TITLE PAGE

Title

Inspiratory muscle training improves proprioceptive postural control in individuals with recurrent non-specific low back pain

Authors and Affiliations

Lotte Janssens[1], PT, PhD

Thierry Troosters[1,2], PT, PhD

Alison K McConnell[3], BSc, MSc, PhD

Madelon Pijnenburg[1], PT

Kurt Claeys[1,4], PT, PhD

Nina Goossens[1], PT

Roeland Lysens[5], MD, PhD

Simon Brumagne,[1] PT, PhD

[1]Department of Rehabilitation Sciences, KU Leuven - University of Leuven, Leuven, Belgium

[2]Respiratory Rehabilitation and Respiratory Division, University Hospitals Leuven, Leuven, Belgium

[3]Centre for Sports Medicine & Human Performance, Brunel University, Uxbridge, United Kingdom

[4]Department of Rehabilitation Sciences, KU Leuven - University of Leuven, KULAB, Bruges, Belgium

[5]Department of Physical Medicine and Rehabilitation, University Hospitals Leuven, Leuven, Belgium

Source of funding and study registration

This work was supported by The Research Foundation – Flanders (FWO) grants 1.5.104.03, G.0674.09 and G.0871.13. Madelon Pijnenburg is PhD fellow of Agency for Innovation by Science and Technology – Flanders (IWT). The study was approved by the local Ethics Committee of Biomedical Sciences, KU Leuven (University of Leuven) and registered at www.clinicaltrails.gov (NCT01505582).

Corresponding author

Lotte Janssens, KU Leuven - University of Leuven, Department of Rehabilitation Sciences, Tervuursevest 101 - bus 1501, 3000 Leuven, Belgium, Lotte.Janssens@faber.kuleuven.be

ANONYMOUS TITLE PAGE

Title

Inspiratory muscle training improves proprioceptive postural control in individuals with recurrent non-specific low back pain

Statement of financial disclosure and conflict of interest

This work was supported by The Research Foundation – Flanders (FWO) grants 1.5.104.03, G.0674.09 and G.0871.13. Madelon Pijnenburg is PhD fellow of Agency for Innovation by Science and Technology – Flanders (IWT). Alison McConnell acknowledges a beneficial interest in an inspiratory muscle training product in the form of a share of license income to the University of Birmingham and Brunel University. She also acts as a consultant to POWERbreathe International Ltd.

Acknowledgements

The authors are grateful to the study volunteers for their participation.

ABSTRACT

Study design. Longitudinal study.

Objectives. To investigate whether inspiratory muscle training (IMT) affects proprioceptive postural control in individuals with recurrent non-specific low back pain (LBP).

Background. We have shown that individuals with LBP decrease their reliance on proprioceptive signals from the trunk, using of an ankle-steered postural control strategy, We have also shown that breathing against an inspiratory load impairs proprioceptive postural control. Since individuals with LBP show a greater susceptibility to diaphragm fatigue it is reasonable to hypothesise that LBP, diaphragm dysfunction and postural control may be interrelated.

Methods. Twenty-eight individuals with LBP were assigned randomly into an intervention (IMT) and placebo group (p-IMT) undergoing eight weeks of high-intensity or placebo IMT, respectively. Proprioceptive strategy was evaluated using center of pressure displacement during local muscle vibration (ankle, back, ankle-back). Secondary outcomes were inspiratory muscle strength, severity of LBP, and disability.

Results. There was a decreased reliance on ankle proprioception and increased reliance on back proprioception after IMT ($p < 0.05$), but not after p-IMT ($p > 0.05$). Inspiratory muscle strength and LBP severity improved after IMT ($p < 0.05$), but not after c-IMT ($p > 0.05$). No changes in disability were observed in either group ($p > 0.05$).

Conclusion. After eight weeks of IMT, individuals with LBP showed a more multi-segmental control strategy, and improved inspiratory muscle strength and severity of LBP, not seen after p-IMT. Although preliminary, our data suggest that improving the strength of the inspiratory

muscles may facilitate the involvement of the trunk in proprioceptive postural control in people with LBP, and that IMT might be a useful rehabilitation tool for these patients.

Level of evidence: Therapy, level 1b

KEY WORDS

postural balance, sensory reweighting, metaboreflex, diaphragm

INTRODUCTION

Low back pain (LBP) has become a well-known health problem in the Western society, and now seems to be extending worldwide.[3] Various studies have identified changes in postural control as a potential factor in the aetiology of LBP.[49] The human upright standing requires proprioceptive input at the level of the ankles, knees, hips and spine.[1,33] When ankle proprioceptive input becomes less reliable, for example by standing on an unstable support surface, people rely more on proximal proprioceptive input, a process known as proprioceptive reweighting (REF?). However, when back proprioceptive signals lose reliability due to LBP, individuals adopt an ankle-steered strategy, irrespective the postural demands.[9] In other words, the ability of individuals with LBP to adapt their proprioceptive strategy to the changing postural demands is impaired, since they maintain an ankle-steered strategy, rather than a flexible, multi-segmental one.[11]

We have recently shown that individuals with chronic obstructive pulmonary disease (COPD), in particular those with compromised inspiratory muscle function, exhibit postural control strategies that are similar to those of people with LBP.[23] We have also shown that healthy individuals breathing against inspiratory loads adopt postural control strategies that are similar to those of people with LBP and COPD (REF). Moreover, individuals with breathing problems such as COPD have an increased risk for the development of LBP,[50,51] and individuals with LBP are also more likely to develop breathing problems.[50] Collectively, these, and other data, suggest a strong association between LBP, proprioceptive postural control and inspiratory muscle function, but the mechanisms underlying this association remain poorly understood.

The human diaphragm is the principal inspiratory muscle, and plays an essential role in controlling the spine during postural control.[20] It seems reasonable that an increased demand for inspiratory function of the diaphragm might inhibit its contribution to trunk stabilisation during challenges to postural balance. Healthy individuals appear to be capable of compensating efficiently for modest increases in inspiratory demand by active multi-segmental control.[21] Nevertheless, this compensation seems less effective in individuals with LBP, resulting in impaired balance control.[18] Furthermore, and ss mentioned above, specific loading of the inspiratory muscles impairs postural control forcing adoption of an ankle-steered strategy.[25] This might be explained by fatigue signaling of the inspiratory muscles inducing a decrease in peripheral muscle oxygenation and blood flow, which also affects the back muscles.[26] Furthermore, individuals with LBP show a greater magnitude, as well as a greater prevalence of diaphragm fatigue compared to healthy controls.[24] Although it is tempting to speculate on a causal relationship between inspiratory muscle function and proprioceptive postural control, support for this mechanism awaits the results of studies that enhance inspiratory muscle function, and assess the influence of this change upon postural control. Inspiratory muscle training (IMT) provides such an intervention, and has already been shown to affect spinal curvature in swimmers,[42] functional balance in heart failure,[7] and inspiratory muscle strength and endurance in COPD.[16]

Therefore, the primary objective of this study was to investigate the influence of IMT on proprioceptive postural control in individuals with recurrent non-specific LBP. A secondary aim was to study the effect of IMT on inspiratory muscle strength, severity of LBP and disability. We hypothesise that IMT would enable individuals with LBP to adopt a multi-segmental strategy, rather than an ankle-steered strategy during postural control. In addition, we speculate that this may improve LBP.

METHODS

Participants

Twenty-eight individuals (18 women, 10 men) with a history of non-specific recurrent LBP participated voluntarily in this study. Participants were included in the study if they had at least three episodes of non-specific LBP in the last six months and reported a score of at least 10 of 100 on the Oswestry Disability Index, version 2 (adapted Dutch version) (ODI-2).[15] The participants did not have a more specific medical diagnosis than non-specific mechanical LBP. Participants were excluded from the study in case of previous spinal surgery, specific balance problems (e.g. vestibular or neurological disorder), respiratory disorders, smoking, lower limb problems, neck pain or the use of pain relieving medication or physical treatment. A physical examination was performed by a physician to confirm eligibility. Participants meeting the inclusion criteria were further selected on the basis of their habitual proprioceptive postural control strategy (Relative Proprioceptive Weighting ratio > 0.5) in an upright stance (see *Data reduction and analysis*). None of the participants showed evidence of airflow obstruction upon examination of forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC). A physical activity questionnaire was completed.[2] Isometric hand grip force (HGF) was measured using a hydraulic hand grip dynamometer (Jamar Preston, Jackson, MI).[36]

The characteristics of the study participants are summarized in Table 1. All participants gave their written informed consent. The study conformed to the principles of the Declaration of Helsinki (1964) and was approved by the local Ethics Committee of Biomedical Sciences, KU Leuven and registered at www.clinicaltrails.gov (NCT01505582).

***** Please insert TABLE 1 near here *****

Study design

The study participants were assigned randomly to an intervention group ('IMT group') and a placebo group ('p-IMT group'). The primary objective of this study was to investigate the effect of IMT on proprioceptive postural control. Secondary outcomes were inspiratory muscle strength, severity of LBP and LBP-related disability. Outcome measures were evaluated at baseline and after eight weeks of intervention. Figure 1 displays the flowchart of the study.

***** Please insert FIGURE 1 near here *****

Materials

1. Proprioceptive postural control

Postural sway characteristics were assessed by anterior-posterior center of pressure (CoP) displacement using a 6-channel force plate (Bertec, OH, USA), which recorded the moment of force around the frontal axis (Mx) and the vertical ground reaction force (Fz). Force plate signals were sampled at 500 Hz using a Micro1401 data acquisition system using Spike2 software (Cambridge Electronic Design, UK) and were filtered using a low pass filter with a cut-off frequency of 5 Hz.

Local muscle vibration was used to investigate the role of proprioception in postural control. Muscle vibration is a powerful stimulus of muscle spindle Ia afferents.[12,46] It evokes an illusion of muscle lengthening. If the central nervous system uses proprioceptive signals of the vibrated muscles for postural control, it will cause a directional corrective CoP displacement. When the triceps surae (TS) muscles are vibrated, a postural sway in a backward direction is expected, whereas during lumbar paraspinal (LP) muscles vibration, a forward postural body sway is expected, which has been shown by previous studies.[9,11,23,25,26,28] The amount of CoP displacement during local vibration may represent the extent to which an individual makes use of the proprioceptive signals of the vibrated muscles to maintain the upright posture. Simultaneous vibration on TS and LP muscles may identify the individual's ability to gate conflicting proprioceptive signals (TS versus LP) during postural control.[23,26] During simultaneous TS-LP muscle vibration, a dominant backward body sway suggests an ankle-steered strategy whereas a forward body sway indicates a more multi-segmental strategy. Muscle vibrators (Maxon motors, Switzerland) were applied bilaterally over the TS and LP muscles and vibration was offered at a high frequency and low amplitude (60Hz, 0.5mm). [46]

To evaluate proprioceptive postural control, the participants were instructed to stand barefoot on the force plate, with their arms relaxed along the body. Two conditions were used: (1) upright standing on stable support surface (force plate) and (2) upright standing on unstable support surface (Airex balance pad; 49.5 centimeter (cm) length x 40.5 cm width x 6.5 cm height). On unstable support surface, ankle proprioceptive signals are less reliable, which enforces reliance upon proximal proprioceptive signals (i.e., proprioceptive weighting), thereby highlighting proprioceptive deficits.[22,29] A standardized foot position was used, with the heels placed 10 cm apart, and a free forefoot position. The vision of the participants was occluded by means of non-transparent goggles. Participants were instructed to maintain their balance at all times and an investigator was standing next to the participant to prevent actual falls. Within each of the two conditions, three experimental trials were implemented; muscle vibration was added bilaterally to the TS muscles (trial 1), LP muscles (trial 2), and to the TS and LP muscles simultaneously (trial 3). Muscle vibration started at 15 seconds, lasted for 15 seconds and data collection continued for 30 seconds.

2. Severity of LBP, LBP-related disability and LBP-related fear and beliefs

Severity of LBP was scored by the Numerical Rating Scale (NRS) from zero ('no pain') to ten ('worst pain'),[27] and LBP-related disability was evaluated using the ODI-2.[15] The Fear-Avoidance Beliefs Questionnaire (FABQ) was completed to identify how work and physical activity affect LBP.[52] The Tampa Scale for Kinesiophobia (TSK) was completed to identify the participants' fear of (re)injury following movements or activities.[32]

3. Inspiratory muscle strength

Inspiratory muscle strength was evaluated by measuring maximal inspiratory pressure (PImax) using an electronic pressure transducer (MicroRPM, Micromedical Ltd., Kent, UK). The PImax was measured at residual volume according to the method of Black and Hyatt.[4] A minimum of five repetitions was performed and tests were repeated until there was less than five percent difference between the best and second best test. The highest pressure sustained over one second was defined as PImax and was compared to reference values.[45]

4. Inspiratory muscle training (IMT)

The participants completed an IMT training program over a period of eight weeks. They were instructed to breathe through a mouthpiece (POWERbreathe Medic, HaB International Ltd., Warwickshire, UK) with their nose occluded while standing upright.[38] With every inspiration, resistance was added to the inspiratory valve forcing the individuals to generate a negative pressure of 60% of their PImax (IMT group) or 10% of PImax (p-IMT group), respectively.[37] The participants were instructed to perform 30 breathes, twice daily, with a breathing frequency of 15 breathes/minute and a duty cycle of 0.5. The participants of both groups were coached to use diaphragmatic (bucket handle) breathing rather than thoracic (pump handle) breathing, by providing verbal and tactile cues. With each training session, the participants were instructed to write down the applied resistance, perceived effort (Borg scale; 0-10), and additional remarks (e.g., dizziness, dyspnea) on a standardized form. Once a week, the training was evaluated under supervision of an investigator, and the resistance was adapted to the newly produced PImax.

Data reduction and analysis

Force plate data were calculated using Spike2 software and Microsoft Excel. To evaluate proprioceptive postural control, the directional effect of muscle vibration on mean values of anterior-posterior CoP displacement was calculated. Positive values indicate a forward body sway and negative values indicate a backward body sway. To provide additional information about the proprioceptive dominance, a Relative Proprioceptive Weighting ratio (RPW) was calculated using the equation: RPW= (Abs TS)/(Abs TS + Abs LP). 'Abs TS' is the absolute value of the mean CoP displacement during TS muscle vibration and 'Abs LP' during LP muscle vibration. A RPW score equal to one corresponds to 100% reliance on TS muscle input ('ankle-steered strategy'), whereas a score equal to zero corresponds to 100% reliance on LP muscle input ('multi-segmental strategy').[9,11,23,25,26,28] Participants were included in the study if they showed a RPW score > 0.5 ('ankle-steered strategy') when standing on unstable support surface.

A one-way analysis of variance (ANOVA) was used to examine differences in baseline characteristics between the two groups (Table 1). A repeated measures ANOVA was used to examine differences between subjects and within-subjects. A post hoc test (Tukey) was performed to further analyze these results in detail. The statistical analysis was performed with Statistica 9.0 (Statsoft, USA). The level of significance was set at $p < 0.05$.

RESULTS

Inspiratory muscle strength

Inspiratory muscle strength (PImax) increased significantly in the IMT group post-intervention (94±30 vs, 136±34 cmH_2O) (Δ 42 cm cmH_2O; p= 0.001). In contrast, c-IMT did not infleunce PImax (92±27 vs. 94±26 cmH_2O) (Δ 2 cm cmH_2O; p= 0.989). After the intervention, inspiratory muscle strength was significantly different between both groups (p= 0.001).

Proprioceptive postural control

1. *Relative proprioceptive weighting during standing on stable and unstable support surface*

When comparing the relative use of ankle *versus* back muscle proprioceptive input on a stable support surface (RPW 0–1),. the IMT group exhibited a decreased in RPW, suggestive of a more multi-segmental strategy compared to pre-IMT (Δ 0.19; p= 0.002). No such difference was apparent in the p-IMT group (Δ 0.09; p= 0.465). However, there was no difference between the groups was after the intervention (p= 0.081), although a trend was present.

When standing on an unstable support surface, the IMT group also showed a switch to a multi-segmental strategy, as shown by the decreased RPW values after IMT compared baseline (Δ 0.23; p= 0.001). No such difference was apparent in the p-IMT group (Δ 0.10; p= 0.579). A significant difference in RPW between the groups was observed after the intervention (p= 0.047). Figure 2 and 3 display the individual RPW ratios pre and post intervention on stable and unstable support surface, respectively.

No significant correlation was found between the change in RPW on stable support surface and the change in PImax post-intervention (r= -0.22; p= 0.305). In contrast, on an unstable support surface, a significant negative correlation was observed (r= -0.41; p= 0.049), suggesting higher PImax values were associated with a more multi-segmental strategy.

***** Please insert FIGURE 2 near here*****

***** Please insert FIGURE 3 near here*****

2. *Standing on stable support surface*

After the intervention, no differences were observed between the IMT and p-IMT group in the stable support surface condition (p= 0.846 (TS vibration); p= 0.146 (LP vibration); p= 0.278 (TS-LP vibration)). However, post-intervention, the IMT group decreased their reliance on ankle proprioceptive signals, evidenced by a significant reduction in posterior body sway during TS muscles vibration (Δ 2.6 cm; p= 0.049). This is corroborated by the finding that the IMT group showed a significantly smaller posterior body sway during simultaneous TS and LP muscles vibration compared to pre-IMT (Δ 3.8 cm; p= 0.048). The IMT group did not show a change in reliance on back proprioceptive signals post-IMT (Δ 1.7 cm; p= 0.128). In contrast, in the p-IMT group, there were no changes in responses to TS vibration (Δ 2.4 cm; p= 0.105), LP vibration (Δ 0.1 cm; p= 0.995) and simultaneous TS-LP vibration (Δ 2.4 cm: p= 0.644) post-intervention. Figure 4 displays the absolute CoP displacements during muscle vibration whilst standing on stable support surface.

No significant correlation was found between the change in PImax and the change in CoP displacement during TS vibration (r= -0.16; p= 0.457), TS-LP vibration (r= 0.14; p= 0.506) or LP vibration (r= 0.31; p= 0.145).

***** Please insert FIGURE 4 near here*****

3. Standing on unstable support surface

In the IMT group, LP vibration elicited significantly larger anterior body sway post-intervention (Δ 2 cm; p= 0.027), indicative of an increased use of back proprioceptive signals during postural control. Furthermore, the IMT group also decreased their reliance on ankle proprioceptive signals, as evidenced by a significantly smaller posterior body sway during simultaneous TS-LP vibration post-intervention (Δ 2.0 cm; p= 0.040). This difference was not present during TS vibration post-IMT (Δ 0.9 cm; p= 0.665). In contrast, in the p-IMT group, there were no changes in responses to TS (Δ 0.5 cm; p= 0.999), LP (Δ 0.7 cm; p= 0.856) and TS-LP (Δ 0.4 cm; p= 0.986) vibration post-intervention. After the intervention, no differences were observed between the IMT and p-IMT group in the unstable support surface condition for TS vibration (p= 0.384) and LP vibration (p= 0.126), however for TS-LP vibration a significant difference was found (p= 0.034). Figure 5 displays the absolute CoP displacements during muscle vibration while standing on unstable support surface.

No significant correlation was found between the change in PImax and the change in CoP displacement during TS vibration (r= -0.10; p= 0.639) or TS-LP vibration (r= 0.18; p= 0.395), although a significant positive correlation was observed in the change in CoP displacement during LP vibration (r= 0.44; p= 0.034), suggesting higher PImax values were associated with an increased reliance on back proprioceptive signals.

***** Please insert FIGURE 5 near here*****

Severity of LBP, LBP-related disability and LBP-related fear and beliefs

After the intervention, severity of LBP (NRS score 1–10) was lower in the IMT group compared to the p-IMT group (p= 0.013). More specifically, LBP severity decreased significantly in the individuals following IMT (5±2 vs. 2±2) (Δ 3; p= 0.001), whereas no changes was observed in the p-IMT group (5±2 vs. 5±2) (Δ 0; p= 0.864). Disability associated with LBP did not differ between groups after the intervention ($p= 0.402$), and was not significantly different before and after IMT (19±9 vs. 13±10 %) (Δ 6 %; $p= 0.099$), nor before and after p-IMT (20±8 vs. 17±7 %) (Δ 3 %; $p= 0.628$). Scores on the FABQ did not differ between groups after the intervention ($p= 0.343$), and were not significantly different before and after IMT (28±5 vs. 24±5) (Δ 4; $p= 0.073$), nor before and after p-IMT (27±9 vs. 26±13) (Δ 1; $p= 0.662$). Scores on the TSK were not different between groups after the intervention ($p= 1.000$), and were not significant different before and after IMT (39±5 vs. 36±6) (Δ 3; $p= 0.735$), nor before and after p-IMT (35±6 vs. 36±6) (Δ 1; $p= 0.735$).

DISCUSSION

The results of this study suggest that IMT affects proprioceptive postural control to a greater extent than p-IMT when standing on unstable support surface (significant interaction effect). As a consistent within-group effect was observed only in the IMT group, the study suggests that individuals with recurrent non-specific LBP decrease their reliance on ankle proprioceptive input and increase their reliance on back proprioceptive input during postural control after eight weeks of IMT. Moreover, IMT improved inspiratory muscle strength and decreased the severity of LBP; the decrease in NRS is clinically important according to international consensus.[43] These changes were not present in individuals with LBP who underwent p-IMT. These findings indicate that improving inspiratory muscle strength enhances proprioceptive weighting, supporting that inspiratory muscle dysfunction may exacerbate poor proprioceptive postural control in individuals with LBP.

Inspiratory muscle training may contribute to an enhancement of proprioceptive postural control in individuals with LBP via a number of potential mechanisms. First, previous research has demonstrated that an increase in intra-abdominal pressure provides 'relative stiffness' and thus control, of the lumbar spine, which is needed to unload the spine during balance and loading tasks (REF?). The diaphragm has been shown to contribute to postural control by increasing intra-abdominal pressure, possibly via its anatomical connection to the spine.[19] Our findings showed that the enhanced inspiratory muscle strength after IMT is accompanied by an improved (i.e. multi-segmental) proprioceptive postural control. A study examining the effect of glottal control (breath-holding or not) on postural balance concluded that optimal postural control needs a dynamic, midrange respiratory muscle control that is neither too flexible, nor too stiff.[35] This may be facilitated by IMT, as it is known to induce changes in pressure generation (improve relative stiffness) on the one hand;[48] and on the other hand, IMT may also reduce excessive expiratory/trunk muscle activity (improve relative flexibility), known to compromise postural control.[41,44] Thus, IMT might enhance the trunk stabilising function of the diaphragm, enabling individuals to up-weight lumbar proprioceptive signals, and to shift to a more optimal, flexible multi-segmental strategy. Recent studies have identified a smaller diaphragm excursion and a higher diaphragm position in individuals with LBP.[31] Furthermore, people with LBP attempt to compensate for their abnormal diaphragm position by increasing their tidal volume during lifting and lowering tasks in order to provide adequate pneumatic pressure support.[17,34] Our data suggest it may be possible to reverse the suboptimal proprioceptive postural control in LBP patients through IMT, and support a role for inspiratory muscle dysfunction in the aetiology of LBP.

A second mechanism by which IMT may contribute to a more optimal proprioceptive strategy in individuals with LBP, is by attenuating the activation of the inspiratory muscle metaboreflex and its consequences.[53] Intense resistive breathing can trigger an increase in sympathetic outflow, which in turn causes peripheral vasoconstriction,[37] leading to preferential perfusion of the loaded respiratory muscles.[47] The resulting vasoconstriction impairs peripheral muscle function, which in turn, may affect the muscles involved in postural control.[8] Consequently, individuals adopt a suboptimal proprioceptive postural control strategy.[26] It has been shown that the metaboreflex is attenuated by IMT in tasks involving the lower limb, more specifically in patients with chronic heart failure[5,10] and COPD.[6] Accordingly, it is reasonable to hypothesise that improving inspiratory muscle function by IMT reduces the negative effect of the metaboreflex on trunk muscle perfusion. As muscle spindles show a dense network of blood vessels,[30] IMT may favor the muscle spindle function by its impact on the vasoconstrictor influence of inspiratory muscle loading,[14] and thus may induce access to a larger variety of proprioceptive postural control strategies.

A third possible mechanism explaining the positive effect of IMT in individuals with LBP can be found in the effect of IMT on body awareness. Both IMT and p-IMT might have stimulated body awareness by enhanced sensing, localizing and discriminating, which might have previously been overwhelmed by a nociceptive input.[40] The use of proprioception, which includes body awareness, might be optimized after IMT, which in turn enables the use of a multi-segmental strategy to maintain upright posture. This might explain why p-IMT (10% as well as IMT, decreased the ankle proprioceptive use, despite that fact that no effect of p-IMT was observed upon PImax or severity of LBP. Moreover, it has been shown that altered breathing itself, free from resistive loading, can change the respiratory physiology and tissue oxygenation, consequently.[39] Taken together, this might suggest that IMT favors the use of an optimal proprioceptive strategy in individuals with LBP, possible by an improved trunk stabilizing function of the diaphragm, an attenuated metaboreflex, and enriched body awareness.

A top priority identified in 2013 for LBP research relates to the identification of underlying mechanisms, rather than to the effect of interventional studies.[13] Our study reveals a potential association between inspiratory muscle function and recurrent non-specific LBP. More specifically, the findings suggest that relative over-loading of the inspiratory musculature as a potential, but reversible contributor in proprioceptive postural control and LBP. We believe our data provide justification for further exploration of this phenomenon in a randomised controlled trial with a larger sample size and long term follow-up. This will reveal whether IMT is a valuable tool in the rehabilitation of individuals with recurrent non-specific LBP.

CONCLUSION

After eight weeks of IMT, individuals with recurrent non-specific LBP adopt a more multi-segmental postural control strategy, show an increase in inspiratory muscle strength, and report a decrease in LBP severity. Proprioceptive postural control might be improved following IMT by enhancing the trunk stabilising function of the diaphragm, by attenuating the vasoconstrictor influence of the metaboreflex, and/or by increasing body awareness. These changes may enable individuals to reweight proprioceptive signals and to shift to a more optimal proprioceptive strategy. The results of this study provide evidence that relative over-loading of the inspiratory musculature may be one potential underlying mechanism of altered proprioceptive postural control and LBP, which can be reversed by IMT. A randomized controlled trial with a larger sample size and long-term follow-up is required to reveal whether IMT is a valuable tool in the rehabilitation of individuals with recurrent non-specific LBP.

KEY POINTS

Findings. Inspiratory muscle training facilitates individuals with low back pain to adopt a multi-segmental strategy adjusted to the postural demands, rather than a rigid ankle-steered postural control strategy.

Implications. These findings indicate that improving inspiratory muscle function enhances proprioceptive weighting, suggesting an association between the inspiratory muscles and proprioceptive postural control in individuals with low back pain.

Cautions. A randomized controlled trial with a larger sample size and long term follow-up must reveal whether inspiratory muscle training might be a valuable tool in the rehabilitation of individuals with recurrent non-specific low back pain.

REFERENCES

1. Allum JH, Bloem BR, Carpenter MG, Hulliger M, Hadders-Algra M. Proprioceptive control of posture: a review of new concepts. *Gait Posture*. 1998;8:214-242.
2. Baecke JA, Burema J, Frijters JE. A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *Am J Clin Nutr.* 1982;36:936-942.
3. Balagué F, Mannion AF, Pellisé F, Cedraschi C. Non-specific low back pain. *Lancet.* 2012;379:482-491. doi: 10.1016/S0140-6736(11)60610-7.
4. Black LF, Hyatt RE. Maximal respiratory pressures: normal values and relationship to age and sex. *Am Rev Respir Dis.* 1969;99:696-702.
5. Borghi-Silva A, Carrascosa C, Oliveira CC, et al. Effects of respiratory muscle unloading on leg muscle oxygenation and blood volume during high-intensity exercise in chronic heart failure. *Am J Physiol Heart Circ Physiol.* 2008;294:H2465-472. doi: 10.1152/ajpheart.91520.2007.
6. Borghi-Silva A, Oliveira CC, Carrascosa C, et al. Respiratory muscle unloading improves leg muscle oxygenation during exercise in patients with COPD. *Thorax.* 2008;63:910-915. doi: 10.1136/thx.2007.090167.
7. Bosnak-Guclu M, Arikan H, Savci S, et al. Effects of inspiratory muscle training in patients with heart failure. *Respir Med.* 2011;105:1671-1681. doi: 10.1016/j.rmed.2011.05.001.
8. Brown PI, McConnell AK. Respiratory-related limitations in physically demanding occupations. *Aviat Space Environ Med.* 2012;83:424-430.
9. Brumagne S, Janssens L, Janssens E, Goddyn L. Altered postural control in anticipation of postural instability in persons with recurrent low back pain. *Gait Posture*. 2008;28:657-662. doi: 10.1016/j.gaitpost.2008.04.015

10. Chiappi GR, Roseguini BT, Vieira PJ, et al. Inspiratory muscle training improves blood flow to resting and exercising limbs in patients with chronic heart failure. *J Am Coll Cardiol*. 2008;51:1663-1671. doi: 10.1016/j.jacc.2007.12.045.
11. Claeys K, Brumagne S, Dankaerts W, Kiers H, Janssens L. Decreased variability in postural control strategies in young people with non-specific low back pain is associated with altered proprioceptive reweighting. *Eur J Appl Physiol*. 2011;111:115-123. doi: 10.1007/s00421-010-1637-x.
12. Cordo PJ, Gurfinkel VS, Brumagne S, Flores-Vieira C. Effect of slow, small movement on the vibration-evoked kinesthetic illusion. *Exp Brain Res*. 2005;167:324-333.
13. Costa LD, Koes BW, Pransky G, Borkan J, Maher CG, Smeets RJ. Primary Care Research Priorities in Low Back Pain: An Update. *Spine.* 2013;38:148-156. doi: 10.1097/BRS.0b013e318267a92f.
14. Delliaux S, Jammes Y. Effects of hypoxia on muscle response to tendon vibration in humans. *Muscle Nerve*. 2006;34:754-761.
15. Fairbank JC, Pynsent PB. The Oswestry Disability Index. *Spine.* 2000;25:2940-2952.
16. Gosselink R, De Vos J, van den Heuvel SP, Segers J, Decramer M, Kwakkel G. Impact of inspiratory muscle training in patients with COPD: what is the evidence? *Eur Respir J*. 2011;37:416-425. doi: 10.1183/09031936.00031810.
17. Hagins M, Lamberg EM. Individuals with low back pain breathe differently than healthy individuals during a lifting task. *J Orthop Sports Phys Ther.* 2011;41:141-148. doi: 10.2519/jospt.2011.3437.
18. Hamaoui A, Do Mc, Poupard L, Bouisset S. Does respiration perturb body balance more in chronic low back pain subjects than in healthy subjects? *Clin Biomech*. 2002;17:548-550.

19. Hodges PW, Eriksson AE, Shirley D, Gandevia SC. Intra-abdominal pressure increases stiffness of the lumbar spine. *J Biomech*. 2005;38:1873-1880.
20. Hodges PW, Gandevia SC. Changes in intra-abdominal pressure during postural and respiratory activation of the human diaphragm. *J Appl Physiol*. 2000;89:967-976.
21. Hodges PW, Gurfinkel VS, Brumagne S, Smith TC, Cordo PC. Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. *Exp Brain Res*. 2002;144:293-302.
22. Ivanenko YP, Talis VL, Kazennikov OV. Support stability influences postural responses to muscle vibration in humans. *Eur J Neurosci.* 1999;11:647-654.
23. Janssens L, Brumagne S, McConnell AK, et al. Proprioceptive changes impair balance control in individuals with chronic obstructive pulmonary disease. *PLoS One*. 2013; 8:e57949. doi: 10.1371/journal.pone.0057949.
24. Janssens L, Brumagne S, McConnell AK, Hermans G, Troosters T, Gayan-Ramirez G. Greater diaphragm fatigability in patients with recurrent low back pain. *Respir Physiol Neurobiol*. 2013;188:119-123. doi: 10.1016/j.resp.2013.05.028.
25. Janssens L, Brumagne S, Polspoel K, Troosters T, McConnell A. The effect of inspiratory muscles fatigue on postural control in people with and without recurrent low back pain. *Spine*. 2010;35:1088-1094. doi: 10.1097/BRS.0b013e3181bee5c3.
26. Janssens L, Pijnenburg M, Claeys K, McConnell AK, Troosters T, Brumagne S. Postural strategy and back muscle oxygenation during inspiratory muscle loading. *Med Sci Sport Exerc*. 2013;45:1355-1362. doi: 10.1249/MSS.0b013e3182853d27.
27. Jensen MP, Karoly P, Braver S. The measurement of clinical pain intensity: a comparison of six methods. *Pain.* 1986;27:117-126.
28. Johanson E, Brumagne S, Janssens L, Pijnenburg M, Claeys K, Pääsuke M. The effect of acute back muscle fatigue on postural control strategy in people with and without

recurrent low back pain. *Eur Spine J*. 2011;20:2152-2159. doi: 10.1007/s00586-011-1825-3.

29. Kiers H, Brumagne S, van Dieën J, van der Wees P, Vanhees L. Ankle proprioception is not targeted by exercises on an unstable surface. *Eur J Appl Physiol.* 2012;112: 1577-1585. doi: 10.1007/s00421-011-2124-8.
30. Kokkorogiannis T. Somatic and intramuscular distribution of muscle spindles and their relation to muscular angiotypes. *J Theor Biol*. 2004;229:263-280.
31. Kolar P, Sulc J, Kyncl M, et al. Postural function of the diaphragm in persons with and without chronic low back pain. *J Orthop Sports Phys Ther.* 2012;42:352-362. doi: 10.2519/jospt.2012.3830.
32. Kori KS, Miller RP, Todd DD. Kinesiophobia: A new view of chronic pain behaviour. *Pain*. 1990;3:35-43.
33. Lackner JR, DiZio P. Vestibular, proprioceptive, and haptic contributions to spatial orientation. *Annu Rev Pshychol*. 2005;56:115-147.
34. Lamberg EM, Hagins M. The effects of low back pain on natural breath control during a lowering task. *Eur J Appl Physiol.* 2012;112:3519-3524. doi: 10.1007/s00421-012-2328-6.
35. Massery M,, Hagins M, Stafford R, Moerchen V, Hodges PW. Effect of airway control by glottal structures on postural stability. *J Appl Physiol*. 2013;115:483-490. doi: 10.1152/japplphysiol.01226.2012.
36. Mathiowetz V, Kashman N, Volland G, Weber K, Dowe M, Rogers S. Grip and pinch strength: normative data for adults. *Arch Phys Med Rehabil*. 1985;66:69-74.
37. McConnell AK, Griffiths LA. Acute cardiorespiratory responses to inspiratory pressure threshold loading. *Med Sci Sports Exerc*. 2010;42:1696-1703. doi: 10.1249/MSS.0b013e3181d435cf.

38. McConnell AK, Romer LM. Respiratory muscle training in healthy humans: resolving the controversy. *Int J Sports Med*. 2004;25:284-293.

39. McLaughlin L. Breathing evaluation and retraining in manual therapy. *J Bodyw Mov Ther*. 2009;13:276-282. doi: 10.1016/j.jbmt.2009.01.005.

40. Mehling WE, Hamel KA, Acree M, Byl N, Hecht FM. Randomized, controlled trial of breath therapy for patients with chronic low-back pain. *Altern Ther Health Med*. 2005; 11:44-52.

41. Mok NW, Brauer SG, Hodges PW. Changes in lumbar movement in people with low back pain are related to compromised balance. *Spine.* 2011;36:E45-52. doi: 10.1097/BRS.0b013e3181dfce83.

42. Obayashi H, Urabe Y, Yamanaka Y, Okuma R. Effects of respiratory-muscle exercise on spinal curvature. *J Sport Rehabil.* 2012;21:63-68.

43. Ostelo RW, Deyo RA, Stratford P, et al. Interpreting change scores for pain and functional status in low back pain: towards international consensus regarding minimal important change. *Spine*. 2008;33:90-94. doi: 10.1097/BRS.0b013e31815e3a10.

44. Reeves NP, Everding VQ, Cholewicki J, Morrisette DC. The effects of trunk stiffness on postural control during unstable seated balance. *Exp Brain Res.* 2006;174:694-700.

45. Rochester DF, Arora NS. Respiratory muscle failure. *Med Clin North Am.* 1983;67: 573-597.

46. Roll JP, Vedel JP. Kinaesthetic role of muscle afferents in man, studied by tendon vibration and microneurography. *Exp Brain Res*. 1982;47:177-190.

47. Romer LM, Lovering AT, Haverkamp HC, Pegelow DF, Dempsey JA. Effect of inspiratory muscle work on peripheral fatigue of locomotor muscles in healthy humans. *J Physiol*. 2006;571:425-439.

48. Romer LM, McConnell AK. Specificity and reversibility of inspiratory muscle training. *Med Sci Sports Exerc.* 2003;35:237-244.
49. Ruhe A, Fejer R, Walker B. Center of pressure excursion as a measure of balance performance in patients with non-specific low back pain compared to healthy controls: a systematic review of the literature. *Eur Spine J.* 2011;20:358-368.
50. Smith MD, Russell A, Hodges PW. The Relationship Between Incontinence, Breathing Disorders, Gastrointestinal Symptoms, and Back Pain in Women: A Longitudinal Cohort Study. *Clin J Pain*. 2013 Mar 12. [Epub ahead of print]
51. Synnot A, Williams M. Low back pain in individuals with chronic airflow limitation and their partners--a preliminary prevalence study. *Physiother Res Int*. 2002;7:215-227.
52. Waddell G, Newton M, Henderson I, Somerville D, Main CJ. A fear-avoidance beliefs questionnaire (FABQ) and the role of fear-avoidance beliefs in chronic low back pain and disability. *Pain*. 1993;52:157-168.
53. Witt JD, Guenette JA, Rupert JL, McKenzie DC, Sheel AW. Inspiratory muscle training attenuates the human respiratory muscle metaboreflex. *J Physiol*. 2007; 584:1019-1028.

TABLE 1 Participants characteristics

	IMT group (n= 14)	Control group (n= 14)	p-value
Age (yrs)	32 ± 9	33 ± 7	0.770
Height (cm)	172 ± 8	171 ± 8	0.824
Weight (kg)	73 ± 11	68 ± 10	0.189
BMI (kg/m^2)	25 ± 4	23 ± 3	0.261
ODI-2	19 ± 9	20 ± 8	0.665
NRS back pain	5 ± 2	5 ± 2	0.785
Duration back pain (yrs)	7 ± 7	7 ± 5	0.988
FEV_1 (% pred)	113 ± 11	110 ± 11	0.473
FVC (% pred)	116 ± 6	116 ± 8	0.945
PAI	8.16 ± 1.17	8.06 ± 1.76	0.866
HGF (kg)	44 ± 14	38 ± 13	0.253

Data are presented as mean ± standard deviation. BMI: Body Mass Index; ODI-2: Oswestry Disability Index version 2 (0-100); NRS: Numerical Rating Scale for pain (0-10); FVC: Forced Vital Capacity; FEV_1: Forced Expiratory Volume in 1 second; % pred: percentage predicted; PAI: Physical Activity Index (maximum score = 15); HGF: hand grip force; IMT: inspiratory muscle training;

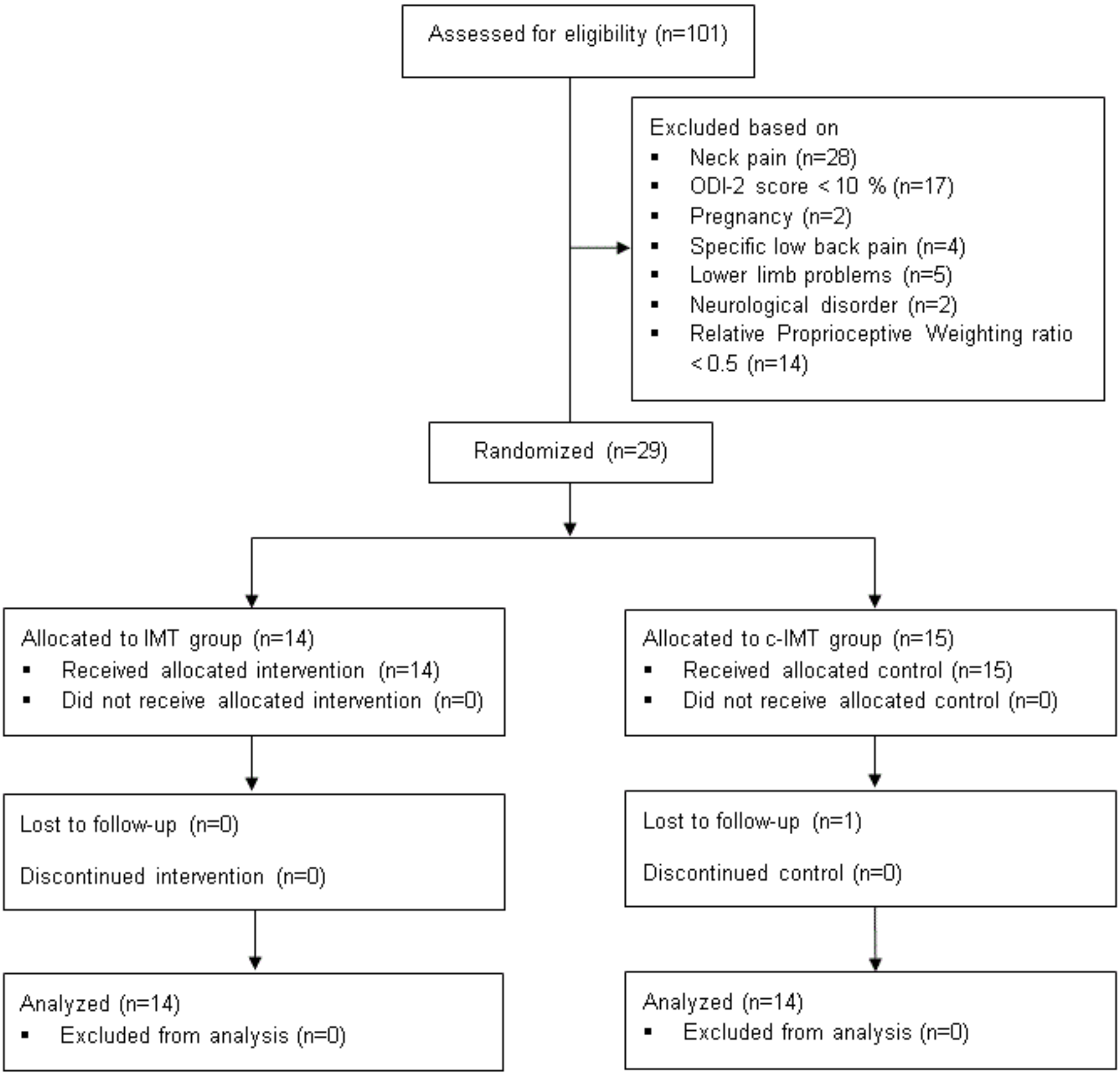

FIGURE 1 Flowchart of the study

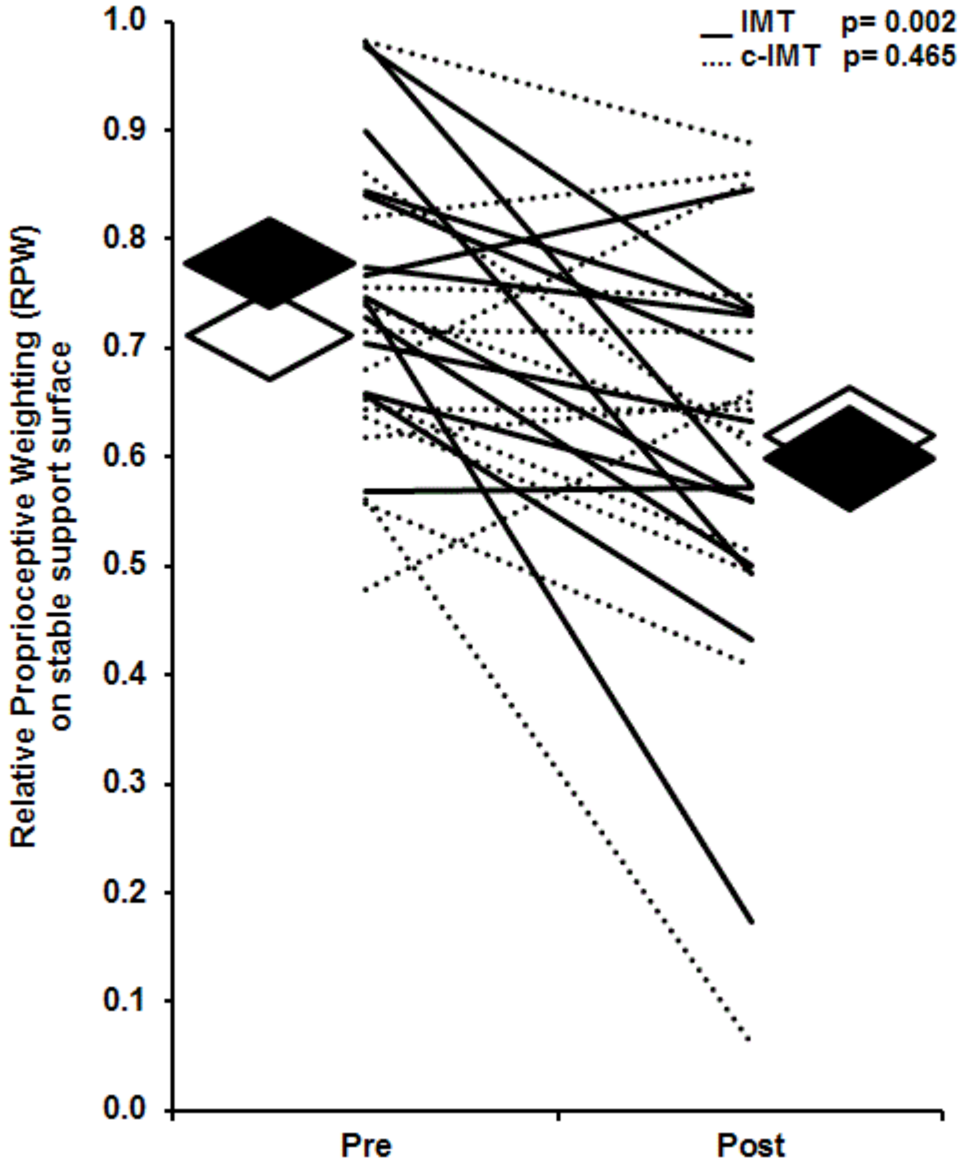

FIGURE 2 Individual and mean ± SD Relative Proprioceptive Weighting (RPW) ratios while standing on stable support surface, measured pre and post inspiratory muscle training (IMT) at a resistance of 60% (IMT group) and 10% (c-IMT group) of their maximal inspiratory pressure (PImax). Higher values correspond to higher reliance on ankle muscle proprioception; lower values correspond to higher reliance on back muscle proprioception.

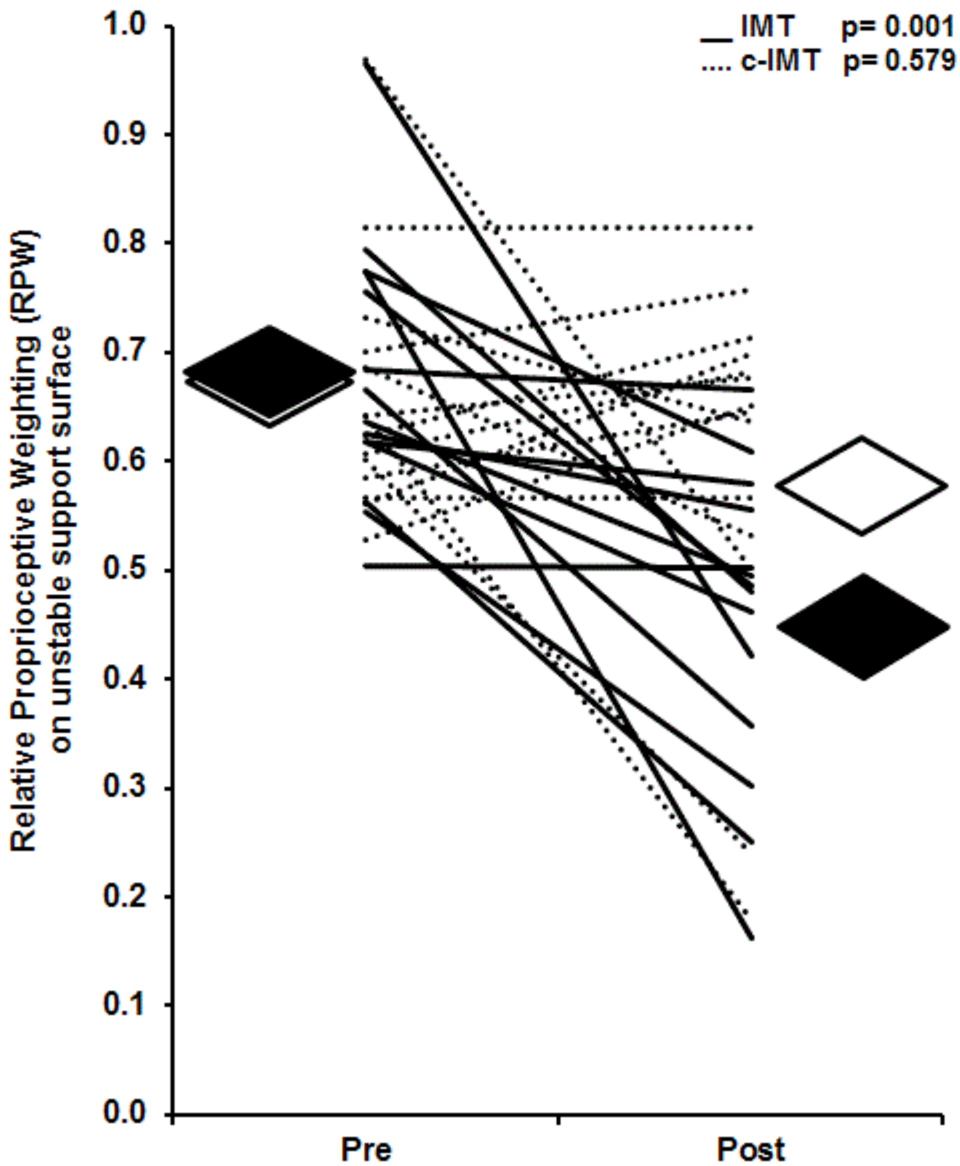

FIGURE 3 Individual and mean ± SD Relative Proprioceptive Weighting (RPW) ratios while standing on unstable support surface, measured pre and post inspiratory muscle training (IMT) at a resistance of 60% (IMT group) and 10% (c-IMT group) of their maximal inspiratory pressure (PImax). Higher values correspond to higher reliance on ankle muscle proprioception; lower values correspond to higher reliance on back muscle proprioception.

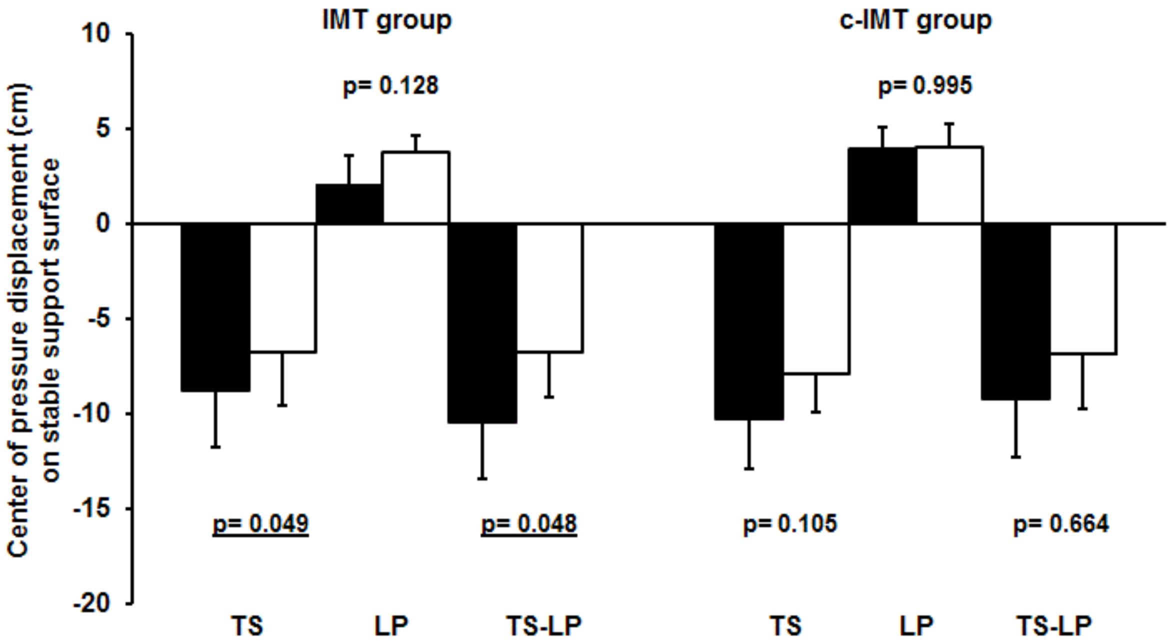

FIGURE 4 Center of pressure displacement (mean ± SD) while standing on stable support surface during vibration on (1) triceps surae (TS) muscles, (2) lumbar paraspinal (LP) muscles, and (3) TS and LP muscles simultaneously, measured before (black) and after (white) inspiratory muscle training (IMT) at a resistance of 60% (IMT group) and 10% (c-IMT group) of their maximal inspiratory pressure (PImax). Positive values indicate an anterior body sway, negative values indicate a posterior body sway.

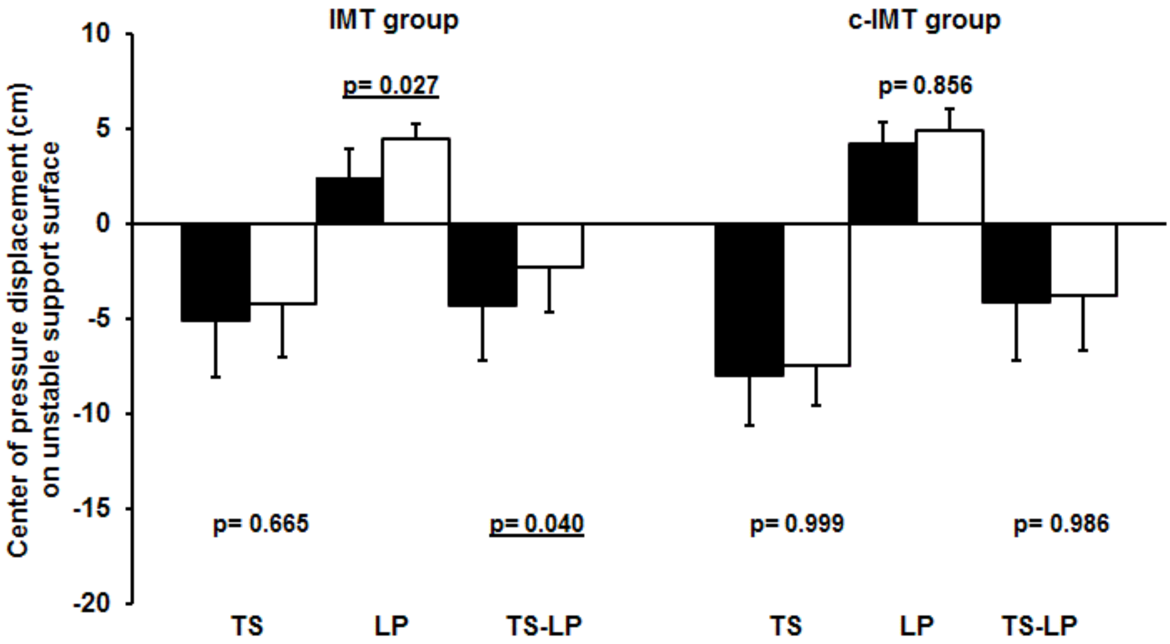

FIGURE 5 Center of pressure displacement (mean ± SD) while standing on unstable support surface during vibration on (1) triceps surae (TS) muscles, (2) lumbar paraspinal (LP) muscles, and (3) TS and LP muscles simultaneously, measured pre (black) and post (white) inspiratory muscle training (IMT) at a resistance of 60% (IMT group) and 10% (c-IMT group) of their maximal inspiratory pressure (PImax). Positive values indicate an anterior body sway, negative values indicate a posterior body sway.