# Inspiratory Muscle Training Affects Proprioceptive Use and Low Back Pain

LOTTE JANSSENS[1], ALISON K. MCCONNELL[2], MADELON PIJNENBURG[1], KURT CLAEYS[1,3], NINA GOOSSENS[1], ROELAND LYSENS[4], THIERRY TROOSTERS[1,5], and SIMON BRUMAGNE[1]

*[1]KU Leuven Department of Rehabilitation Sciences, University of Leuven, Leuven, BELGIUM; [2]Centre for Sports Medicine and Human Performance, Brunel University, Uxbridge, UNITED KINGDOM; [3]KU Leuven Department of Rehabilitation Sciences, University of Leuven, Kulab, Bruges, BELGIUM; [4]Department of Physical Medicine and Rehabilitation, University Hospitals Leuven, Leuven, BELGIUM; [5]Respiratory Rehabilitation and Respiratory Division, University Hospitals Leuven, Leuven, BELGIUM*

## ABSTRACT

JANSSENS, L., A. K. MCCONNELL, M. PIJNENBURG, K. CLAEYS, N. GOOSSENS, R. LYSENS, T. TROOSTERS, and S. BRUMAGNE. Inspiratory Muscle Training Affects Proprioceptive Use and Low Back Pain. *Med. Sci. Sports Exerc.*, Vol. 47, No. 1, pp. 12–19, 2015. **Purpose**: We have shown that individuals with recurrent nonspecific low back pain (LBP) and healthy individuals breathing against an inspiratory load decrease their reliance on back proprioceptive signals in upright standing. Because individuals with LBP show greater susceptibility to diaphragm fatigue, it is reasonable to hypothesize that LBP, diaphragm dysfunction, and proprioceptive use may be interrelated. The purpose of this study was to investigate whether inspiratory muscle training (IMT) affects proprioceptive use during postural control in individuals with LBP. **Methods**: Twenty-eight individuals with LBP were assigned randomly into a high-intensity IMT group (high IMT) and low-intensity IMT group (low IMT). The use of proprioception in upright standing was evaluated by measuring center of pressure displacement during local muscle vibration (ankle, back, and ankle–back). Secondary outcomes were inspiratory muscle strength, severity of LBP, and disability. **Results**: After high IMT, individuals showed smaller responses to ankle muscle vibration, larger responses to back muscle vibration, higher inspiratory muscle strength, and reduced LBP severity ($P < 0.05$). These changes were not seen after low IMT ($P > 0.05$). No changes in disability were observed in either group ($P > 0.05$). **Conclusions**: After 8 wk of high IMT, individuals with LBP showed an increased reliance on back proprioceptive signals during postural control and improved inspiratory muscle strength and severity of LBP, not seen after low IMT. Hence, IMT may facilitate the proprioceptive involvement of the trunk in postural control in individuals with LBP and thus might be a useful rehabilitation tool for these patients. **Key Words:** POSTURAL BALANCE, SENSORY REWEIGHTING, METABOREFLEX, DIAPHRAGM

Low back pain (LBP) is a well-known health problem in the Western society and now seems to be extending worldwide (3). Various studies have identified impaired postural control in individuals with LBP, although it depends on the postural demands (33). The human upright standing requires proprioceptive input at the level of the ankles, knees, hips, and spine (1). 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 (8,10,21). Previous studies showed reduced back proprioceptive acuity in individuals with LBP (42), although others have questioned this (30). When back proprioceptive signals lose reliability because of LBP, individuals rely on ankle proprioception, irrespective of the postural demands (8). In other words, the ability of individuals with LBP to adapt their proprioceptive use to the changing postural demands is impaired because they show a dominant ankle proprioceptive use rather than a flexible reliance on more proximal proprioceptive input (10).

Similar to people with LBP, this dominant ankle proprioceptive use is also observed in individuals with chronic obstructive pulmonary disease (COPD), particularly those with compromised inspiratory muscle function, and in healthy individuals breathing against inspiratory loads (22,25). Although the mechanisms may differ between these populations, the proprioceptive dominance possibly contributes to deficits at proximal level whether in terms of reduced spinal muscle control (8,10) or joint mobility (22). These findings suggest an important role for inspiratory muscle function in LBP and proprioceptive control, but the underlying mechanisms remain poorly understood.

The human diaphragm is the principal inspiratory muscle, and it plays an essential role in controlling the spine during postural control (19). It seems reasonable that an increased

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Address for correspondence: Lotte Janssens, Ph.D., KU Leuven Department of Rehabilitation Sciences, University of Leuven, Tervuursevest 101 Box 1501, 3001 Leuven, Belgium; E-mail: Lotte.Janssens@faber.kuleuven.be.
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demand for inspiratory function of the diaphragm might inhibit its contribution to trunk stabilization during challenges to postural balance. Healthy individuals seem to be capable of compensating efficiently for modest increases in inspiratory demand by active multisegmental control (20). Nevertheless, this compensation seems less effective in individuals with LBP, resulting in impaired balance control (16). Furthermore, and as mentioned previously, specific loading of the inspiratory muscles impairs postural control by decreasing lumbar proprioceptive sensitivity, forcing dominant ankle proprioceptive use (24). 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 (25). Furthermore, individuals with LBP show a greater magnitude and a greater prevalence of diaphragm fatigue compared with healthy controls (23). Although it is tempting to speculate on a causal relation between inspiratory muscle function and proprioceptive use during 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 (40), functional balance in those with heart failure (6), and inspiratory muscle strength and endurance in those with COPD (14). Furthermore, IMT improves blood flow to resting and exercising limb muscles in patients with COPD (5). However, to the authors' knowledge, no studies exist on the effect of IMT on individuals with LBP.

Therefore, the primary objective of this study was to investigate the effect of IMT on proprioceptive use during postural control in individuals with recurrent nonspecific LBP. A secondary aim was to study the effect of IMT on inspiratory muscle strength, severity of LBP, and disability. We hypothesize that IMT would enable individuals with LBP to increase reliance on back proprioceptive input rather than dominantly use ankle proprioception during postural control. Secondary, we speculate that this may improve LBP symptoms.

## METHODS

### Participants

Twenty-eight individuals (18 women and 10 men) with a history of nonspecific recurrent LBP participated voluntarily in this study. Participants were included in the study if they had at least three episodes of nonspecific LBP in the last 6 months and reported a score of at least 10% on the Oswestry Disability Index, version 2 (adapted Dutch version) (ODI-2) (13). The participants did not have a more specific medical diagnosis than nonspecific 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, lower limb problems, neck pain, or 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 relative proprioceptive use during postural control (relative proprioceptive weighting (RPW) 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 1 s ($FEV_1$), forced vital capacity (FVC), and $FEV_1$/FVC (17). A physical activity questionnaire was completed (2). Isometric hand grip force was measured using a hydraulic hand grip dynamometer (Jamar Preston, Jackson, MI).

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.clinicaltrials.gov (NCT01505582).

### Study Design

The study participants were assigned randomly to an intervention group (high-intensity IMT, "high-IMT group") and control group (low-intensity IMT, "low-IMT group"). The primary objective of this study was to investigate the effect of IMT on proprioceptive use during postural control. Secondary outcomes were inspiratory muscle strength, severity of LBP, and LBP-related disability, fear, and beliefs. Outcome measures were evaluated at baseline and after 8 wk of intervention. Figure 1 displays the flowchart of the study. On the basis of previous studies (8,10,22,24,25), a sample size of 14 per group provides adequate power (0.80, two-tailed, $\alpha = 0.05$) to detect a clinically relevant difference in center of pressure (CoP) displacement on unstable support surface (primary outcome measure with smallest effect size).

### Materials

**Proprioceptive use during postural control.** Postural sway characteristics were assessed by anterior–posterior CoP displacement using a six-channel force plate (Bertec, Columbus, OH), which recorded the moment of force around

TABLE 1. Participants characteristics.

| | High-IMT Group (*n* = 14) | Low-IMT Group (*n* = 14) | *P* Value |
|---|---|---|---|
| Age (yr) | 32 ± 9 | 33 ± 7 | 0.770 |
| Height (cm) | 172 ± 8 | 171 ± 8 | 0.824 |
| Weight (kg) | 73 ± 11 | 68 ± 10 | 0.189 |
| BMI ($kg \cdot m^{-2}$) | 25 ± 4 | 23 ± 3 | 0.261 |
| ODI-2 | 19 ± 9 | 20 ± 8 | 0.665 |
| NRS back pain | 5 ± 2 | 5 ± 2 | 0.785 |
| Duration of back pain (yr) | 7 ± 7 | 7 ± 5 | 0.988 |
| $FEV_1$ (% pred) | 113 ± 11 | 110 ± 11 | 0.473 |
| FVC (% pred) | 116 ± 6 | 116 ± 8 | 0.945 |
| $FEV_1$/FVC (% pred) | 84 ± 6 | 80 ± 5 | 0.102 |
| PAI | 8.16 ± 1.17 | 8.06 ± 1.76 | 0.866 |
| HGF (kg) | 44 ± 14 | 38 ± 13 | 0.253 |

Data are presented as mean ± SD.
% pred, percentage predicted; BMI, body mass index; HGF, hand grip force; PAI, Physical Activity Index (maximum score, 15).

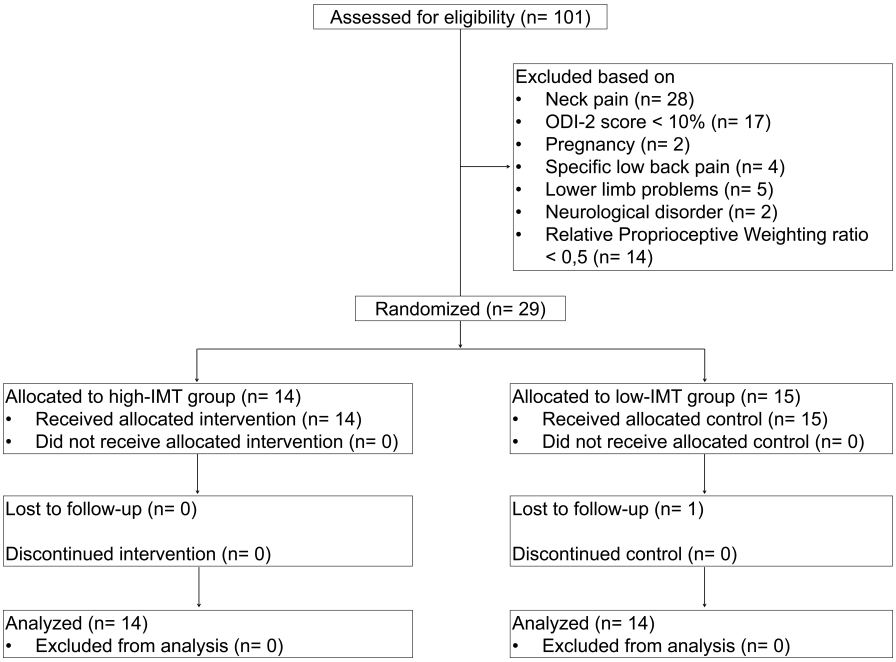

**FIGURE 1—Flowchart of the study.**

the frontal axis and the vertical ground reaction force. Force plate signals were sampled at 500 Hz using a Micro1401 data acquisition system using Spike2 software (Cambridge Electronic Design, United Kingdom), and a fourth-order low-pass Butterworth filter was applied with a cutoff 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 (11,45), which can induce both motor (i.e., tonic vibration reflex and/or antagonistic vibration reflex) and perceptual effects (i.e., an illusion of muscle lengthening) (11). When the CNS 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. During lumbar paraspinal (LP) muscle vibration, a forward postural body sway is expected because in this condition, the brain considers the pelvis as a "mobile" body part compared with the "stationary" trunk (10). These directional body sways have been shown by previous studies (8,10,22,24,25). 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 vs LP) during postural control (22,25). During simultaneous TS–LP muscle vibration, a dominant backward body sway suggests a dominant use of ankle proprioception whereas a forward body sway indicates a dominant use of back proprioception. Straps were used to hold the muscle vibrators (Maxon Motor, Switzerland). The straps were applied bilaterally over the muscle bellies of the TS and LP muscles by the same investigator for all trials, and vibration was offered at high frequency and low amplitude (60 Hz and 0.5 mm) (45).

To evaluate the use of proprioception during 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 a stable support surface (force plate) and 2) upright standing on an unstable support surface (Airex balance pad; 49.5 cm long × 40.5 cm wide × 6.5 cm high). On the unstable support surface, ankle proprioceptive signals are less reliable (21). When visual input is restricted, this enforces reliance upon proximal proprioceptive signals (i.e., proprioceptive weighting), thereby highlighting proprioceptive deficits. 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 nontransparent 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). Each trial lasted for 60 s, with muscle vibration starting at 15 s and lasting 15 s.

**Severity of LBP, LBP-related disability, and LBP-related fear and beliefs.** Severity of LBP was scored by the numerical rating scale (NRS) from 0 ("no pain") to 10 ("worst pain"), and LBP-related disability was evaluated using the ODI-2 (13). The Fear Avoidance Beliefs Questionnaire was completed to identify how work and physical activity affect LBP (49). The Tampa Scale for Kinesiophobia was completed to identify the participants' fear of (re)injury after movements or activities (29).

**Inspiratory muscle strength.** Inspiratory muscle strength was evaluated by measuring maximal inspiratory pressure (PImax) using an electronic pressure transducer (MicroRPM; Micromedical Ltd., Kent, United Kingdom). 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 5% difference between the best and second best test. The highest pressure sustained over 1 s was defined as PImax and was compared with reference values (44).

**IMT.** The participants completed an IMT training program over a period of 8 wk, known as an effective training duration (46). They were instructed to breathe through a mouthpiece (POWERbreathe Medic; HaB International Ltd., Warwickshire, United Kingdom) with their nose occluded while standing upright (35). With every inspiration, resistance was added to the inspiratory valve, forcing the individuals to generate a negative pressure of 60% of their PImax ("high-IMT group") or 10% of PImax ("low-IMT group"), respectively, a protocol also studied in patients with COPD (9). The specific intensity of 60% PImax was justified as "effective" IMT training on the basis of its optimal responses in terms of blood flow and pressure generation (34,47). The participants were instructed to perform 30 breaths, twice daily, 7 days per week, with a breathing frequency of 15 breaths per minute and a duty cycle of 0.5. The participants in 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 (if relevant) in both groups.

### Data Reduction and Analysis

Force plate data were calculated using Spike2 software and Microsoft Excel. To evaluate proprioceptive use during 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, an RPW ratio 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. An RPW score equal to one corresponds to 100% reliance on TS muscle input in upright standing, whereas a score equal to zero corresponds to 100% reliance on LP muscle input (8,10,22,24,25). Participants were included in the study if they showed an RPW score >0.5 (dominant ankle proprioceptive use) when standing on an unstable support surface. According to Kiers et al. (26), the calculations of CoP displacements during muscle vibration and the calculation of RPW are the most reliable indicators of the response to muscle vibration.

A one-way ANOVA was used to examine differences in baseline characteristics between the two groups (Table 1). A two-way ANOVA was used to examine differences between subjects and within subjects with factors of intervention (high IMT vs low IMT) and time (before vs after); results are reported with $F$ and $P$ values. A *post hoc* test (Tukey) was performed to further analyze these results in detail; results are reported with $P$ values. Correlations were calculated by the Pearson test. The statistical analysis was performed with Statistica 9.0 (Statsoft). The level of significance was set at $P < 0.05$.

## RESULTS

At baseline, no differences in the participants' characteristics (Table 1) and primary and secondary outcome measures were found between both groups ($P > 0.05$).

### Inspiratory Muscle Strength

After the intervention, inspiratory muscle strength (PImax) was significantly different between both groups ($F_{1,26} = 19.33$, $P = 0.001$). *Post hoc* results showed that PImax increased significantly in the high-IMT group after the intervention (94 ± 30 vs 136 ± 34 cm $H_2O$) (Δ 42 cm $H_2O$, $P = 0.001$). In contrast, low IMT did not influence PImax (92 ± 27 vs 94 ± 26 cm $H_2O$) (Δ 2 cm $H_2O$, $P = 0.989$).

### Proprioceptive Use during Postural Control

**RPW during standing on a stable and unstable support surface.** On a stable support surface, when comparing the relative use of ankle *versus* back muscle proprioceptive input (RPW, 0–1), there was no difference between groups after the intervention, although a trend was present ($F_{1,26} = 3.29$, $P = 0.081$). However, according to the *post hoc* test, the high-IMT group exhibited a decrease in RPW, suggesting a more dominant back over ankle proprioceptive use compared with that before IMT (Δ 0.19, $P = 0.002$). No such difference was apparent in the low-IMT group (Δ 0.09, $P = 0.465$).

When standing on an unstable support surface, a significant difference in RPW between groups was observed after the intervention ($F_{1,26} = 4.54$, $P = 0.047$). The *post hoc* test revealed that the IMT group switched to a more dominant back over ankle proprioceptive use, as shown by the decreased RPW values after high IMT compared with baseline (Δ 0.23, $P = 0.001$). No such difference was apparent in the low-IMT group (Δ 0.10, $P = 0.579$). Figures 2 and 3 display the individual RPW ratios before and after intervention on a stable and unstable support surface, respectively.

No significant correlation was found between the change in RPW on a stable support surface and the change in PImax

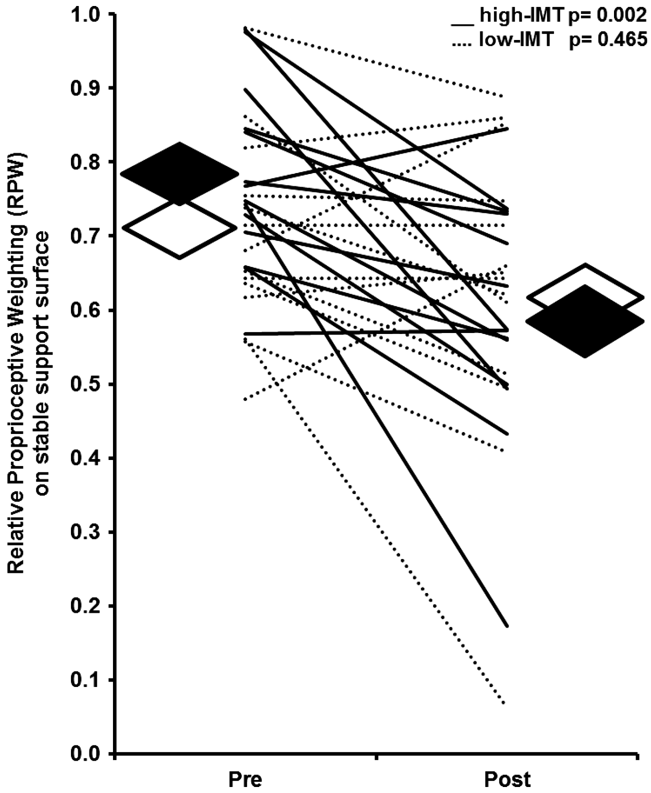

**FIGURE 2—Individual and mean ± SD RPW ratios while standing on a stable support surface, measured before and after high-intensity IMT (high-IMT group) and low-intensity IMT (low-IMT group), respectively. Higher values correspond to higher reliance on ankle muscle proprioception; lower values correspond to higher reliance on back muscle proprioception. *P* values refer to *post hoc* test results.**

after 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 that an increment of PImax was associated with a more facilitated back proprioceptive use during postural control.

**Standing on a stable support surface.** After the intervention and on a stable support surface, no differences in postural responses on muscle vibration were observed between the groups ($F_{1,26} = 0.039$, $P = 0.846$ (TS vibration); $F_{1,26} = 2.10$, $P = 0.146$ (LP vibration); $F_{1,26} = 1.24$, $P = 0.278$ (TS–LP vibration)). However, the *post hoc* test revealed that the high-IMT group decreased their reliance on ankle proprioceptive signals after the intervention, as evidenced by a significant reduction in posterior body sway during TS muscle vibration (Δ 2.6 cm, $P = 0.049$). This is corroborated by the finding that the high-IMT group showed a significantly smaller posterior body sway during simultaneous TS and LP muscle vibration compared with that before IMT (Δ 3.8 cm, $P = 0.048$). The high-IMT group did not show a change in reliance on back proprioceptive signals after IMT (Δ 1.7 cm, $P = 0.128$). In contrast, in the low-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, $P = 0.644$) after the intervention. Figure 4 displays the absolute CoP displacements during muscle vibration while standing on a 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 ($r = 0.31$, $P = 0.145$).

**Standing on an unstable support surface.** After the intervention and on an unstable support surface, no differences in postural responses were observed between the groups during TS vibration ($F_{1,26} = 0.78$, $P = 0.384$) and LP vibration ($F_{1,26} = 2.49$, $P = 0.126$); however, during TS–LP vibration, a significant difference in postural sway was found ($F_{1,26} = 5.10$, $P = 0.034$). The *post hoc* test revealed that in the high-IMT group, LP vibration elicited a significantly larger anterior body sway after the intervention (Δ 2 cm, $P = 0.027$), indicative of an increased use of back proprioceptive signals during postural control. Furthermore, the high-IMT group also decreased their reliance on ankle proprioceptive signals, as evidenced by a significantly smaller posterior body sway during simultaneous TS–LP vibration after the intervention (Δ 2.0 cm, $P = 0.040$). This difference was not present during TS vibration after IMT (Δ 0.9 cm, $P = 0.665$). In contrast, in the low-IMT group, there were no changes in responses to TS (Δ 0.5 cm, $P = 0.999$), LP

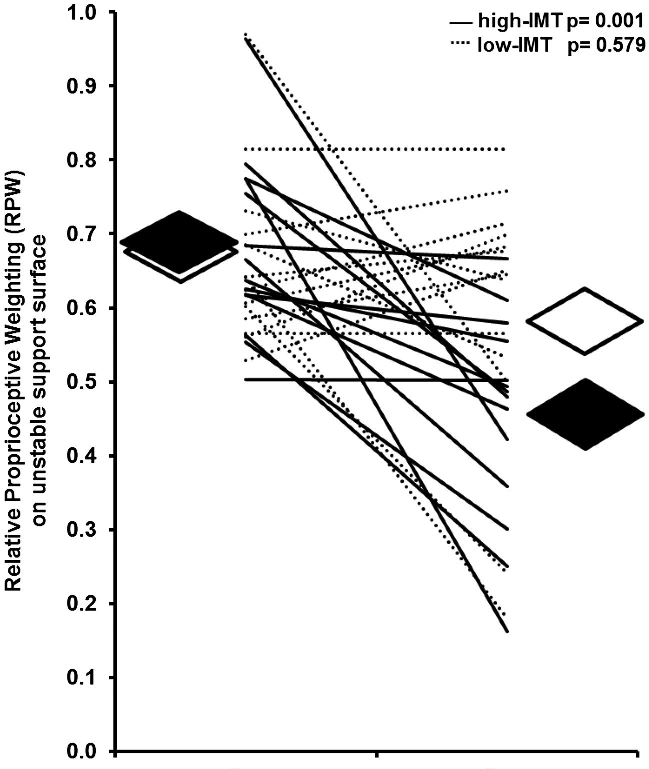

**FIGURE 3—Individual and mean ± SD RPW ratios while standing on an unstable support surface, measured before and after high-intensity IMT (high-IMT group) and low-intensity IMT (low-IMT group), respectively. Higher values correspond to higher reliance on ankle muscle proprioception; lower values correspond to higher reliance on back muscle proprioception. *P* values refer to *post hoc* test results.**

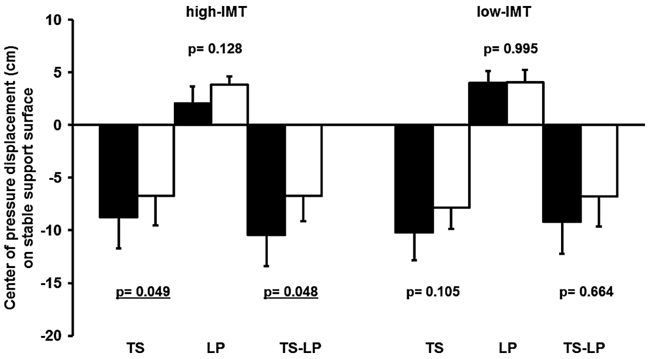

**FIGURE 4—CoP displacement (mean ± SD) while standing on a stable support surface during vibration on 1) TS muscles, 2) LP muscles, and 3) TS and LP muscles simultaneously, measured before (*black*) and after (*white*) high-intensity IMT (high-IMT group) and low-intensity IMT (low-IMT group), respectively. Positive values indicate an anterior body sway; negative values indicate a posterior body sway. *P* values refer to *post hoc* test results.**

(Δ 0.7 cm, $P$ = 0.856), and TS–LP (Δ 0.4 cm, $P$ = 0.986) vibration after the intervention. Figure 5 displays the absolute CoP displacements during muscle vibration while standing on an 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 that an increment of PImax values was associated with a more facilitated back proprioceptive use during postural control.

### Severity of LBP, LBP-Related Disability, and LBP-Related Fear and Beliefs

After the intervention, LBP severity (NRS score, 1–10) was significantly lower in the high-IMT group compared with that in the low-IMT group ($F_{1,26}$ = 7.14, $P$ = 0.013). Severity of LBP decreased significantly in the high-IMT group (5 ± 2 vs 2 ± 2) (Δ 3, $P$ = 0.001), whereas no change was observed in the low-IMT group (5 ± 2 vs 5 ± 2) (Δ 0, $P$ = 0.864). Disability associated with LBP did not differ between groups after the intervention ($F_{1,26}$ = 0.73, $P$ = 0.402) and was not significantly different before and after high-IMT (19% ± 9% vs 13% ± 10%) (Δ 6%, $P$ = 0.099) and before and after low IMT (20% ± 8% vs 17% ± 7%) (Δ 3%, $P$ = 0.628). Scores on the Fear Avoidance Beliefs Questionnaire did not differ between groups after the intervention ($F_{1,26}$ = 0.95, $P$ = 0.343) and were not significantly different before and after high IMT (28 ± 5 vs 24 ± 5) (Δ 4, $P$ = 0.073) and before and after low IMT (27 ± 9 vs 26 ± 13) (Δ 1, $P$ = 0.662). Scores on the Tampa Scale for Kinesiophobia were not different between groups after the intervention ($F_{1,26}$ = 0.01, $P$ = 1.000) and were not significantly different before and after high IMT (39 ± 5 vs 36 ± 6) (Δ 3, $P$ = 0.735) and before and after low IMT (35 ± 6 vs 36 ± 6) (Δ 1, $P$ = 0.735).

## DISCUSSION

The results of this study suggest that high IMT (i.e., 60% PImax) affects proprioceptive use to a greater extent than low IMT (i.e., 10% PImax) when standing on an unstable support surface (significant interaction effect). As a consistent within-group effect was observed only in the high-IMT group, the study suggests that individuals with recurrent nonspecific LBP decrease their reliance on ankle proprioceptive input and increase their reliance on back proprioceptive input during postural control after 8 wk of high IMT. Moreover, high IMT improved inspiratory muscle strength and decreased the severity of LBP; the decrease in NRS is clinically important, according to international consensus (41). These changes were not present in individuals with LBP who underwent low IMT. These findings indicate that improving inspiratory muscle function enhances proprioceptive weighting, supporting the premise that inspiratory muscle dysfunction may exacerbate poor proprioceptive use in individuals with LBP.

IMT may contribute to an enhancement of proprioceptive use in individuals with LBP via several potential mechanisms. First, previous research has demonstrated that an increase in intra-abdominal pressure provides "stiffness" and, thus, control of the lumbar spine, which is needed to unload the spine during balance and loading tasks (18). The diaphragm has been shown to contribute to postural control by increasing intra-abdominal pressure and 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 proprioceptive use (i.e., more reliance on back proprioception) during 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 (32). This may be facilitated by IMT because it is known to induce changes in pressure generation (improve stiffness), on the one hand (46); and on the other hand, IMT may also reduce

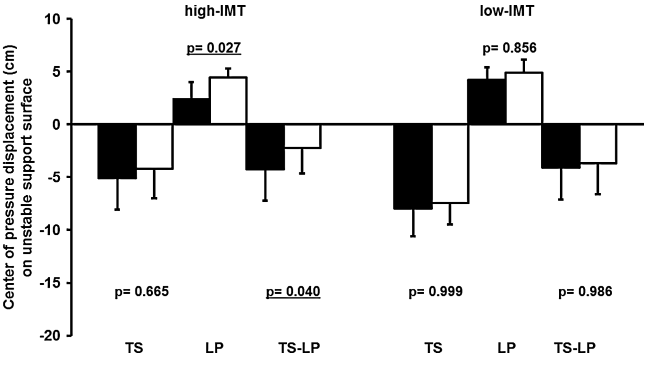

**FIGURE 5—CoP displacement (mean ± SD) while standing on an unstable support surface during vibration on 1) TS muscles, 2) LP muscles, and 3) TS and LP muscles simultaneously, measured before (*black*) and after (*white*) high-intensity IMT (high-IMT group) and low-intensity IMT (low-IMT group), respectively. Positive values indicate an anterior body sway; negative values indicate a posterior body sway. *P* values refer to *post hoc* test results.**

excessive expiratory/trunk muscle activity (improve flexibility), known to compromise postural control (39). As muscle spindles show a dense network of blood vessels (27) and IMT is known to improve blood flow in resting and exercising peripheral muscles (5), IMT may have favored the lumbar muscle spindle function in these individuals. Thus, IMT might enhance the trunk-stabilizing function of the diaphragm, enabling individuals to up-weight lumbar proprioceptive signals and thus induce access to a larger variety in proprioceptive use during postural control. Recent studies have identified a smaller diaphragm excursion and a higher diaphragm position in individuals with LBP (28). Furthermore, people with LBP attempt to compensate for their suboptimal diaphragm position by increasing their tidal volume during lifting and lowering tasks to provide adequate pressure support (15,31). Our data suggest that it may be possible to reverse the suboptimal proprioceptive use in patients with LBP through IMT and support a role for inspiratory muscle dysfunction in some individuals with LBP. Prospective studies must further reveal whether this association can be related to the development and recurrence of nonspecific LBP.

An additional mechanism contributing to the positive effect of IMT in individuals with LBP may be found in the modification of “pain gate control” (38). Next to stimulating inspiratory muscles, IMT also stimulates extrapulmonary muscles, joints, and skin receptors possibly involved in postural control. IMT might stimulate sensory afferents, which enhance sensing, localizing, and discriminating muscle activity and joint position, which might have previously been overwhelmed by a nociceptive input (37). This might explain why low IMT and high IMT decreased the ankle proprioceptive use, even though no effect of low IMT was observed upon PImax. Moreover, it has been shown that altered breathing itself, free from resistive loading, can change the respiratory physiology and improve tissue oxygenation consequently (36). Taken together, this might suggest that IMT favors the use of back proprioception in individuals with LBP possibly by an improved trunk-stabilizing function of the diaphragm and/or additional pain gate control mechanisms.

A top priority identified in 2013 for LBP research relates to the identification of underlying mechanisms rather than to the effect of interventional studies (12). Our study reveals a potential association between inspiratory muscle function and LBP. More specifically, the findings suggest relative overloading of the inspiratory musculature, for example, during high-intensity sports (43) or physically demanding occupations (7), as a potential but reversible contributor in proprioceptive use and LBP. These findings might help unravel why individuals with breathing problems have an increased risk of developing LBP and why individuals with LBP are also more likely to develop breathing problems (48). We believe that our data provide justification for further exploration of this phenomenon in a randomized 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 LBP and which specific individuals will benefit from it. In addition, our results justify additional three-dimensional motion and EMG analysis to unravel the accompanied posturo-kinetic strategy of a specific proprioceptive use (i.e., to study the motor output vs sensory input, to maintain posture).

## CONCLUSIONS

After 8 wk of IMT at an intensity of 60% PImax, individuals with recurrent nonspecific LBP show increased reliance on back proprioceptive signals during postural control, show an increase in inspiratory muscle strength, and report a decrease in LBP severity. Back proprioceptive use might be improved after IMT by enhancing the trunk-stabilizing function of the diaphragm and/or by modifying pain gate control. These changes may enable individuals to reweight proprioceptive signals and to shift to a more optimal proprioceptive use adapted to the postural demands. The results of this study provide evidence that the proprioceptive deficits observed in individuals with LBP, potentially due to relative overloading of the inspiratory musculature, can be reversed by IMT.

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