Seven

DISCUSSION

“Life is a process of becoming, a combination of states we have to go through. Where people fail is that they wish to elect a state and remain in it. This is a kind of death”

Anaïs Nin, D. H. Lawrence: An Unprofessional Study

7.1 Overview of chapter seven

The purpose of this chapter is to synthesise the main findings of the thesis, which have been discussed in more detail in the relevant experimental chapters. Additionally, the limitations and potential mechanism(s) by which IMT improved balance ability are explored.

7.2 Summary of main findings

The research aim was to assess whether 8 weeks of inspiratory muscle training could be used to improve the balance and physical performance with healthy older adults. This was achieved through the completion of three sequential studies, with each study's findings helping to inform the design of the subsequent study.

Study 1 aimed to identify whether 8 weeks of unsupervised, home-based IMT could affect the balance and physical performance outcomes of healthy older adults. The study's results supported the hypothesis that it is feasible to undertake IMT at home, without supervision, and that IMT has the potential to improve the dynamic balance ability and inspiratory muscle function with community-dwelling older adults.

In summary, study 1 found significant changes in peak inspiratory flow rate, maximal inspiratory pressure, peak inspiratory power, dynamic and reactive balance and posterior trunk muscles endurance. This pilot study provided the first proof-of-concept that 8 weeks of IMT may elicit positive effects upon balance outcomes for healthy older adults.

These results were discussed during the transfer *viva voce* examination. Examiners feedback helped to identify possible confounding factors (e.g. diabetes and beta-blocker medication) and brought attention to the necessity to add further exclusion criteria (e.g. cognitive impairment) for the subsequent studies.

Study 2 aimed to examine the effect of 8 weeks of unsupervised, home-based IMT on the balance and physical performance of healthy older adults, using a randomised double-blinded design. The results confirmed that IMT improves reactive and dynamic balance, peak inspiratory flow rate, maximal inspiratory pressure, peak inspiratory power, gait speed and trunk muscle endurance.

The results of this more robust study design (i.e. double-blind randomised control trial), helped to remove potential task learning or placebo effects, as reported by improvements in inspiratory muscle funcion (MIP and PIFR) in the sham-IMT group.

Study 2 reinforced study 1's results, and supported the proof-of-concept that 8 weeks, home-based IMT is a feasible and safe intervention for community-dwelling adults to improve dynamic balance proficiency, and inspiratory muscle function.

Study 3 sought to examine whether balance improvements conferred by 8 weeks of IMT, were similar in magnitude to the improvements conferred by an established intervention for falls prevention (i.e. Otago exercise program [OEP]).

Using a pragmatic parallel study design (non-randomised to either: 8 weeks IMT vs. OEP), study 3 compared the effects of unsupervised, home-based IMT with community-dwelling adults, to the effects of instructor-led, group-based OEP with residential home dwellers. The hypothesis was that, despite the differing characteristics of the two groups, 8 weeks of home-based IMT would improve balance proficiency to the same extent as OEP in a combined cohort of over 75 years old.

Study 3’s findings supported this hypothesis, as IMT improved balance score (measured with the mini-BEST), with an effect magnitude that did not differ significantly to that elicited by OEP. The results were discussed in study 3, along with the additional sub-analyses of the individual balance tasks comprising the mini-BEST, which showed that IMT improved dynamic balance tasks, whereas OEP improved static balance tasks. The results also demonstrated that the IMT group additionally benefitted in: inspiratory muscles shortening velocity, inspiratory muscle strength and physical performance, when compared to the OEP group.

Hence, study 3 revealed the potential to use IMT as a stand-alone intervention, or in combination with the OEP to improve balance proficiency with frailer populations (e.g. care-home residents)

Finally, the findings of studies 1, 2 and 3 were synthesised in Chapter 6 to investigates whether IMT has a greater/lesser effect across different ages. The combined findings showed that balance, inspiratory muscle functions, physical performance and trunk muscle endurance benefit from IMT in an age-specific manner (age ranges: 65 years to over 80 years old), highlighting the feasibility of the IMT intervention and it’s safety, when undertaken daily by older adults.

7.3 Clinical implications

Based on the hypothesis of Hodges and Gandevia (2000) that inspiratory muscles help in balance proficiency (described in Chapter 1.3.5), we demonstrated that an intervention tailored to improve inspiratory muscle function (i.e. IMT) produces improvement in dynamic balance.

The research novelty is to report that IMT produces improvements in tests used to treat and assess patients who have a high risk of falls (e.g. mini-BEST and TUG). Hence it is possible to link what learned with healthy population (i.e. older adults) to frailer cohort (e.g. care home residents).

According to the NICE recommendations (2013) it is important to consider multifactorial falls risk assessment, including falls history, assessment of gait, balance, mobility and muscle weakness.

In light of our findings is rational to consider including also assessments of inspiratory muscle function (i.e. MIP), that indicate possible inspiratory muscle weakness (as mentioned in Chapter 1.5) which appeared to be correlated with balance assessment (i.e. mini-BEST).

NICE recommendations also focused on multifactorial interventions for falls prevention. Particularly strength and balance training are recommended for older people living in the community with a history of recurrent falls to which the exercise programs should be individually prescribed.

As described in study 3, IMT can be prescribed for people with a high risk of falls as unsupervised, home-based exercises therapy, with no-risk of falls accidents (IMT can be performed in a sited position) with similar improvements in balance ability compared to standard falls prevention exercises (i.e. OEP).

The additional benefits of IMT compared to standard balance and strength exercises are that it does not require additional equipment (e.g. dumbbells or other weight resistances), it is possible to modify the dose intensity with the same equipment (as described in Chapter 2.3.9), and it is safe to be administered by non-clinical staff.

Concluding, based on NICE guidelines, IMT can be safely prescribed as an intervention for falls prevention in home setting. Further studies should investigate if frailer population (e.g. care residents) shows a high compliance (as demonstrated in healthy older adults with 60 participants out of 80 that completed the intervention successfully) and with what magnitude of improvements in dynamic balance proficiency and inspiratory muscle function.

7.4 Potential mechanism(s)

The experimental chapters demonstrated that 8 weeks of IMT significantly improves dynamic balance ability. This is the first research to report the effect of IMT on balance outcomes; therefore it is possible to only hypothesis the possible mechanism(s) that lead to these results.

All muscle and tendons surrounding the spinal column can produce forces that increase spinal stability (Myers 2001), a mechanism known as the active balance subsystem (Panjabi 1992). Improvements in inspiratory muscles function (i.e. MIP, PIFR and PIP) might have reinforced the active balance subsystem eliciting to dynamic balance improvements.

Also the intraabdominal pressure (IAP) has been established as a mechanism that improves spinal stiffness (Hodges et al. 2005) as mentioned in the introduction. Recent analysis with magnetic resonance imaging showed that IAP increases with contraction of the diaphragm, during isometric lower limbs flexion (Kolar et al. 2012).

It is then rational to conceive that 8 weeks of IMT produces improvements in dynamic balance as a consequence to improvements in the production of IAP.

7.5 Limitations and recommendations for future research

The main limitations have been addressed within the relevant experimental chapters for each specific study. However, this section will focus on limitations not yet mentioned and described recommendations for future research.

This doctoral project has been the first research to investigate the effects of IMT on the balance ability of healthy older adults, and has demonstrated the feasibility and efficacy of the intervention for this older cohort. In addition, the beneficial effect of IMT on balance (e.g. mini-BEST), functional performance (e.g. motor dual task time up and go), trunk muscle strength (e.g. isometric trunk muscles tests) were unknown prior to this series of research studies.

The main general limitation (briefly introduced in Chapter 5) was that, although it was necessary to establish the safety and feasibility of IMT for healthy older adults, the improvements may have been greater for a frailer cohort (e.g. care residents). However, the research now provides a solid proof-of-concept from which to inform the design of future clinical trials with frail older cohorts.

Additional limitations appear in the assessments not targeted for the specific population of this study (i.e. isotonic, isometric and endurance tests). Weather the respiratory, physical performance and balance assessments have been widely used in research with older adults, tests such as the Biering-Sørensen and sit-up have not. Therefore they have to be interpreted with caution due to practical difficulties (e.g. minor back pain, fatigue, low mobility) of some participants to perform them.

Prevoius reseach with chronic heart failure (Laoutaris et al. 2004) and COPD patients (Beaumont et al. 2018) have established that IMT improves quality of life and functional performance in frail populations, the interventions should now be tested as a stand-alone intervention, or in combination with existing exercises/physical activity interventions, for frail populations (i.e. care homes residents) that are unable to participate in group-based programs (e.g. the Otago exercise program) to improve balance and respiratory muscle function.

Balance was measured with the Mini-Balance Evaluation Systems Test (in all three studies) and the Postural Stability test (only in study 2). Further research should widen the range of balance assessments, for example, examining the effect of IMT on the Berg Balance Scale and the Tinetti Balance Assessment.

These tests will width the number of balance tasks (i.e. pick up an object from the floor from a standing position or turning 360 degrees) that potentially are affected by IMT, helping to determine the possible mechanism(s), that correlates 8 weeks of IMT with improvements in balance ability.

In addition, the studies reported an improvement in walking ability (measured with TUG, TUG_C and TUG_M), therefore further studies can research the effect of IMT on gait proficiency with motion capture system (e.g. Vicon), to determine where the walking improvements occurred (for example whether the participants improved their speed in the stance or swing phases).

Further studies are necessary to understand the mechanism(s) by which the inspiratory muscles may contribute to dynamic balance. Studies should focus not only on the contribution of the diaphragm (as mentioned in Chapter 1), but on the role of other inspiratory muscles such as intercostal muscles.

Analysis with needle electromyography that reveals mechanical properties of the diaphragm complementary with magnetic resonance imaging that allow to measure the diaphragm excursions, can potentially give an insight on how the inspiratory muscles respond to IMT and what mechanism(s) occur that elicit balance improvements.

Briefly, directions for future research, with clinical prospective can include looking at the effect of IMT, OEP and the combination of the two with a frailer population (i.e. high risk of falling participants). In this scenario, participants can be divided into three groups (i.e. IMT-only, OEP-only and IMT + OEP). The first group can perform IMT twice daily for 8 weeks (as reported during the experimental studies). The second group can perform Otago exercises following intervention guidelines for 8 weeks. The third group can perform 8 weeks of OEP in combination with IMT (e.g. during not OEP training days). Potentially the results can show that the combination of IMT and OEP leads to better improvements in balance, and in particular in both static and dynamic balance aspects.

Additionally, another research can look at the effect of IMT on balance assessments with COPD patients reproducing a similar protocol to the one reported in Chapter 4 (i.e. IMT vs sham-IMT). However, it is recommended to add also a control group (i.e. no training group) to better describe potential task learning effects.

Chapter Eight

CONCLUSION

“ἓν οἶδα ὅτι οὐδὲν οἶδα”

“All that I know is that I know nothing”

Socrates

8.1 Conclusion

This is the first research project to report the effects of an 8 weeka home-based, unsupervised, IMT intervention, with healthy older adults, on balance and functional performance outcomes. Good compliance (75%) across the three studies showed that unsupervised, home-based IMT is feasible, and practical to improve balance proficiency with older adults.

No adverse events (i.e. fall accidents, breathing difficulties or chest pain) occurred during any of the unsupervised interventional studies, which support the protocol's safety. Additionally, IMT appeared extremely comprehensible, with only one participant (out of 80) unable to follow the training dairy.

Particularly the devices used in this research (i.e. Powerbreathe Medic Plus) were extremely easy to tailored to participants needs with the aid of numbers (from 0 to 10) that represents the level of pressure (Chapter 2.3.9). The absence of specific complex exercises or the use of cumbersome equipment (as for resistance weights training) made it possible for participants to follow the intervention and to increase the training load by simply turning the spring at the bottom of the POWERbreathe.

The participants who performed IMT (at 50% of [baseline] MIP, twice daily for 8 weeks) showed improvement in dynamic balance with tasks that relate to daily activities (e.g. walking with head turns), rather than static tasks (e.g. standing on one leg) that lack in ecological validity to real life activities.

The research also demonstrated an additional benefit in terms of inspiratory muscle function. This benefit is uncommon in other balance interventions (such as Otago exercises program) and reduced the feeling of breathlessness during daily activities (as reported by participants in Chapter 6).

Further research is required to investigate i) the efficacy of IMT as a falls prevention intervention in frailer population ii) the physiological adaptations that linked an intervention tailored to improve inspiratory muscles strength with balance proficiency.

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Appendix (A-1) – Respiratory muscle training on respiratory and physical performance outcomes

The effects of respiratory muscle training upon respiratory and physical performance with healthy older adults (aged 65^{+}).

Source	Participants	Intervention	Change in respiratory function	Change in physical performance
(Belman and Gaesser 1988)	VMT n = 12 Control n = 13	**VMT:** isocapnic hyperpnea exercises, 30 min per day. 4 days a week. **Duration**: 8 weeks	20% increment in MSVC 17% increment in MVV 4% increment IN VC 24% increment in MSVC/FEV_1	
			Not significant improvement in FEV_1 V_{Emax} VO_{2max} VCO_{2max}	*Not significant* improvement in IET HR

(Aznar-Lain et al. 2007)	IMT n = 9 Sham-IMT n = 9	**IMT:** 8 to 10 sets, 5 to 6 repartitions per set 5 times a week at 50 to 80 % of participants’` MIP **Duration:** 8 weeks	79% improvement in MIP, 3.3% VO_{2peak}	36% improvement in Time fixed load test** *Not significant* improvement in Bruce tests; MVPA
(Watsford and Murphy 2008)	IMT n = 13 Control n = 13	**RMT:** 12 sessions per week. 10 session at 10RM and 2 session at 40RM **Duration:** 8 weeks	4% improvement in FVC 23% improvement in PEF 15% improvement in MVV 35% improvement in IMET *Not significant* improvements in FEV_1	-7% decrement in REP for breathing in IWT -12 %HR *Not significant* improvement in HR, RPE for walking, O_2 consumption, speed, time to rating of perceived exertion in

				IWT.
(Chien-Hui et al. 2011)	Non-COPD n = 24 COPD n = 12 Control n = 24	**IMST:** 4 session of 6 repetition, 7 days per week at 80% of participants` MIP **Duration:** 6 weeks	36% improvement in MIP 20% decrement in BDI	12.5% improvement in 6MWT Improvement in SF-36
(Souza et al. 2014)	IMT n = 13 Sham-IMT n = 12	**IMT:** 8 series twice daily at 40% of participants’` MIP **Duration:** 8 weeks	36% improvement in MIP 12% improvement in MEP 11% improvement in T_{con} 9% improvement in diaphragm mobility *Not significant* improvement in T_{rel}; TR	

(Mills et al. 2015)	IMT (n = 17) Sham-IMT (n = 17)	**IMT:** 30 breathes, twice at 50% of participants’` MIP **Duration:** 8 weeks	34% improvement in MIP 38% improvement in T_{rel} 35% improvement PIFR FVC, FEV1, PEFR	*Not significant* improvement in 6MWT, PAL, QoT
			Not significant improvement in FVC, FEV1, PEFR, MVV_{10}, MEP, plasma cytokine concentrations, DNA damage levels in PBMC, dynamic inspiratory muscle function, inspiratory muscle endurance	

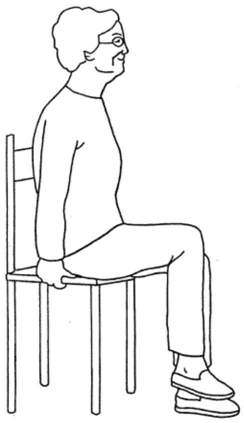
VMT = ventilatory muscle training. IET = incremental exercise test. MSVC = maximum sustained ventilatory capacity, MVV = maximum voluntary ventilation. VC = vital capacity. FEV_1 = forced expiratory volume in 1 s. V_{Emax} = maximal expired minute ventilation. VO_{2max} = maximal oxygen uptake. VO_{2peak} = peak oxygen uptake VCO_{2max} = maximal carbon dioxide production. HR = hear beat per min. IET = incremental exercise training. IMT = inspiratory muscle training. MIP = maximal inspiratory pressure. PIFR = peak inspiratory flow rate. MVPA = moderate-to-vigorous physical activity questionnaire. MEP = maximal expiratory pressure. FVC = forced vital capacity. PEFR = peak expiratory flow ratio. MVV_{10} = maximum voluntary ventilation in 10 s. PBMC = peripheral blood mononuclear cells. 6MWT = 6 minutes walking test. PAL = physical activity levels. QoL = quality of life. IMST = inspiratory muscle strength training. BDI = basic dyspnea index. SF-36 = short form heath survey. T_{con} = diaphragm thickness in maximum contraction. T_{rel} = diaphragm thickness at functional residual capacity. RMT = respiratory muscle training. TR = thickening ratio. IMET = 2 minutes inspiratory muscle endurance test. RPE = rating of perceived exertion (Borg units, 6–20 scale). IWT = incrementing walking test. PIP = peak inspiratory power ABD = abdominal curl ups Significant improvement ($P \leq 0.05$).

Appendix (A-2) – The Otago exercises program

Following the Otago exercises programme as used by the Geriatric Medicine Department at the NHS Christchurch Hospital (Fairmile Road, Christchurch, UK).

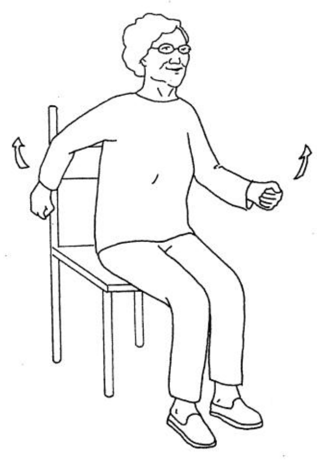
Warm-up exercises.

Always begin with a warm-up to prepare your body for the main exercises.



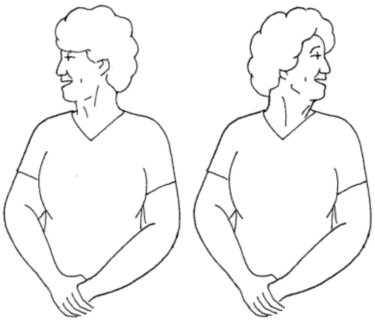
- Chair March

- Sit tall on the front third of the chair seat, away from the chair back
- Hold the sides of the chair
- Alternately lift your feet and place them down with control
- Build to a rhythm that is comfortable for you
- Continue for 30 seconds.



- Arm swings

- Sit tall away from the chair back
- Place your feet flat on the floor below you knees
- Bend your elbows and swing your arms from the shoulder
- Build to a rhythm that is comfortable for you
- Continue for 30 seconds.

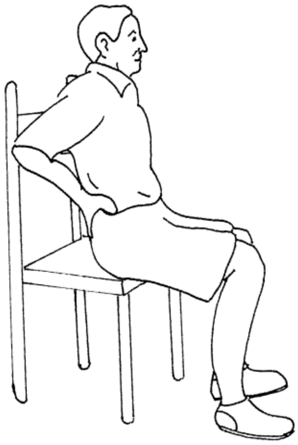


- Head movements

- Sit tall, away from the back of chair
- Turn your head slowly to the left
- Return to start position and turn to the right side
- Repeat 5 times.

- Neck movements

- Sit tall and place one hand on your chin
- Slowly guide chin straight back with your hand (not bending the neck back or forwards)
- Relax and repeat 5 times.

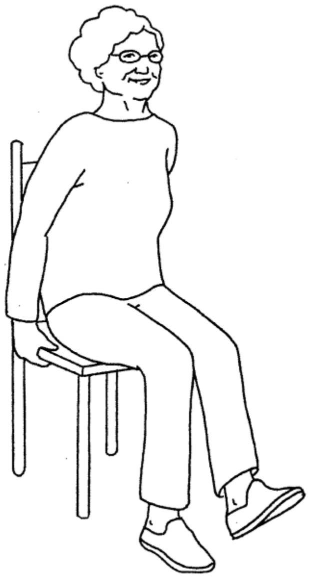


- Back extension

- Sit tall, on front third of chair, way form back of chair
- Place hands on bottom just below small of back
- Lift chest and gently arch backward
- Repeat 5 times.

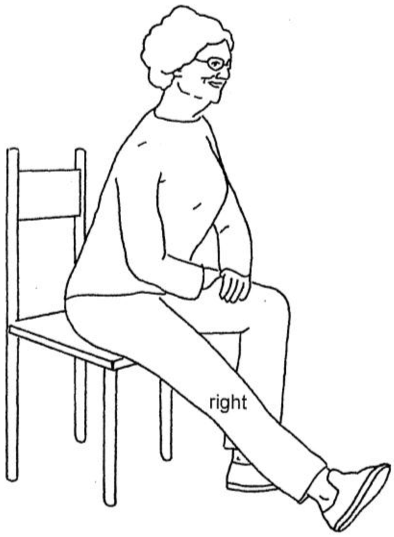
- Trunk movements

- Sit tall with your feet flat on the floor, hip-width apart
- Fold your arms across your chest
- Check your posture, with control, turn your upper body and head towards you left
- Repeat on the opposite side
- Repeat 5 times.



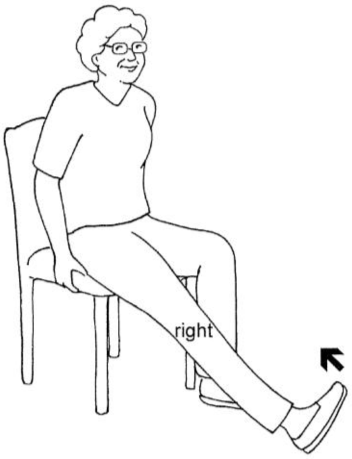
- Ankle movements

- Sit tall away from the back of the chair
- Hold the sides of the chair
- Place the hell of one foot on the floor, then lift and put the toe down in the same spot
- Repeat 5 times on each leg.



- Back of thigh stretch

- Sit tall with your bottom on the front third of the chair
- Place your left foot flat on the floor, then straighten your right leg out in front with your heel on the floor, foot relaxed
- Place both hands on the left thigh, then sit tall, lean forward and upward until you feel the stretch in the back of your right thigh
- Hold for 8 seconds
- Repeat on your other leg.

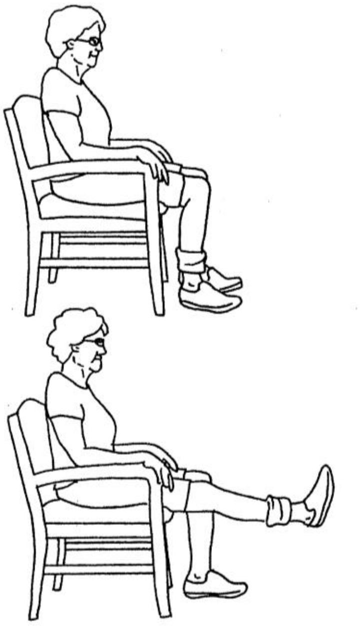


- Calf Stretch

- Sit tall with your bottom to the front third of the chair
- Hold the sides of the chair
- Place your left foot flat on the floor then straighten your right leg out in front with your heel on the floor
- Pull the toes up towards the shin until you feel the stretch in the back of your calf
- Hold for 8 seconds
- Repeat on your other leg.

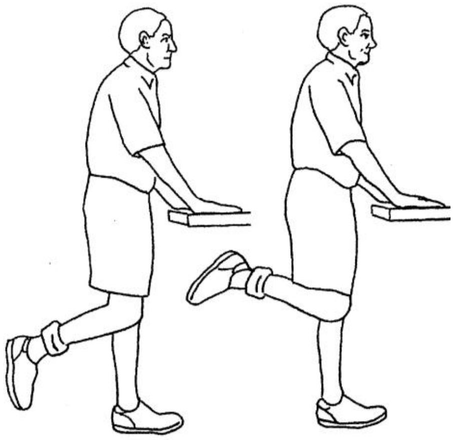
Exercise to help improve your bone and muscle strength

Build up to 10 repetitions of each exercise on each leg as you progress then build up to 2 or more sets of 10.



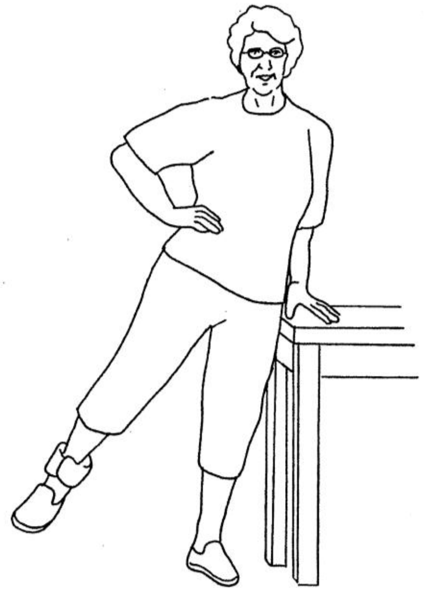
- Front knee strengthening

- You can do this without a weight
- Strap the weight around your ankle, if you were issued with a weight
- Sit tall with your back well supported
- Slowly straighten the leg out in front of you for a court of 2
- Lower the leg for a count of 4
- Rest and repeat, build up to 10 times or more as you progress
- Repeat on the other leg.



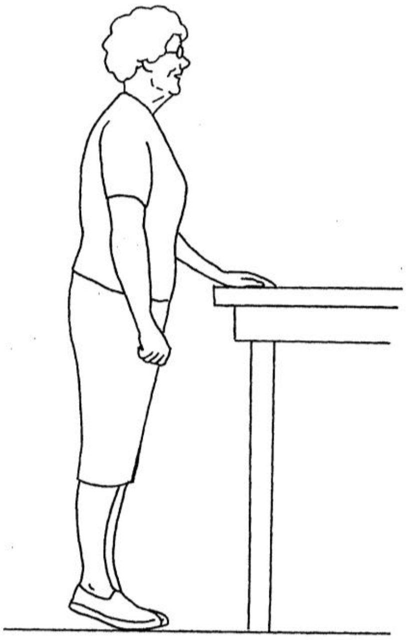
- Back knee strengthening

- Strap the ankle weight around you ankle (if you were issued with a weight) you can do this without a weight
- Stand tall with both hands on the table or kitchen worktop
- Ben the knee, slowly bringing the foot towards your bottom, keeping your knee beside the other knee
- Lower the leg with control
- Place your weight evenly over both feet to rest
- Repeat building up to 10 times or more as you progress
- Repeat on the other leg.



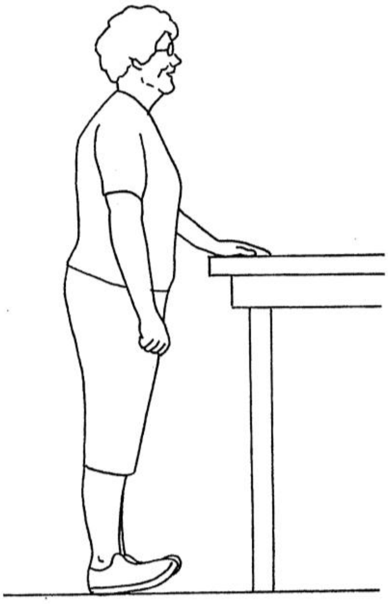
- Side hip strengthening

- Strap the ankle weight around your ankle (if you were issued with a weight) you can do this without a weight
- Stand tall beside the table, or kitchen worktop keeping one or two hands on the table for support
- Keep the exercising leg straight and the toes facing forward
- Slowly lift the leg out to the side
- Slowly lower the leg with control
- Place your body weight evenly over both feet to rest repeat 10 times on each leg take weights off.



- Calf raises

- Stand tall facing the table, keeping one or both hands on the table support
- Look straight ahead
- Place your feet hip-width apart
- Slowly lift your heels and come up onto your toes
- Slowly lower you heels to the ground with control
- Repeat this exercises 10 to 20 times.

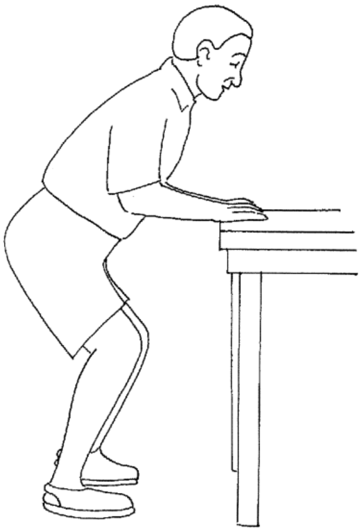


- Toe raises

- Stand tall facing the table, keeping one or two hands on the table for support
- Look straight ahead
- Place your feet hip-width apart
- Slowly lift your toes and come onto your heels (remain tall not leaning backwards, bottom tucked in)
- Slowly lower your toes to the group with control
- Repeat this exercises 10 to 20 times.

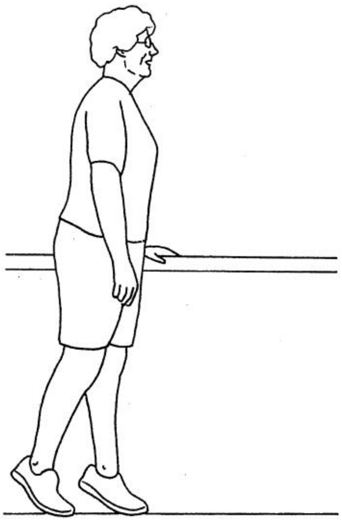
Exercises to help improve your balance

Do these holding on with both hands for support and as you progress reduce the support to holding with one hand, support with fingertips etc.



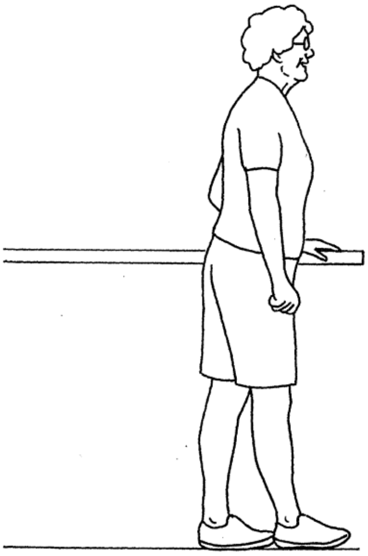
- Knee bends

- Stand tall with both hands on the table, feet hip-width apart
- Take bottom backwards and bend knees as if to sit down, make sure heels don-t lift and knees are above toes
- Slowly push through both feet to stand up again
- Repeat 5 times initially and build up to 10 times.



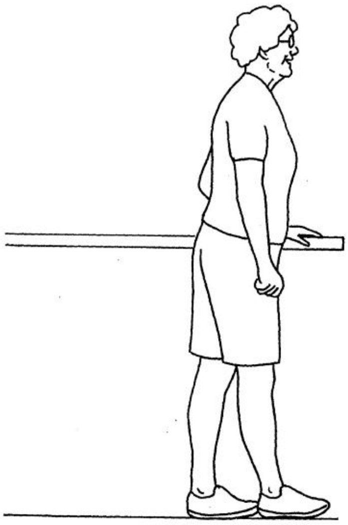
- Heel-toe standing

- Stand tall beside the table or worktop
- Look straight ahead
- Lift your heels and come up onto your toes
- Slowly walk 10 steps on your toes
- Bing the back foot beside the front foot and lower the heels to the ground
- Turn around and walk 10 steps on your toes in the opposite direction.



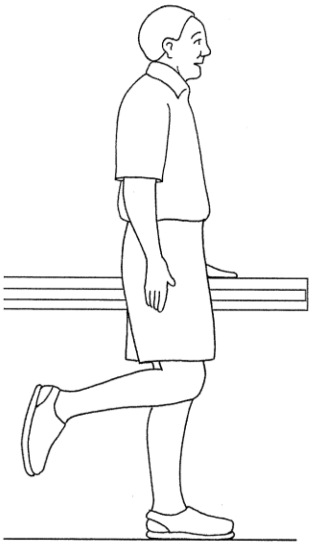
- Heel-toe standing

- Stand tall beside the table or worktop
- Look straight ahead
- Place one foot directly in front of the other foot so that the feet form a straight line
- Hold this position for 10 seconds
- Now bring the back foot directly in front of the other foot
- Hold this position for 10 seconds.



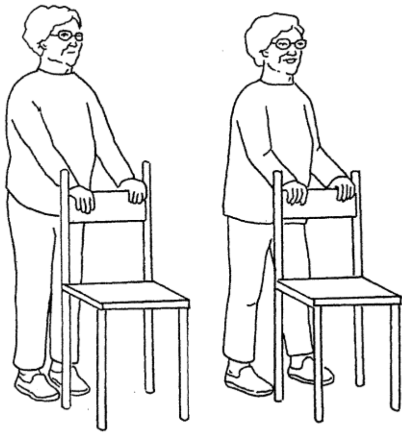
- Heel toes walking

- Stand tall beside the table or worktop
- Look straight ahead
- Place one foot directly in front of the other so that the feet form a straight line and repeat for 10 steps
- Turn around and walk 10 steps in the opposite direction.



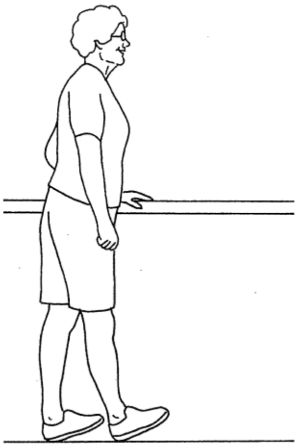
- One leg stand

- Stand tall beside the table or worktop
- Look straight ahead
- Balance on one leg, keep the knees clos3e together
- Hold this position for 10 seconds place the foot down and repeat on the other leg.



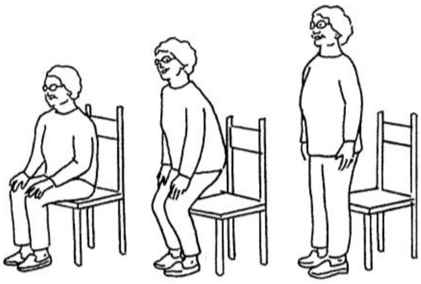
- Side walk

- Stand tall holding the chair or kitchen worktop with both hands, feet hip-width apart (when confident, try holding with only one hand)
- Take a step to the right and then to the left
- Continue for 30 seconds
- Now try to take 2 steps to the right and then two to the left continue for 30 seconds
- Alternatively stand at kitchen surface and take 5 small steps to the side and repeat in opposite direction
- Build up to 10 steps in each direction.



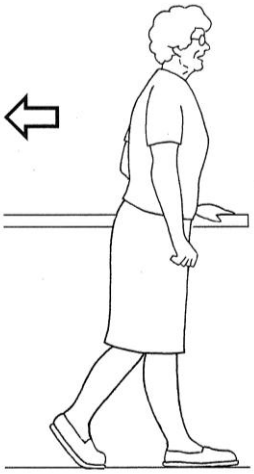
- Heel walking

- Stand tall beside the table or worktop
- Lift your toes and come onto your heels
- Look straight ahead, bottom tucked in
- Walk 10 steps forward on your heels
- Bring the back foot beside the front foot and lower the toes to the ground with control
- Turn around and walk 10 steps on your heels in the opposite direction.



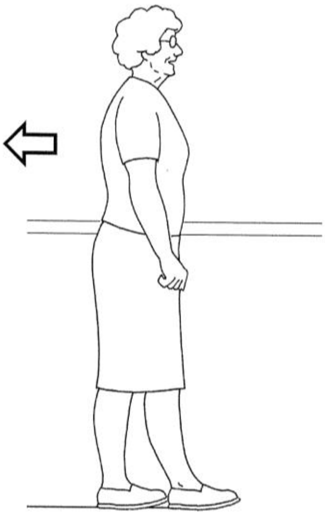
- Sit to stand

- Sit tall, move bottom to front of the chair
- Place your feet slightly behind your knees, feet hip-width apart
- Lean slightly forwards, look straight ahead
- Stand up (using your hands on the chair for support if needed. Progress to no hands over time)
- Step back until your legs touch the chair then stand tall, lean forward bend your knees and slowly lower your bottom back into the chair
- Repeat 10 times.



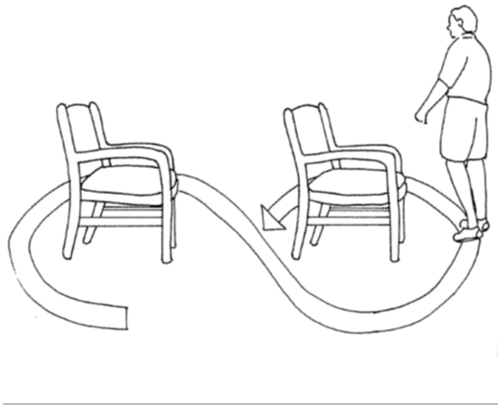
- Backwards walking

- Stand tall beside the table or worktop
- Look straight ahead
- Place feet hip-width apart
- Slowly walk backwards 10 steps
- Turn around and walk 10 steps backwards in the opposite direction.



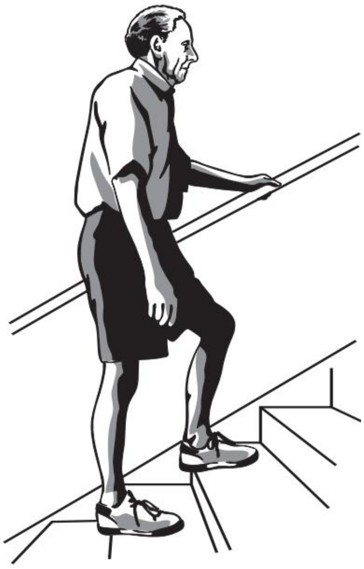
- Heel toes walking backwards

- Stand tall beside the table or worktop
- Look straight ahead
- Place one foot directly behind the other foot so that the feet form a straight line
- Place the front foot directly behind
- Repeat for 10 more steps
- Turn around and walk 10 steps in the opposite direction.



- Walking and turning around

- Stand tall between two chairs placed body width apart
- Walk at a regular pace to circle on chair in a clockwise direction and return to the starting position
- Walk in a circle around the second chair in a anti-clockwise direction and return to the starting position
- The whole movement should form a figure of 8
- Begin with one and build to 2 figures of 8.

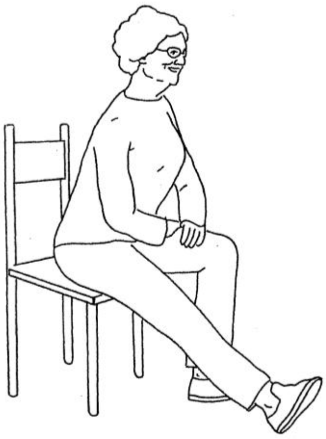


- Stair walking as part of your exercises

- Ask your exercise instructor, physiotherapist or falls prevention practitioner if you should be doing stair walking as exercise
- Hold on to the hand-rail for this exercise
- Go up and down the stair for 10 times.

Cool-down session

Cool-down exercises help you to relax and recover from exercise and maintain flexibility



- Back of thigh stretch

- Move your bottom to the front of the chair
- Place your left foot flat on the floor, then straighten your right leg out in front with your heel on the floor, foot relaxed
- Place both hands on the left thigh, then sit tall
- Lean forwards and upwards until your feel the stretch in the back of your left thigh
- Hold for 10 to 20 seconds, with a straight back
- Repeat 1 to 3 times
- Repeat to your other leg.

- Calf stretches

- Move your bottom to the front of the chair
- Hold the sides of the chair
- Place your left foot flat on the floor then straighten your right leg out in front with your heel on the floor
- Pull the toes up towards the shin until you feel the stretch in the back of your right calf
- Hold for 12 to 20 seconds
- Repeat 1 to 3 times
- Repeat on your other leg.

Appendix (A-3) – Participant Agreement Form

The effect of 8 weeks of inspiratory muscle training on balance for healthy older adults.

Principal Investigator: PGR Francesco Ferraro, department of health and social science Bournemouth University, phone: 01202 964207, fferraro@bournemouth.ac.uk

Co-Investigator: Prof Alison McConnell, department of health and social science Bournemouth University, phone: 01202 962313, amcconnell@bournemouth.ac.uk

	Please Initial or Tick Here
I have read and understood the participant information sheet for the above research project.	
I confirm that I have had the opportunity to ask questions.	
I understand that my participation is voluntary.	
I understand that I am free to withdraw up to the point where the data are processed and become anonymous, so my identity cannot be determined.	
During the assessments, I am free to withdraw without giving a reason and without there being any negative consequences.	
Should I not wish to answer any particular question(s) or complete an assessment, I am free to decline.	
I give permission for members of the research team to have access to my anonymised responses. I understand that my name will not be linked to the research materials, and I will not be identified or identifiable in the outputs that result from the research.	
I give permission for photographic images and video recording to be taken during any assessments. I understand that this material will	

become anonymous, so my identity cannot be determined and that it will be used only for research purpose.	
I agree to take part in the above research project.	

Name of Participant ____________________ Date ______________ Signature ____________________

Name of researcher ____________________ Date ______________ Signature ____________________

This form should be signed and dated by all parties after the participant receives a copy of the participant information sheet and any other written information provided to the participants. A copy of the signed and dated participant agreement form should be kept with the project's main documents which must be kept in a secure location.

Appendix (A-4) – Participant Information Sheet

Study Title: **Comparing the effects of 8 weeks of inspiratory muscle training with Otago exercise training on the balance and functional mobility of healthy older adults.**

You are being invited to take part in a research study at Bournemouth University.

Before deciding to take part or not, you need to understand why the research is being done and what it would involve for you.

Please take time to read the following information carefully.

If anything you read is not clear or you would like more information please ask questions. Ensure that you understand all requirements of the study.

What is the purpose of the study?

To understand whether training the breathing muscles (specifically the muscles we use to inhale) can affect the balance and functional mobility of healthy older adults when compared to an existing, routine exercise intervention (the Otago programme).

Why have I been invited?

We are recruiting healthy adults (aged over 70 years) to participate in this study.

Do I have to take part?

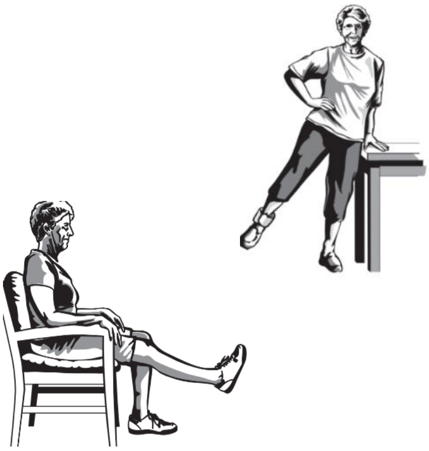
Taking part in the research is entirely voluntary. This means that it is up to you to decide whether to participate or not, and you will be free to withdraw at any time. The Principal Investigator (Francesco Ferraro) will answer any questions you might have. If you are content to participate, you will be asked to sign a consent form and provide verbal agreement to take part.

What will happen to me if I take part?

If you decide to take part you will be allocated at random to one of two different exercise groups. One group will train for eight weeks using a protocol that improves inspiratory muscle strength, and the other group will train using a protocol that improves leg muscle strength.

Inspiratory Muscles Training consists of 30 breaths through the POWERbreathe® device, twice daily (morning and evening), for eight consecutive weeks. You will do this training on your own.

POWERbreathe® allows you to train the inspiratory muscles safely by making it slightly more challenging to inhale. It is drug-free and has already been successfully tested for more than a decade (more information can be found on www.powerbreathe.com)



Otago exercise program consists of very mild physical activities, which you will carry out in a group session under the supervision of a researcher. Each training session lasts about 45 minutes, further details about timing and location will be provided to you if allocated to this group. If you are part of a group taking part from a residential facility, training will take place at that facility.

The Otago exercise program is a routine intervention that is widely used by the NHS to enhance balance. It is developed to target leg weakness and impaired balance.

What are the possible disadvantages and risks of taking part?

The potential risks are very low as all the assessments and equipment are used routinely in rehabilitation. The POWERbreathe® training is also very safe and has been used in clinical research for almost 20 years.

What are the possible benefits of taking part?

Gain insight into applied health science and physiology research.

Learn your body mass index, your balance ability, your breathing capacity and mobility performance.

What are the main assessments?

Before the 8 weeks of training, you will be asked to complete a health questionnaire to ensure there are no medical reasons to prevent you from participating in the study. Next, you will have your height, weight and body composition measured using special weighing scales, and you will be asked to perform some assessments. These will measure aspects of your fitness and your balance (see box below for details). Each task will be explained so that you can learn the outcomes and ask questions.

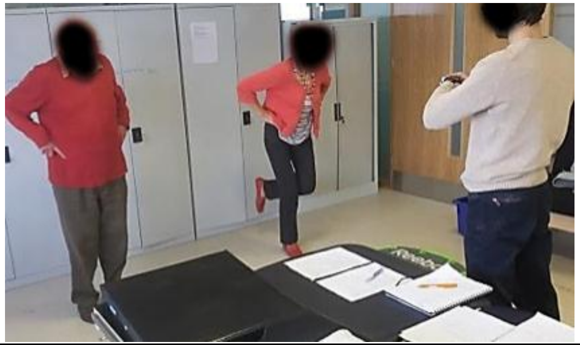
You are free to withdraw from the assessments at any point.

<u>If suitable for the research study</u> you will perform the following tasks:

Non-invasive breathing assessments to measure your lung function.
There will be four breathing assessments to measure:

<u>Test 1</u>: the function of your lungs
<u>Test 2</u>: the function of your breathing muscles
<u>Test 3</u>: the velocity of your inhalation
<u>Test 4</u>: the power of your inhalation

You will be asked to breathe in and out in several different ways, via a sterile mouthpiece, wearing a nose clip.
This will take about 30 minutes.



Simple balance tasks to assess your balance ability. A researcher will be close by at all times to ensure that you do not fall during any of the following tasks:

<u>Test 1</u>: balance on one-leg for 20 seconds
<u>Test 2</u>: balance on an inclined ramp 30 seconds.
<u>Test 3</u>: balance on your toes for 3 seconds
<u>Test 4</u>: lean forward against researcher`s hands to the forward limit of your balance
<u>Test 5</u>: step over small obstacles
<u>Test 6</u>: walk in a straight line with head turns (left or right)

This will take about 30 minutes.

 A  B	Muscle performance and mobility assessments. A trained researcher will assist you with all these tasks, and there will be plenty of time to rest between tasks. Test 1: hold a sit-up position as in picture (A) Test 2: stand up and sit down for 30 seconds Test 3: walk 3 meters (10ft) in a straight line turn walk back Test 4: repeat test 3 while holding a tray Test 5: repeat the 3 while counting backwards Test 6: hold a prone position as in picture (B) This will to take about 15 minutes.

To complete these tests, it is important that you dress in tracksuit or shorts and t-shirt with plimsoles/trainers.

What if there is a problem?

If you have any questions or doubts, you can contact the Principal Investigator (Mr Ferraro) or Co-Investigator (see below). In case of an emergency, Mr Ferraro is trained on first aid emergencies and will promptly assist you. In case you feel unhappy and want to complain you can contact the Independent Complaints Contact (see below).

How will my information be kept?

Your identity and all the information collected will be kept strictly confidential in accordance with the current Data Protection Regulations. Your annonymised data will be used in Mr Ferraro's PhD thesis, and in research publications and presentations. You have the right to ask for copies of all data, papers, transcripts and other material published or presented. The investigators will retain test data (including Pre-test Health Questionnaire information), which will be stored securely for no longer than 5 years after study completion; after that, all the information will be destroyed.

If you agree, photographic images may be taken during laboratory assessments for the sole purpose of scientific publications, presentations, and information sheets, such as this. Identifying features will be covered so that individuals cannot be identified from these images. Pictures will not be used for promotional purpose.

All data and pictures will be stored on a secured, password-protected computer hard disk within a Bournemouth University server. The files will only be accessible by the Principal Investigator.

What will happen if I do not carry on with the study?

You can withdraw at any time up to the point where data are anonymised for analysis; after that, it will not be possible to remove your data. If you withdraw from the study before the training is completed, we may use the data collected up to your withdrawal, with your permission.

Please be aware that there are no consequences for withdrawing, but you would need to return the equipment.

Who is organising or sponsoring the research?

The research is part of a PhD project. Hence it is organised and sponsored by Bournemouth University.

Investigator Contact Details

Principal Investigator
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Independent Complaints Contact

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Deputy Dean for Research and Professional Practice,

Faculty of Health & Social Sciences

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Appendix (A-5) – Health check questionnaire

Bournemouth University

The effects of 8 weeks of inspiratory muscle or Otago exercise training on the balance and functional mobility of healthy older adults.

Health and safety within this investigation are of paramount importance. For this reason, it is essential that researchers be aware of your current health status before you begin any testing procedures. We recommend that you seek medical advice before participating, and the researchers will provide a document for you to show to your doctor, which describes the requirements of participation.

Additionally, the following questions are designed to establish whether you are suited to take part in this study or not, and your doctor can also help you to complete these if you are unsure. This information is confidential and **will not** be used for research purposes.

Participant name: …………………………………… Date of birth: ___/___/______

Emergency Contact Name:……………………… Emergency Contact Tel:.............

Please answer the following questions:

1. Has your doctor said you have a heart problem or recommend only medically supervised exercise? ☐ YES ☐ NO

If yes, please specify the heart condition:

2. Have you ever experience vertigo, fainting or dizziness (in the past 6 months)? If yes, please give details of the circumstances	YES	NO
3. Are you taking medication? If yes, please give details (e.g. beta-blockers, Rytmonorm®, etc.)	YES	NO
4. Has your doctor ever said you have diabetes?	YES	NO
5. Have you experienced any fall accidents in the past two years? If yes, how many and how did it/they happen?	YES	NO
6. Are you a smoker? If yes, please give the number of cigarettes per week	YES	NO
7. Have you had any surgery on your lower limbs? If yes, please give details (e.g. hip or knee replacement, etc.)	YES	NO
8. Has your doctor ever said that you have a neurodegenerative condition? (e.g. Parkinson's disease, Alzheimer's disease)	YES	NO

9. Has your doctor ever said that you have a respiratory condition? (e.g. emphysema, asthma, etc.) YES NO

Please provide details below of your current weekly exercise routine:

Type of exercise (e.g. cycling, walking, Pilates, Tai-Chi, etc.)	**Number of sessions/week**	**Duration of sessions**

I have read and fully understand this questionnaire. I confirm that to the best of my knowledge the answers provided are correct and accurate. I am aware of no reasons why I should not participate in physical activity, and I am fit and fully able to volunteer for this research study.

Participant’s name & signature:______________________________Date:__________

Principal Investigator’s name & signature:____________________Date: _________

Appendix (A-6) – Training diary

Week number	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
Week number	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
	Level	Breaths	Level	Breaths	Level	Breaths	Level	Breaths	Level	Breaths	Level	Breaths	Level	Breaths
Morning														
Evening														

How did you feel, and did you complete all breath without stopping?

Please use the following codes to record notes on training:

A Trained as expected

B Trained less than expected

C Did not train (forgot)

D Did not training (too busy)

E Did not train (too difficult)

F Did not train (lack of motivation)

G Did not train (too unwell)

H Did not train (too tired)

I Did not train (other reason)

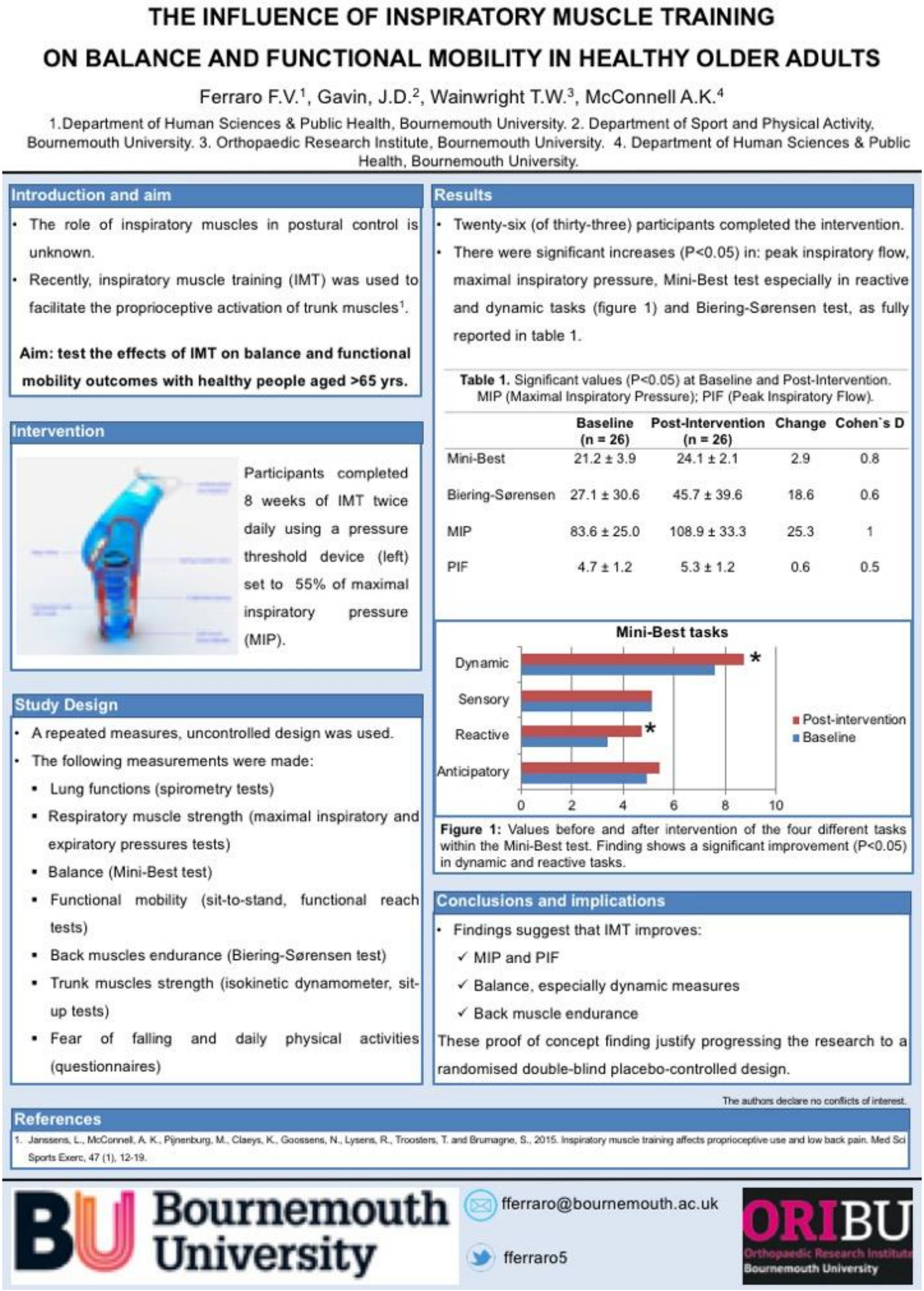
J Increase training load

K Had to stop during the 30 breaths (please indicate why)

L Train but felt uneasy to complete the 30 breaths (please indicate why)

Monday		Thursday	
Tuesday		Friday	
Wednesday		Saturday	
		Sunday	

Appendix (A-7) – Poster presented at the Young Life Scientific Symposium



THE INFLUENCE OF INSPIRATORY MUSCLE TRAINING ON BALANCE AND FUNCTIONAL MOBILITY IN HEALTHY OLDER ADULTS

Ferraro F.V.[1], Gavin, J.D.[2], Wainwright T.W.[3], McConnell A.K.[4]

1.Department of Human Sciences & Public Health, Bournemouth University. 2. Department of Sport and Physical Activity, Bournemouth University. 3. Orthopaedic Research Institute, Bournemouth University. 4. Department of Human Sciences & Public Health, Bournemouth University.

Introduction and aim

- The role of inspiratory muscles in postural control is unknown.
- Recently, inspiratory muscle training (IMT) was used to facilitate the proprioceptive activation of trunk muscles[1].

Aim: test the effects of IMT on balance and functional mobility outcomes with healthy people aged >65 yrs.

Intervention

Participants completed 8 weeks of IMT twice daily using a pressure threshold device (left) set to 55% of maximal inspiratory pressure (MIP).

Study Design

- A repeated measures, uncontrolled design was used.
- The following measurements were made:
  - Lung functions (spirometry tests)
  - Respiratory muscle strength (maximal inspiratory and expiratory pressures tests)
  - Balance (Mini-Best test)
  - Functional mobility (sit-to-stand, functional reach tests)
  - Back muscles endurance (Biering-Sørensen test)
  - Trunk muscles strength (isokinetic dynamometer, sit-up tests)
  - Fear of falling and daily physical activities (questionnaires)

Results

- Twenty-six (of thirty-three) participants completed the intervention.
- There were significant increases (P<0.05) in: peak inspiratory flow, maximal inspiratory pressure, Mini-Best test especially in reactive and dynamic tasks (figure 1) and Biering-Sørensen test, as fully reported in table 1.

Table 1. Significant values (P<0.05) at Baseline and Post-Intervention. MIP (Maximal Inspiratory Pressure); PIF (Peak Inspiratory Flow).

	Baseline (n = 26)	Post-Intervention (n = 26)	Change	Cohen`s D
Mini-Best	21.2 ± 3.9	24.1 ± 2.1	2.9	0.8
Biering-Sørensen	27.1 ± 30.6	45.7 ± 39.6	18.6	0.6
MIP	83.6 ± 25.0	108.9 ± 33.3	25.3	1
PIF	4.7 ± 1.2	5.3 ± 1.2	0.6	0.5

Figure 1: Values before and after intervention of the four different tasks within the Mini-Best test. Finding shows a significant improvement (P<0.05) in dynamic and reactive tasks.

Conclusions and implications

- Findings suggest that IMT improves:
  - ✓ MIP and PIF
  - ✓ Balance, especially dynamic measures
  - ✓ Back muscle endurance

These proof of concept finding justify progressing the research to a randomised double-blind placebo-controlled design.

The authors declare no conflicts of interest.

References

1. Janssens, L., McConnell, A. K., Pijnenburg, M., Claeys, K., Goossens, N., Lysens, R., Troosters, T. and Brumagne, S., 2015. Inspiratory muscle training affects proprioceptive use and low back pain. Med Sci Sports Exerc, 47 (1), 12-19.

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Appendix (A-8) – Poster presented at BASES student conference

The effects of 8 weeks of inspiratory muscle training on the balance of healthy older people: a randomised, double-blind, placebo controlled trial

Ferraro F.V.[1], Gavin, J.G.[2], Wainwright T.W.[1,3], McConnell A.K.[1]
[1]Department of Human Sciences & Public Health, [2]Department of Sport & Physical Activity, [3]Orthopaedic Research Institute
Faculty of Health & Social Sciences, Bournemouth University.

Introduction

- Ageing is associated with an increased risk of falls
- Senile emphysema is a common condition associated with aging that directly weakens inspiratory muscles
- Inspiratory muscles assist balance and the mechanical stabilisation of the trunk
- We tested the influence of inspiratory muscle training (IMT) on balance and functional mobility in healthy older adults

Methods

Design: repeated measures, double-blinded randomised controlled trial.

Inclusion Criteria: age >65 yr, no acute respiratory infections, Oswestry low back pain score <21%, Mini-mental state examination test >24, and no falls in the past two years.

Outcomes: lung and inspiratory muscle function (PIF, MIP), balance (Mini-BEST test), functional mobility performance (TUG_m), anterior and posterior trunk muscle endurance, and self-reported fear of falling.

Groups allocation.

Descriptive characteristics of participants.

n = 46	Mean ± SD
Gender (M/F)	18/28
Age (y)	73±5.6
BMI (kg/m^2)	26.3±3.3

Interventions:

IMT Group: 8 weeks of training, twice daily for 30 breaths at 55% of maximal inspiratory pressure using a pressure threshold device.

POWERbreathe® inspiratory muscle trainer.

Sham-IMT Group: 8 weeks of training, twice daily for 60 breaths at ~9 cmH_2O using a pressure threshold device.

Results

Maximal Inspiratory Pressure (MIP)

Anterior Trunk Muscle Endurance

Mini-BEST Test

Peak Inspiratory Flow (PIF)

Posterior Trunk Muscle Endurance

Time Up and Go Motor (TUG_m)

Conclusions

- Participants showed an improvement in balance (Mini-BEST) and functional mobility (TUG_m) after 8 weeks of IMT
- Inspiratory muscle training could be a safer alternative to falls prevention exercises due to the absence of fall risks during the treatment
- A comparative study of IMT and balance exercise programme is undergoing
- Further research on how inspiratory muscles training affect balance and postural control outcomes is warranted

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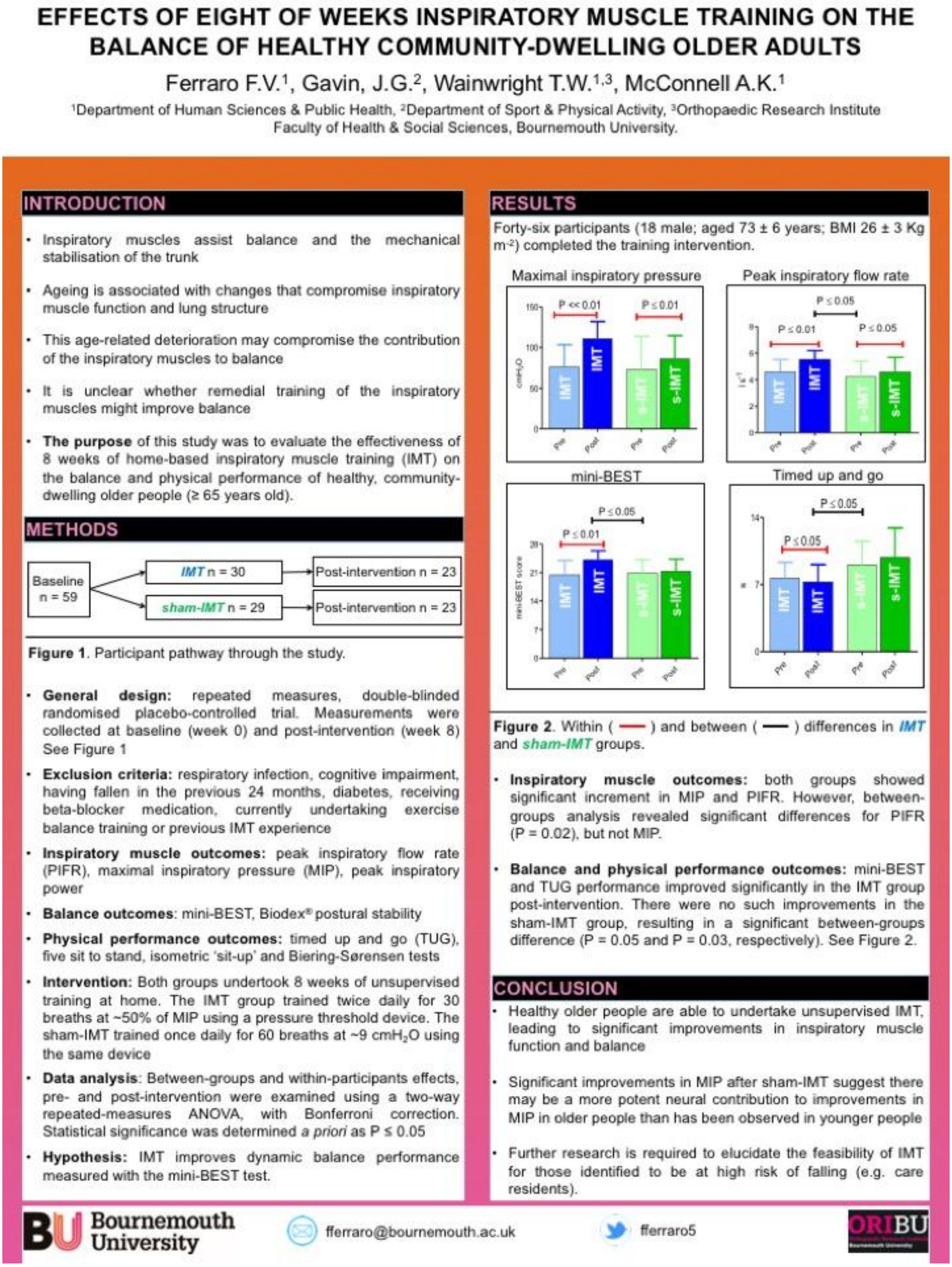
Appendix (A-9) – Poster presented at BASES conference



EFFECTS OF EIGHT OF WEEKS INSPIRATORY MUSCLE TRAINING ON THE BALANCE OF HEALTHY COMMUNITY-DWELLING OLDER ADULTS

Ferraro F.V.[1], Gavin, J.G.[2], Wainwright T.W.[1,3], McConnell A.K.[1]

[1]Department of Human Sciences & Public Health, [2]Department of Sport & Physical Activity, [3]Orthopaedic Research Institute
Faculty of Health & Social Sciences, Bournemouth University.

INTRODUCTION

- Inspiratory muscles assist balance and the mechanical stabilisation of the trunk
- Ageing is associated with changes that compromise inspiratory muscle function and lung structure
- This age-related deterioration may compromise the contribution of the inspiratory muscles to balance
- It is unclear whether remedial training of the inspiratory muscles might improve balance
- **The purpose** of this study was to evaluate the effectiveness of 8 weeks of home-based inspiratory muscle training (IMT) on the balance and physical performance of healthy, community-dwelling older people (≥ 65 years old).

METHODS

Baseline
n = 59

IMT n = 30 → Post-intervention n = 23

sham-IMT n = 29 → Post-intervention n = 23

Figure 1. Participant pathway through the study.

- **General design:** repeated measures, double-blinded randomised placebo-controlled trial. Measurements were collected at baseline (week 0) and post-intervention (week 8) See Figure 1
- **Exclusion criteria:** respiratory infection, cognitive impairment, having fallen in the previous 24 months, diabetes, receiving beta-blocker medication, currently undertaking exercise balance training or previous IMT experience
- **Inspiratory muscle outcomes:** peak inspiratory flow rate (PIFR), maximal inspiratory pressure (MIP), peak inspiratory power
- **Balance outcomes**: mini-BEST, Biodex® postural stability
- **Physical performance outcomes:** timed up and go (TUG), five sit to stand, isometric 'sit-up' and Biering-Sørensen tests
- **Intervention:** Both groups undertook 8 weeks of unsupervised training at home. The IMT group trained twice daily for 30 breaths at ~50% of MIP using a pressure threshold device. The sham-IMT trained once daily for 60 breaths at ~9 cmH$_2$O using the same device
- **Data analysis**: Between-groups and within-participants effects, pre- and post-intervention were examined using a two-way repeated-measures ANOVA, with Bonferroni correction. Statistical significance was determined *a priori* as $P \leq 0.05$
- **Hypothesis:** IMT improves dynamic balance performance measured with the mini-BEST test.

RESULTS

Forty-six participants (18 male; aged 73 ± 6 years; BMI 26 ± 3 Kg m^{-2}) completed the training intervention.

Figure 2. Within (—) and between (—) differences in ***IMT*** and ***sham-IMT*** groups.

- **Inspiratory muscle outcomes:** both groups showed significant increment in MIP and PIFR. However, between-groups analysis revealed significant differences for PIFR (P = 0.02), but not MIP.
- **Balance and physical performance outcomes:** mini-BEST and TUG performance improved significantly in the IMT group post-intervention. There were no such improvements in the sham-IMT group, resulting in a significant between-groups difference (P = 0.05 and P = 0.03, respectively). See Figure 2.

CONCLUSION

- Healthy older people are able to undertake unsupervised IMT, leading to significant improvements in inspiratory muscle function and balance
- Significant improvements in MIP after sham-IMT suggest there may be a more potent neural contribution to improvements in MIP in older people than has been observed in younger people
- Further research is required to elucidate the feasibility of IMT for those identified to be at high risk of falling (e.g. care residents).

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Appendix (A-10) – Ethical approvals

Dear Francesco Ferraro,

Your checklist (The influence of 8 weeks of inspiratory muscle training upon physiological and balance outcomes with healthy older adults.) has now been reviewed and APPROVED in line with BU's Research Ethics Code of Practice.

You can now save and/or print off a hard copy of the checklist at https://ethics.bournemouth.ac.uk.

This approval relates to the ethical context of the work. Specific aspects of the implementation of the research project remain your professional responsibility.

It is your responsibility to ensure that where the scope of the research project changes, such changes are evaluated to ensure that the ethical approval you have been granted remains appropriate. You must re-submit for ethical approval if changes to the research project mean that your current ethical approval is no longer valid.

Students – if the scope of your research changes, please discuss with your Tutors/Supervisors before submitting a new checklist.

Many thanks

For UG/PGT enquiries – please contact your Supervisor in the first instance

For general enquiries – please email researchethics@bournemouth.ac.uk

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Dear Francesco Ferraro,

Your checklist (The effect on balance for Healthy Adults undertaking an 8 weeks of inspiratory muscles training: a random, double-blind, controlled trial.) has now been reviewed and APPROVED in line with BU's Research Ethics Code of Practice.

You can now save and/or print off a hard copy of the checklist at https://ethics.bournemouth.ac.uk.

This approval relates to the ethical context of the work. Specific aspects of the implementation of the research project remain your professional responsibility.

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Students – if the scope of your research changes, please discuss with your Tutors/Supervisors before submitting a new checklist.

Many thanks

For UG/PGT enquiries – please contact your Supervisor in the first instance

For general enquiries – please email researchethics@bournemouth.ac.uk

Dear Francesco Ferraro,

Your checklist (Comparing the effects of 8 weeks of inspiratory muscle training with Otago exercise training on the balance and functional mobility of healthy older adults: a single-blind randomised controlled trial) has now been reviewed and APPROVED in line with BU's Research Ethics Code of Practice.

You can now save and/or print off a hard copy of the checklist at https://ethics.bournemouth.ac.uk.

This approval relates to the ethical context of the work. Specific aspects of the implementation of the research project remain your professional responsibility.

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Students – if the scope of your research changes, please discuss with your Tutors/Supervisors before submitting a new checklist.

Many thanks

For UG/PGT enquiries – please contact your Supervisor in the first instance

For general enquiries – please email researchethics@bournemouth.ac.uk

Risk Assessments

Please ensure that an appropriate risk assessment has been completed before the commencement of your research. Access to the BU On-line Risk Assessment Tools & Information can be found at:

Staff: https://staffintranet.bournemouth.ac.uk/workingatbu/healthsafetywellbeing/

Students: https://www1.bournemouth.ac.uk/students/log-services