ASSOCIATION BETWEEN INSPIRATORY MUSCLE FUNCTION AND BALANCE ABILITY IN OLDER PEOPLE: A POOLED DATA ANALYSIS BEFORE AND AFTER INSPIRATORY MUSCLE TRAINING

**Abstract:**

Inspiratory muscle training (IMT) improved balance ability and respiratory muscle function in healthy older adults. The current study is a retrospective analysis to explore the relationship between inspiratory muscle function, balance ability and adaptation to IMT. All participants (total = 129; IMT = 60; age range 65-85) performed inspiratory and balance assessments, including the mini Balance Evaluation System Test, maximal inspiratory pressure and peak inspiratory flow tests. Baseline inspiratory muscle function was positively related to balance ability (P < 0.05), and IMT-induced improvements in inspiratory function (23.3% in MIP, 8.0% in PIFR, 14.9% in MAXPP) were related to improvements in balance (10.6% in mini-BEST), with the greatest improvements (17.0%) observed in the oldest participants (76-85 years old, P < 0.05). In conclusion, with or without IMT positive associations between inspiratory function and balance ability exist, with greater improvements in inspiratory muscle function related to greater improvements in balance ability.

**Keywords:** fall prevention, respiratory muscle training, pulmonary physiology, elderly, functional mobility

**Introduction**

Over future decades the estimated aging of our population underlines the importance of identifying self-management interventions to prevent falls. This is so that older people can avoid harm, remain independent (Matson & Schinkel-Ivy, 2020), and associated healthcare costs can be controlled (Heinrich et al., 2010). Recent systemic reviews suggest that balance training is most effective in reducing the rate of falls when combined with multifactorial interventions, including functional and resistance training or anticipatory, dynamic training and flexibility exercises (Sherrington et al., 2020; Sibley et al., 2020). The National Institute for Health and Care Excellence falls prevention guidelines (NICE, 2019) recommend that the risk identification for falls should involve multifunctional balance assessments (e.g. mini-BEST), and that fall prevention interventions should focus on multifactorial exercises that combine upper and lower body movements, including yoga, Pilates and dance (Shahtahmassebi et al., 2019).

Ageing is associated with a progressive deterioration in respiratory system function (Watsford et al., 2007), including a significant decline in inspiratory muscle function (Britto et al., 2009) and an increase in pulmonary inflammation, known as senile emphysema (Janssens et al., 1999). These progressive declines may impair the inspiratory muscles’ contribution to their secondary role in balance stabilisation, as evident in patients with chronic obstructive pulmonary disease (COPD) (Oliveira et al., 2013). Inspiratory muscles (particularly the diaphragm) have been proposed to have a role in balance stabilisation (Hodges & Gandevia, 2000). It has been found that 8 weeks of Inspiratory muscle training (IMT), defined as a series of resisted inspirations that strengthen the inspiratory muscles, is an effective therapeutic exercise to improve inspiratory muscle function, as well as dynamic balance for healthy older adults (Ferraro et al., 2019; Ferraro et al., 2020). These findings raise questions about the extent to which inspiratory muscle function and balance ability are related, both with and without IMT. Therefore, we performed a retrospective analysis of 60 participants who underwent IMT and 69 non-training controls (total cohort, n = 129); data were based on two published, randomised controlled IMT studies (Ferraro et al., 2019; Ferraro et al., 2020), as well as one unpublished feasibility IMT study.

The data represents the largest dataset available on IMT with healthy older adults and was used to investigate whether i) inspiratory muscle function was related to balance ability (without IMT), ii) inspiratory muscle and balance functions were associated with the magnitude of improvements following IMT (with IMT), and iii) age influenced respiratory muscle, balance functions and responsiveness to IMT. Regarding age, we hypothesised that the oldest group (i.e. 76 to 85 year olds) would benefit the most from IMT due to greater age-related declines in inspiratory muscle function when compared to ‘younger’ old cohorts (i.e. 65-70 and 71-75 year olds).

**Materials and Methods**

*General design*

One hundred and twenty-nine participants were recruited between September 2016 and August 2018, as part of a larger project comprising three studies (XXXX, YEAR). These studies aimed at investigating the potential effects of IMT on balance and functional mobility with healthy community dwellers. Ethical approval was received from the XXXX University Research Ethics Committee (in 2016, 2017 and 2018). In each or the three studies, participants were randomly assigned resulting with 82 individuals undertaking unsupervised inspiratory muscle training (IMT) for 8 consecutive weeks, whereas 47 individuals performed 8 consecutive weeks of sham-IMT (n = 29) or a balance exercise programme (n = 18). The intervention period of 8 weeks has predicated upon previous research indicating that training beyond 8 weeks does not continue to produce improvements in inspiratory muscle strength and power, due to a plateau effect (Romer & McConnell, 2003). In the sham-IMT participant 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). The balance exercises program refers to the Otago Exercises Program, which is a 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). Participants were recruited locally from Dorset and Hampshire (UK) via public engagement events, and each provided written informed consent before data collection. The principal investigator met with each participant on two occasions: at baseline (week 1), and post-intervention (week 8), Figure 1.

<< figure 1 >>

*Participant characteristics*

The exclusion criteria involved: people aged under 65 years; chronic lung condition(s), such as asthma or obstructive pulmonary disease, identified during spirometry assessments (Tiffeneau-Pinelli index higher than 0.7); low self-perceived balance ability (Activities Balance Confidence [ABC] scale lower than 67%); having fallen, or with a history of falls accident in the previous 24 months; vertigo in the past 6 months; currently, or planning to undertake any exercise balance training (e.g. Tai Chi or Pilates); and any experience of IMT. On test days, participants were requested to avoid drinking alcohol and caffeinated beverages, and taking any substances known to affect human physiological function (including beta-blockers). Participants were also instructed to dress in a tracksuit or shorts and t-shirts, with plimsolls or trainers to perform the physical performance tests.

Testing environment

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

Intervention: inspiratory muscle training

The following intervention is described according to the Template for Intervention Description and Replication (TIDieR) (Hoffmann et al., 2016). Inspiratory muscle training is defined as a series of forced, quick inspirations against an inspiratory threshold pressure, generated by a spring in the breathing device. The inspiratory pressure was tailored to the 50% of participant`s maximal inspiratory pressure as measured at baseline. Each participant performed individual, home-based, unsupervised IMT for 8 consecutive weeks, using a mechanical pressure threshold loading device (POWERbreathe Plus, POWERbreathe® International Ltd, Southam, UK), following an established training protocol known to improve inspiratory muscle function. This involved 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). To maintain the training stimulus, all participants were instructed to increase their inspiratory resistance when they felt that 30 breaths were achievable with ease, or if they could reach 35 consecutive breaths (McConnell, 2013). Training adherence (i.e., number of sessions, number of breaths per session and training stimulus) was monitored using self-reported training diaries and with objective measurement (i.e. maximal inspiratory pressure) at baseline (week 1) and post-intervention (week 8).

*Procedures*

Balance confidence questionnaire

The ABC questionnaire was included to measure self-confidence for situation-specific activities. The ABC questionnaire consists of 16 items from vestibular balance (e.g. standing on tiptoes) to functional mobility (e.g. get in, 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 the sum of each item score, divided by the total number of items (Powell & Myers, 1995).

Pulmonary function

A spirometer (SpiroUSB, Care Fusion, Wokingham, Berkshire, UK) was used to measure forced vital capacity (FVC) and forced expiratory volume in 1 second (FEV1), according to the American Thoracic Society guidelines (Miller et al., 2005). Peak inspiratory flow rate (PIFR) was measured using POWERbreathe® K5, with Breathe-Link 2.0 software, using a technique validated by Langer and colleagues (2013). Participants performed the forced breathing manoeuvres, at least five, and no more than eight times until the breathing variability was within 5% for three consecutive breathing manoeuvres.

Inspiratory muscle function

Inspiratory muscle function defined as the capacity of the inspiratory muscles to produce force (pressure), velocity (flow) of contraction and/or power (pressure/flow product). A hand-held mouth pressure meter (MicroRPM, Micro Medical Ltd, Rochester, Kent, UK) was used to determine maximal inspiratory pressure (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. Inspiratory muscle power analysis was undertaken at six different loads (40, 50, 55, 60, 70 and 80% of participants` [baseline] MIP). Participants were requested to inhale with a maximal effort against the six loads, each of which was performed in random order. Three trials were performed for each of the loading intensities, with 30 seconds rest intervals, making a total of 18 forced inspiratory manoeuvres from which the higher values (MAXPP = maximal peak inspiratory power) was recorded. Nose-clips were worn for all pulmonary and inspiratory muscle tests, and verbal encouragement was provided to promote maximal efforts.

Physical performance and Balance

In this study the term physical performance is defined as an objective performance measure in which an individual is asked to perform a specific task and is evaluated in an objective, uniform manner using predetermined criteria, which may include counting of repetitions or timing of the activity as appropriate (Guralnik et al., 1989).

The timed up and go tests

The timed up and go test (TUG) and cognitive dual-task TUG (TUGC) were used to assess mobility and physical performance (Herman et al., 2011; Rydwik et al., 2011). Briefly, 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 & Richardson, 1991). During the TUGC, participants were instructed to perform the same task, while counting aloud backwards in threes, from a randomly selected number between 80 and 100 (Commandeur et al., 2018).

Mini-BEST test

Static and dynamic balance were assessed using the Mini-Balance Evaluation Systems Test (Mini-BEST), which included fourteen different tasks, including 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) (Marques et al., 2016).

Trunk muscle endurance

To measure the effects of IMT on anterior trunk muscle endurance the sit-up test, adhering to the guidelines of McGill and colleagues (1999), was used. Briefly, participants were required to sit supine on an examination bench, and place the upper body against a support, with a 60° angle from the examination bench. Both the knees and hips were flexed to 90°. The participant’s arms were folded across the chest, and their feet were secured with straps. Participants were instructed to contract their abdominal muscles and maintain the position, whilst the support was pulled back by approximately 10 cm at the command “3, 2, 1 and go”. To measure the effect of IMT on posterior trunk muscle endurance the Biering-Sørensen test was used. Participants were asked to maintain a prone position on the examination bench, with their torso unsupported over the edge of the test bench. Three straps secured their legs and hips, and their hands were placed behind their head (Biering-Sørensen, 1984). For both assessments, participants were instructed to hold the static positions until volitional exhaustion (i.e. the limit of tolerance). If they experienced discomfort during the static positions (e.g. neck or back pain) they were instructed to stop immediately, the test was then terminated and time recorded. Trunk endurance (hold) time was recorded using a digital stopwatch, and no verbal encouragement neither practical trial were provided.

**Data analysis**

Data were grouped by age [65-70 (n = 31) , 71-75 (n = 16) and 76-85 (n = 13) years old] and gender (male and female). To test our hypothesis that the oldest group (i.e. 76-85 years old) would benefit most from IMT, percentage changes in outcome scores were analysed using a one-way analysis of variance (ANOVA) to compare changes by age and gender (i.e. assess any gender by age interaction). As the results were grouped in unequal size (23 male, 37 female), a Scheffe’s post-hoc test was used to correct the alpha value, and reduce the likelihood of a type I error. Data are reported with the F ratio and P values. To explore the effects of IMT on our cohort irrespective of age and gender, separate t-tests were used, the threshold for statistical significance was P < 0.01. To assess the magnitude of potential effects, Cohen’s (d) effect sizes were calculated, as small: d ≤ 0.2; medium: 0.2 < d ≤ 0.8; and large: d > 0.8. Finally, to examine the association between improvements in inspiratory muscle function and balance ability, a Pearson’s correlations were used with statistical significance defined, a priori, as P ≤ 0.05. All data were analysed using SPSS 26.

**Results**

*Participant characteristics*

A total of 129 participants were included in the analysis, of which, 82 had been assigned to IMT and 47 to sham-IMT, or balance training. Sixty participants (72 ± 5 years old, 23 male, 37 female, BMI: 26.0 ± 3.7 kg/m2) out of 82, completed 8 weeks of IMT. Participants’ baseline characteristics for inspiratory muscle function and balance are reported in Table 1. At baseline, participants were similar (P > 0.05) in balance confidence (i.e. ABC questionnaire), inspiratory muscle function, physical performance and balance performance.

<< Table 1 >>

*Interrelationship of baseline characteristics*

Increasing age was associated with lower inspiratory muscle strength (Figure 2A) and balance ability (Figure 2B), with a stronger association for female participants, Figure 2.

<< Figure 2 >>

Increasing age was associated with a reduction in inspiratory muscle strength (male MIP: MAX value = 153.0 cmH2O; MIN value = 17.0 cmH2O; female MIP MAX value = 139.0 cmH2O; MIN value = 19.0 cmH2O ) and balance ability (male mini-BEST MAX value = 28/30 ; MIN value = 9/30; female mini-BEST MAX value = 27/30; MIN value = 7/30 ). All indices of inspiratory muscle function (i.e. PIFR, MIP and MAXPP) were related positively, and significantly, with balance ability (mini-BEST) (Figure 3). Both MIP and PIFR accounted for 40% of the variation in mini-BEST performance.

<< Figure 3 >>

*Influence of baseline characteristics on responses to IMT*

The effect of participant baseline characteristics upon percentage changes following IMT is reported in Figure 4, which depicts the percentage changes in balance (i.e. mini-BEST) and in inspiratory muscle function (i.e. MIP, PIFR, MAXPP) for both males and females according to their age.

<< Figure 4 >>

*Inspiratory muscle function following IMT*

All indices of inspiratory muscle function improved significantly following IMT (P < 0.001); specifically, MIP by 23.2% (d = 0.7); PIFR by 8.0% (d = 0.4) and MAXPP by 14.9% (d = 0.2). Results were similar for MIP, PIFR and MAXPP (MIP: F = 0.31, P = 0.73; PIFR: F = 0.28, P = 0.76; MAXPP: F = 0.34, P = 0.71). However, percentage changes in FEV1 and FVC post-IMT showed no significant relationship with age or gender (FEV1: F = 0.61, P = 0.55; FVC: F = 1.4, P = 0.26) (see Table 2).

<< Table 2 >>

Baseline characteristics are in accordance with the available normative data for ABC , FVC, FEV1,MIP (Huang & Wang, 2009; Watsford et al., 2007).

*Physical performance and Balance following IMT*

There were no significant changes in our physical performance measures following IMT. Age and gender did not have significant effects on the percentage change of physical performance (TUG: F = 0.69, P = 0.51; TUGC: F = 0.41, P = 0.67, sit-up: F = 1.33, P = 0.28; Biering-Sørensen: F = 0.07, P = 0.93) (see Table 3).

Overall balance performance improved following IMT (P < 0.001, d = 0.7), as did the anticipatory (d = 0.6), reactive (d = 0.9) and dynamic balance (d = 1.0) tasks (see Table 3). Also, balance improved across all age and gender groups following IMT, specifically: overall mini-BEST (F = 0.63, P = 0.53), as well as anticipatory (F = 0.29, P = 0.74), reactive (F = 0.39, P = 0.43), sensory (F = 3.33, P = 0.43), and dynamic balance (F = 1.72, P = 0.19) tasks. Additionally, the oldest group (76 to 85 years olds) showed the greatest improvements (by 63%) in dynamic balance ability, when compared to the younger groups (see Figure 5).

<< Table 3 >>

<< Figure 5 >>

Baseline characteristic are in accordance with the available normative data for TUG and mini-BEST (O'Hoski et al., 2014; Pondal & del Ser, 2008).

*Association between changes in inspiratory muscle function and changes in balance ability*

There were significant associations between percentage changes in inspiratory muscle function (i.e. MIP, PIFR and MAXPP), and balance (i.e. mini-BEST, anticipatory and dynamic tasks). The greater the improvement in inspiratory muscle function, the greater the improvement in balance ability, Table 4, Figure 6.

<< Table 4 >>

<< Figure 6 >>

**Discussion**

This study’s main aim was to investigate i) whether baseline function of the inspiratory muscles was related to balance ability (without IMT), ii) whether baseline inspiratory muscle and balance functions were related to the magnitude of improvements following IMT and iii) whether age influenced respiratory muscle, balance functions and responsiveness to IMT. Our secondary aim was to examine the extent to which inspiratory muscle function tests can predict balance ability. This advances recent observations that IMT improves balance ability for older adults, for specific dynamic balance tasks (Ferraro et al., 2019; Ferraro et al., 2020). The current research represents the largest data set recording the effects of IMT, with healthy older adults, and demonstrates the multifaceted benefit of increasing inspiratory muscle function for this group. In particular results show that superior inspiratory muscle function is associated with greater balance ability, independent of gender and age. Following 8 weeks of IMT the association is maintained, with our oldest cohort showing the greatest improvements. Total adherence to training was high (74%), which is perhaps attributable to the ‘user-friendliness’ of IMT interventions (Bowen et al., 2009). For example, for 8 weeks participants exercised unsupervised in their home, without cumbersome or expensive equipment (e.g. heavy weights or cycle ergometers). Baseline data (pre-IMT) are in accordance with normative data for healthy older adults and showed that advancing age is associated with a progressive decline of inspiratory muscle function, particularly in the oldest group (over 80 years old) (Figure 2). Inspiratory muscle function (i.e. MIP and PIFR) accounted for approximately 40% of the variation in balance ability. The progressive decline in inspiratory muscle function might impair the contribution made by the inspiratory muscles (particularly the diaphragm) to their secondary role, of balance stabilisation (Kocjan et al., 2018), as evident in patients with chronic obstructive pulmonary disease (COPD) (Oliveira et al., 2013). Following IMT, inspiratory muscle strength improved, with dynamic and reactive balance also improving for those with the lowest strength and balance at baseline. In addition, greater improvements in inspiratory muscle function were associated with greater improvements in balance ability, particularly for reactive and anticipatory balance tasks. In accordance to the National Institute for Health and Care Excellence’s recommendations (NICE, 2019), our findings provide novel evidence to support a clinical protocol to assess different factors related to falls risk. This includes fear of falling (ABC questionnaire), respiratory function (FEV1, FVC, MIP, PIFR and MAXPP), assessments of gait (TUG and TUGC), balance (mini-BEST), and trunk muscle endurance (sit-up and Biering-Sørensen tests).

*Inspiratory muscle function and balance ability*

Prior to any training intervention, participants were similar in inspiratory muscle function and balance ability. Independent of gender, the better the respiratory muscle function (e.g. MIP, PIFR and MAXPP), the better the participant’s balance ability (Figure 3). This raises the possibility that the respiratory muscles might, indirectly or directly, play a role in balance maintenance in healthy older adults, as previously demonstrated for those with cancer (Kocjan et al., 2018) and COPD (Loughran et al., 2020). Inspiratory muscle function improved following IMT (Table 1). In particular, MIP showed a large effect size, whilst PIFR and MAXPP showed lower, but still significant effect sizes (i.e. smaller magnitudes of effects). The significant improvement in MIP, PIFR and MAXPP after 8 weeks of unsupervised IMT, independent of age and gender, indicates that all groups, regardless of age and gender, improved respiratory muscle function similarly in our studies. These results agree with previous findings with older adults following IMT (Mills et al., 2015; Souza et al., 2014), as well as in frailer individuals, such as patients with COPD (Beaumont et al., 2018) and chronic heart failure (Smart et al., 2013). Furthermore, 8 weeks of IMT improved overall balance, with the greatest effect observed in anticipatory, reactive and dynamic balance sub-asks. We also found that the largest balance improvements were demonstrated in the oldest group (76 to 85 years old; Figure 5). Analysis of the associations between the magnitude of changes in inspiratory muscle function and balance ability, showed a significant relationship between PIRF, MAXPP and balance, particularly in anticipatory and reactive balance tasks. The anticipatory balance task includes standing on one leg and calf raises, whilst reactive balance tasks, includes compensatory stepping forward, backwards and laterally. These results support an intrinsic, dual role of inspiratory muscles, in assisting balance tasks for sudden perturbed/unexpected movements (i.e. reactive) (Hodges & Gandevia, 2000), and in static positions during unstable postures (i.e. anticipatory) (Hodges et al., 2005).

*Balance ability in older adults after IMT*

As hypothesised, the oldest group in our sample (people aged 76-85 years old) showed the greatest improvement in balance ability following 8 weeks of unsupervised IMT (Table 3), and in particular in the dynamic balance tasks (Figure 5). Although balance ability improved for all three cohorts, in three of the four mini-BEST tasks, people over 75 years of age benefited the most from training their inspiratory muscles. This is likely attributable to the longer period of age-related deterioration in balance (Balogun, 1994) and in inspiratory muscle function (Janssens et al., 1999; Watsford et al., 2007). The thoracic muscles and tendons can produce forces that increase spinal stability (Myers, 2015) , mechanism(s) known as the active balance subsystem (Panjabi, 1992). Improvements in inspiratory muscle function, particularly related to the diaphragm (characterised using MIP, PIFR and MAXPP), might reinforced the active balance subsystem contributing to dynamic balance improvements. Additionally, the intraabdominal pressure (IAP) is a known mechanism that improves spinal stiffness (Hodges et al., 2005). Using magnetic resonance imaging during isometric lower limbs flexion, Kolář and colleagues showed that IAP increases in response to diaphragm contraction (Kolář et al., 2012). It is therefore reasonable to suggest that IMT might enhanced participants’ capacity to produce quicker and more sustained changes in IAP, improving the interaction between the inspiratory (e.g., diaphragm) and expiratory muscles (e.g. transverse abdominis) (Cholewicki et al., 1999). However, the physiological mechanisms underpinning the association between improvements in inspiratory muscle function and balance ability afforded by 8 weeks of unsupervised IMT, require further investigation. Future research should examine the clinical implications of our findings. For example, whether IMT might be integrated in community and clinical settings as a multifactional intervention for older people with recurrent, or high risk, of falls. Recent NICE recommendations (2019) describe how strength and balance exercises should be individually prescribed (i.e. targeted to the individual needs). It is therefore, rational to propose that IMT, being a strength training intervention that is self-managed by people in their homes (Formiga et al., 2020), has the potential to be used in combination with lower limb exercises training such as OTAGO exercise program (Ozsoy et al., 2021) . The clinical advantages of using IMT as a strength intervention to improve balance, and respiratory muscle function, are its pragmatism as it is self-managed, with low costs and low risks (e.g. fall accidents). In addition, IMT has also been shown to improve exercise tolerance, dyspnoea and quality of life for patients with COPD (Sánchez Riera et al., 2001) and heart failure (Wu et al., 2018), providing older people with benefits above and beyond those related to balance proficiency.

**Limitations**

The main limitation of the study was the heterogeneity of our sample of older adults. The data were collected from a project that examined the effect of IMT on balance and functional mobility. The project was not powered for comparison analysis, nor was recruitment stratified to prevent heterogeneity in age and gender. However, the data from the three trials that formed the main project are collectively the largest sample of inspiratory muscle function and training data collected and published from older people by the same laboratory, investigator and with consistent data collection processes.

**Conclusions**

We found a positive relationship between inspiratory muscle function with anticipatory and reactive balance ability in healthy older adults. In our sample, better inspiratory muscle function was associated with better balance ability, independent of gender and age. The association is also held after 8 weeks of unsupervised, home-based IMT, with our oldest cohort showing the greatest improvements after IMT. These findings reveal the potential use of IMT as a fall’s prevention strategy alone. Additionally, due to the minimal risk of fall accidents during IMT, it can potentially be incorporated into multifactorial interventions (e.g., OTAGO exercise program) for frailer populations (e.g. individuals with recurrent falls), as advocated by NICE. The improvements seen in inspiratory muscle function and balance following 8 weeks of IMT raise questions about the clinical implications of the intervention, not only in patients with breathing difficulties, but also as pre- and post-operative interventions for with patients prior to abdominal surgery (Moran et al., 2016; Pouwels et al., 2020) . However, further research should now investigate the mechanistic contribution of inspiratory muscles in balance. For instance, analysis with needle electromyography (Ando et al., 2020), or with magnetic resonance imaging (Laohachai et al., 2017).

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**Conflicts of Interest** This work was sponsored by XXXX University.XX, XX and XX declare no conflicts of interests. XX acknowledges a previous (now expired) beneficial interest in POWERbreathe® inspiratory muscle trainers, in the form of a share of royalty income to the University XXXX. In the past, XX has also provided consultancy services to POWERbreathe® International Ltd., but no longer does so. XX is also named on two patents relating to POWERbreathe® products, including the devices used in the present study (POWERbreathe Plus and POWERbreathe K 5). XX has no current or future financial interest in either of these patents. XX is also the author of two books on inspiratory muscle training (‘XXXX’ and ‘XXXX’).

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