The automatic activity of abdominal muscles during stable and unstable standing postural tasks in older adults with and without low back pain- A cross-sectional study

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Abstract

Background The postural control and abdominal muscles' automatic activity were found to be impaired in subjects with low back pain (LBP) during static activities. However, the studies are predominantly conducted on younger adults and a limited number of studies have evaluated abdominal muscles' automatic activity during dynamic standing activities in subjects with LBP. The present study investigated the automatic activity of abdominal muscles during stable and unstable standing postural tasks in older adults with and without LBP.

Methods Twenty subjects with and 20 subjects without LBP were included. The thickness of the transversus abdominis (TrA), internal oblique (IO), and external oblique (EO) muscles was measured during rest (in supine), static, and dynamic standing postural tasks. To estimate automatic muscle activity, each muscle's thickness during a standing task was normalized to its thickness during the rest. Standing postural tasks were performed using the Biodex Balance System.

Results The mixed-model analysis of variance revealed that task dynamicity significantly affected thickness change only in the TrA muscle ($P = 0.02$), but the main effect for the group and the interaction were not significantly different ($P > 0.05$). There were no significant main effects of the group, task dynamicity, or their interaction for the IO and EO muscles ($P > 0.05$). During dynamic standing, only the TrA muscle in the control group showed greater thickness changes than during the static standing task ($P < 0.05$).

Conclusions Standing on a dynamic level increased the automatic activity of the TrA muscle in participants without LBP compared to standing on a static level. Further research is required to investigate the effects of TrA muscle training during standing on dynamic surfaces for the treatment of older adults with LBP.

Keywords Low back pain, Ultrasonography, Standing postural task, Automatic activity, Abdominal muscles, Postural control

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Kalantari *et al. BMC Geriatrics*   (2024) 24:308

Page 2 of 8

Introduction

Over the last decade, human lifespans have increased significantly, and by 2050, the world population over 60 years old is expected to triple [1, 2]. A rapidly aging population increases the likelihood of non-communicable diseases such as musculoskeletal disorders. The prevalence of musculoskeletal disorders among older adults ranges from 65 to 85% [1, 3], with 36 to 70% suffering from low back pain (LBP) [4, 5].

Previous studies have demonstrated the importance of trunk muscles for spinal stability and their role in the prevention and rehabilitation of LBP [6, 7]. A decrease in trunk muscle efficiency increases the load on the lumbar discs and ligaments, leaving the lumbar region more susceptible to injury and instability [8]. Evidence also suggests that trunk muscles play a critical role in dynamic control of posture [7, 9]. There is a causal link between trunk muscle activity, LBP, and physical function among older adults [10, 11]. Due to these interrelationships and the desire to prevent/treat LBP in this group, trunk muscle activity assessments are needed for older adults.

Abdominal muscles' automatic activity is sustained tonic activity of these muscles that occurs during a task that loads the spine and pelvis and is considered a protective mechanism for the lumbar spine [12]. Previous studies reported different patterns of abdominal muscles' automatic activity in subjects with LBP compared to healthy individuals [13–16]. In this regard, one study reported higher automatic activity of superficial abdominal muscle (external oblique (EO)) than deep abdominal muscles (transverse abdominis (TrA), internal oblique (IO)) in subjects with LBP as compared to healthy individuals during standing tasks [15]. Some other studies compared the automatic activity of abdominal muscles between subjects with and without LBP during various tasks and reported a significant difference between groups in abdominal muscles' automatic activity [17–19].

Studies on the trunk muscles' automatic activity have been conducted predominantly on younger adults with LBP [13, 15–17]. A healthy aging process is associated with changes in muscle morphology [20]. This age-related change in muscle morphology can impact skeletal muscle activity [21], so, the generalizability of the findings on young people to older adults is questionable. Moreover, a limited number of studies have examined the automatic activity of the abdominal muscles during dynamic tasks.

Daily activities frequently involve dynamic tasks such as standing on unstable surfaces, walking, and climbing stairs that may cause pain in subjects with LBP [22]. One of the final goals of rehabilitation in subjects with LBP is controlling their dynamic posture and pain during daily standing activities. It will enable them to increase their functional capacity [19] gradually. It is unclear whether dynamic postural tasks affect abdominal muscles' automatic activity in older adults with and without LBP. An evaluation of the effects of standing on unstable surfaces on the automatic activity of superficial and deep abdominal muscles in older adults with and without LBP could provide useful clinical information. This study investigated the automatic activity of superficial and deep abdominal muscles in older adults with and without LBP during stable and unstable standing postural tasks.

Method

Study design

This was an observational, cross-sectional study with a two-factor mixed design (two groups × two postural tasks). The human ethical committee of the Iran University of Medical Sciences approved the study (IR.IUMS. REC.1400.265) and participants gave written informed consent to participate in the study. Data collection was performed between March and December 2022.

Participants

Twenty men with LBP and twenty asymptomatic subjects over 60 years old were recruited. In terms of absolute thickness, males' abdominal muscles are significantly thicker than females' [12]. This study examined only males to ensure the homogeneity of the data and better judgment about abdominal muscles thickness changes during postural tasks. Older adults with LBP were recruited from Iran University orthopedic and/or physiotherapy outpatient clinics. Older adults with a history of LBP for more than 3 months, recurrent LBP with at least two episodes that lasted two consecutive days during the last year [23], and a pain score between 0 and 30 mm (mild pain) on a Visual Analog Scale (VAS) on the testing day were included. VAS measures the intensity of pain, and patients rate pain intensity on a scale of 0 (no pain) to 100 mm (worst imaginable pain) [24].

Older adults without LBP (control group) were recruited through advertisements in the University and the local community. The inclusion criteria for the control group were no LBP in the previous year or back pain lasting more than one week in the previous year [25]. The control and LBP groups were matched based on demographic characteristics.

Exclusion criteria for both groups were: history of foot, knee, and hip disorders, pelvic or spinal surgery, congenital spinal malformation or scoliosis, degenerative neurologic disease, severe labyrinthitis; chronic cardiovascular or respiratory diseases, taking medication for pain in the week before the assessment, falls in the past year, Mini-Mental State Examination score < 21 and the Oswestry Disability Index scores between 20 and 60% (moderate to severe disability) [25].

Standing postural tasks

Static and dynamic standing postural tasks were created through the use of the Biodex Balance System (950−304 System, Japan). The Biodex Balance System provides valid and reliable measures of a participant's ability to maintain balance on stable and unstable surfaces. The platform stability ranges from 1 to 12, with 12 representing the lowest and 1 the greatest instability level [26]. Considering the age of participants and preventing them from losing balance or aggravating LBP symptoms, the bilateral stance at the static level and dynamic level of 8 was used for test postural tasks.

Ultrasonography

A Diagnostic Ultrasound Imaging (US) system (SONO-ACE R7, SAMSUNG MEDISON, Korea) set in B-mode with a bandwidth frequency of 6–9 MHz (General frequency), and a linear head transducer was used to measure the thickness of the TrA, IO, and EO muscles. A change in muscle thickness measured with US imaging during a dynamic task could indicate muscle activity [27, 28]. A professionally trained physiotherapist who was blind to the groups of subjects conducted the ultrasound examination.

For the evaluation of the resting thickness of EO, IO, and TrA muscles, subjects were positioned in a supine position (because other positions such as quiet standing, require some muscle activation) [15, 29]. The US transducer was transversely positioned across the right side of the abdominal wall over the anterior axillary line, midway between the 12th rib and the anterior superior iliac crest, allowing a clear image of all three lateral abdominal muscles (TrA, IO, and EO). The distance between the deep and superficial fascia was measured to determine muscle thickness. Analysis was based on average values from the three images [12].

The participants were asked to stand barefoot on the Biodex Balance System platform with arms crossed behind their backs. They were instructed to control their balance without holding the handrails. US transducer motion during dynamic test conditions may distort the images, thus causing errors [30]. Therefore, a transducer fixator was used during standing postural tasks to minimize motion artifacts and improve US reliability [31]. High-density foam was used to make the transducer fixator, which was mounted on an elastic belt [15, 32]. A standard US gel was used during the US assessment either with or without a transducer fixator. Each standing postural task was held enough until the examiner had a clear image of the muscle thickness at the end of expiration, usually no more than 2 min [33]. Abdominal muscles thickness was measured at rest, and while standing on a static level and level 8 of the Biodex Balance System. The measurements were taken on the right side of

the abdominal wall with a five-minute interval between trials.

The thickness of each abdominal muscle during postural tasks was expressed as a percentage of that at resting supine position (thickness during postural task/thickness at rest $\times$ 100) [34].

To determine within-day and intra-rater reliability, the ultrasound measurements in both standing postural tasks were repeated twice within a session on 19 participants (9 with LBP, 10 without LBP). The tests were performed in the physiotherapy department of the Iran University of Medical Sciences laboratory in a single session.

Data analysis

The sample size was calculated based on pilot data collected from 10 subjects in each group, using the G*Power software (version 3.1.9.4) and considering the TrA thickness while standing on an unstable surface. From a priori analysis, a power of 0.8, $\alpha = 0.05$, and an effect size of 0.46 were set. The sample size of 20 in each group was calculated.

SPSS version 24 was used for analyses. The Shapiro–Wilk test was conducted to evaluate the normality of the distribution of tested variables. In both groups, variables had a normal distribution. Relative reliability was assessed using the two-way mixed model of intra-class correlation coefficients (ICCs).

The association of resting muscle thickness with muscle thickness during standing on dynamic and static levels of the Biodex was represented by data points on scatterplots.

To assess the main effects of the dynamicity of task (2 standing postural tasks (static level, and level 8)) and group (2 health status (LBP, without LBP)), and their interaction effects on the thickness change of abdominal muscles, the 2×2 mixed-design analysis of variance (ANOVA) was used. Statistical significance was set at $P = 0.05$ and a post-hoc (Bonferroni) analysis for pairwise comparisons was used to analyze significant main effects and interactions.

Results

The demographic data are summarized in Table 1. There were no significant differences in age, height, weight, and BMI between groups ($P > 0.05$).

In general, there was excellent within-day reliability for US measurements of abdominal muscle thickness in both groups, during both standing postural tasks. The within-day ICCs ranged from 0.95 to 0.99 in LBP and 0.96 to 0.99 in without LBP groups, respectively.

Scatter plot graphs with the abdominal muscle's resting thickness in the supine position and abdominal muscles' thickness while standing on dynamic and static levels of the Biodex are presented in Fig. 1. The R square values for

Kalantari *et al. BMC Geriatrics*   (2024) 24:308

Page 4 of 8

Table 1 Demographic data of the subjects in each group (mean (SD))

Variable	Without LBP ($n=20$)	With LBP ($n=20$)	P-value
Age (years)	65.20 (5.15)	66.75 (5.78)	0.37
Body mass (kg)	73.25 (6.82)	74.6 (8.94)	0.62
Stature (cm)	170.25 (4.63)	169.35 (6.85)	0.59
BMI (kg/m^2)	25.32 (2.62)	25.96 (2.25)	0.41
Pain (mm)	-	2.10 (0.78)	-

BMI: body mass index, cm=centimeter, Kg=kilogram, kg/m2: kg is a person's weight in kilograms and m2 is their stature in meters squared, LBP: low back pain, mm=millimeter, SD: standard deviation

the association of resting muscle thickness with muscle thickness during standing position on a dynamic level of Biodex ranged from 0.11 to 0.63 in LBP and 0.18 to 0.44 in control groups. For the association of resting muscle thickness with muscle thickness during standing on a static level of the Biodex, R square values ranged from 0.19 to 0.87 and 0.08 to 0.46 in LBP and control groups respectively.

The results of 2×2 mixed-design ANOVA (Table 2) indicate the significant main effect of task dynamicity on the thickness change of only the TrA muscle ($P=0.02$), but the main effect for health status (group) and the interaction were not significantly different ($P>0.05$). There were no significant main effects of health status (group), task dynamicity, or their interaction for the IO and EO muscles ($P>0.05$).

The percentage of thickness changes of each muscle between two standing tasks in each group is shown in Table 3. Only the TrA muscle in the control group demonstrated significantly greater automatic activity in standing on level 8 than standing on a static level ($P=0.03$).

Discussion

In this study, the automatic activity of the abdominal muscles during stable and unstable standing postural tasks was assessed in older adults with and without LBP. According to the results, there was a main effect of task dynamicity for the TrA muscle. Standing on a dynamic level significantly increased TrA muscle automatic activity compared to standing on the static level in the control group.

Multiple factors are involved in maintaining postural control or balance. Previous studies have investigated several aspects of postural control during standing in older adults including muscle strength, force [35, 36], and endurance [37]. Since maintaining postural control relies on constant position correction via muscle activity [38, 39], examining muscle activity in dynamic positions is important. Abdominal muscles are widely believed to assist in spinal stabilization [40, 41]. It is believed that the automatic activation of these muscles is a protective

mechanism for the lumbar spine when the stability level decreases [16, 18].

Typically, electromyographic measurements are used to describe muscle activity, such as the onset and amplitude of electrical excitation. In order to accurately measure deep abdominal muscle activity using electromyography, fine-wire electrodes must be inserted into the muscles. Subjects usually experience discomfort during this process, especially if they have to move [42, 43]. Several studies have used US imaging to measure changes in muscle thickness to indirectly assess muscle activity in recent years [44–46]. Compared to intramuscular EMG recordings, US is noninvasive and could be used clinically. Moreover, it allows for an examination of a larger area of the muscle than is possible with a single intramuscular electrode [47, 48].

The results of the present study showed that only the TrA muscle was significantly affected by task dynamicity. In the control group, while standing on a dynamic level, TrA, the deepest abdominal muscle [49], appears more active than when standing on a static level. This finding supports the hypothesis that dynamic standing tasks can increase the activity of deep abdominal muscles more than static standing tasks [15, 29]. However, the task dynamicity did not significantly affect the IO and EO muscles' automatic activity. This is contrary to the findings of a previous study that found significantly greater activation of all three abdominal muscles during standing on a dynamic surface as compared to static standing tasks in young adults with and without LBP [15]. The reason for the difference in the findings could be due to the age of the participants. The results of a study investigating age-related changes in the thickness of the deep and superficial abdominal muscles showed that loss of muscle thickness may occur earlier in the IO and EO muscles than in the TrA muscle [20]. In the present study, standing on a dynamic level, increased the TrA muscle automatic activity compared to standing on a static level, only in older adults without LBP. In contrast, other studies reported more TrA muscle automatic activity on dynamic surfaces than on static surfaces among participants with and without LBP [18, 20]. Age-related changes in muscle quantity and quality might explain these differences in findings. Although the thickness loss is lower in the TrA as a result of aging, the actual contractile tissue in this muscle has decreased in comparison with young people due to an augmentation of fat and connective tissue [20]. Even though both groups were probably affected by the age-related changes in muscle morphology, the difference in the response of the TrA muscle to task dynamicity may be explained by other factors, such as pain or changes in neuromuscular activation in the LBP group [50–52].

The increased automatic activity of the TrA muscle in the control group, when the postural control challenge is
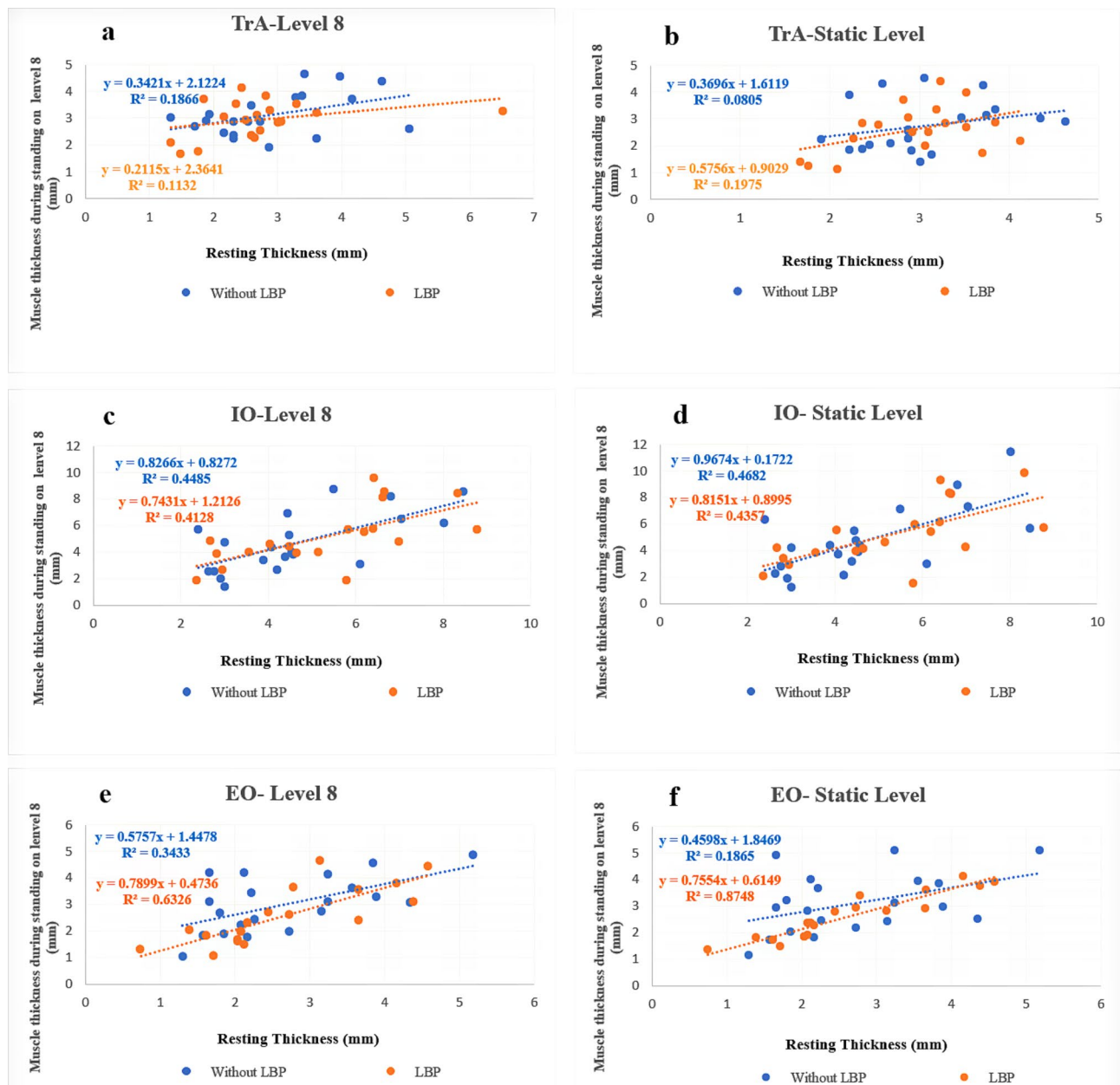
Fig. 1 Scatter plots for: **(a)** TrA muscle thickness while standing on level 8 of the Biodex and TrA resting thickness in the supine position. **(b)** TrA muscle thickness while standing on a static level of the Biodex and TrA resting thickness in the supine position. **(c)** IO muscle thickness while standing on level 8 of the Biodex and IO resting thickness in the supine position. **(d)** IO muscle thickness while standing on a static level of the Biodex and IO resting thickness in the supine position. **(e)** EO muscle thickness while standing on level 8 of the Biodex and EO resting thickness in the supine position. **(f)** EO muscle thickness while standing on a static level of the Biodex and EO resting thickness in the supine position. EO: external oblique, IO: internal oblique, LBP: low back pain, mm: millimeters, TrA: transverse abdominis

Table 2 Results of the 2×2 mixed-design ANOVA (percentage of changes in the thickness of abdominal muscles during two standing postural tasks in elderly subjects with and without low back pain)

Muscle	Task			Group			Task×Group		
	F	P-value	Partial eta squared	F	P-value	Partial eta squared	F	P-value	Partial eta squared
TrA	5.28	0.02*	0.12	0.00	0.93	0.00	1.59	0.21	0.04
IO	0.44	0.50	0.01	0.00	0.93	0.00	1.10	0.30	0.02
EO	0.97	0.33	0.02	3.61	0.06	0.08	0.54	0.46	0.14

EO: external oblique, IO: internal oblique, TrA: transverse abdominis

Kalantari *et al. BMC Geriatrics*   (2024) 24:308

Page 6 of 8

Table 3 Pair-wise comparison of the percentage of changes in the thickness of abdominal muscles between postural tasks in elderly subjects with and without low back pain

Muscle	Group	Task	Task	Mean difference (95% CI)	P- value	Effect size
TrA	Without LBP	1	2	-7.47 (-14.29; -0.66)	0.03*	0.21
	With LBP	1	2	-2.17 (-7.72; 3.38)	0.42	0.06
IO	Without LBP	1	2	-0.3.93 (-12.03; 4.16)	0.32	0.08
	With LBP	1	2	0.88 (-4.25; 6.01)	0.72	0.02
EO	Without LBP	1	2	0.71 (-9.41; 10.83)	0.88	0.01
	With LBP	1	2	4.95 (-1.56; 11.47)	0.12	0.17

CI: confidence interval, EO: external oblique, IO: internal oblique, LBP: low back pain, TrA: transverse abdominis, Task 1: standing on a static level, Task 2: standing on level 8 (dynamic level

increased, is consistent with the theory of an increased postural role for TrA during more challenging postures [53]. The automatic activity of the TrA muscle has been proposed as an indicator of deep abdominal muscles' ability to increase lumbar stability [54, 55]. Improving lumbar stability is an important step in the treatment of LBP [56]. Accordingly, some researchers advocate unstable training in rehabilitation to improve deep abdominal muscle activity and increase lumbar stability [57, 58]. It is recommended that future studies investigate the effects of TrA muscle training while standing on dynamic surfaces for the treatment of older adults with LBP.

The findings of this study revealed that most subjects in both groups demonstrated a linear positive correlation between the resting thickness of the IO and EO muscles and the thickness of these muscles during standing tasks. However, there was a poor correlation between the resting thickness of the TrA muscle and its thickness during standing tasks in both groups. In other words, the TrA muscle thickness during standing tasks was unpredictable based on its resting thickness, which may allow flexible activation of this muscle to exploit its mechanical properties and to adapt movement to environmental perturbations [59].

The results of the present study differed from those observed in young adults that indicated standing on unstable surfaces compared to standing on stable surfaces significantly increases the automatic activity of TrA, IO, and EO muscles in both with and without LBP groups [15, 18]. Inherent age-related factors such as sarcopenia and changes in motor control possibly influenced the findings of this study.

Limitations
In this study, only old men with mild pain were recruited. So, the results cannot be generalized to the older female population or old men with higher levels of pain intensity. Further studies on the effects of task dynamicity on abdominal muscles' automatic activity in old women, middle-aged men, and women with higher levels of pain intensity are suggested.

Also, it is suggested that future research compares the effects of unstable standing on other aspects of

muscle activity such as muscle timing variables (e.g., onset, latency), in older adults with and without LBP. Moreover, this study did not assess the participants' physical activity levels, so there may have been differences between the groups. Future studies should consider this factor. Despite these limitations, these findings provide some clues to future research on motor control exercise in rehabilitation programs for older adults with LBP.

Conclusion
Based on the results of the study, the automatic activity of the TrA muscle in participants without LBP increases during standing on the dynamic level compared to standing on the static level. This finding suggests that standing on a dynamic level of Biodex can increase the demand on the TrA muscle to maintain trunk posture in older adults without LBP. Future research is needed to examine the effects of TrA muscle training during standing on dynamic surfaces for the treatment of older adults with LBP.

Declarations

Disclosure statement
The authors report there are no competing interests to declare.

References

1. Wong AYL, Karppinen J, Samartzis D. Low back pain in older adults: risk factors, management options and future directions. Scoliosis Spinal Disorders. 2017;12(1):14.
2. Economic UNDo, Affairs S. World Population Ageing 2019. United Nations; 2020.
3. Bressler HB, Keyes WJ, Rochon PA, Badley E. The prevalence of low back pain in the elderly. A systematic review of the literature. Spine (Phila Pa 1976). 1999;24(17):1813–9.
4. Podichetty VK, Mazanec DJ, Biscup RS. Chronic non-malignant musculoskeletal pain in older adults: clinical issues and opioid intervention. Postgrad Med J. 2003;79(937):627–33.
5. Edmond SL, Felson DT. Prevalence of back symptoms in elders. J Rheumatol. 2000;27(1):220–5.
6. Sutanto D, Ho RST, Poon ETC, Yang Y, Wong SHS. Effects of different trunk training methods for chronic low back Pain: a Meta-analysis. Int J Environ Res Public Health 2022, 19(5).
7. Cholewicki J, VanVliet Iv JJ. Relative contribution of trunk muscles to the stability of the lumbar spine during isometric exertions. Clin Biomech Elsevier Ltd. 2002;17(2):99–105.
8. O'Sullivan PB, Grahamslaw KM, Kendell M, Lapenskie SC, Möller NE, Richards KV. The effect of different standing and sitting postures on trunk muscle activity in a pain-free population. Spine. 2002;27(11):1238–44.
9. Barrio ED, Ramirez-Campillo R, Garcia de Alcaraz Serrano A, RaquelHernandez-García R. Effects of core training on dynamic balance stability: a systematic review and meta-analysis. J Sports Sci. 2022;40(16):1815–23.
10. Hicks GE, Simonsick EM, Harris TB, Newman AB, Weiner DK, Nevitt MA, Tylavsky FA. Trunk muscle composition as a predictor of reduced functional capacity in the health, aging and body composition study: the moderating role of back pain. J Gerontol Biol Sci Med Sci. 2005;60(11):1420–4.
11. Van Dieën JH, Reeves NP, Kawchuk G, Van Dillen LR. Hodges PWJjoo, therapy sp: motor control changes in low back pain: divergence in presentations and mechanisms. 2019, 49(6):370–9.
12. Whittaker JL. Ultrasound imaging for rehabilitation of the lumbopelvic region a clinical approach. Edinburgh; New York: Churchill Livingstone; 2007.
13. ShahAli S, Arab AM, Ebrahimi E, ShahAli S, Rahmani N, Negahban H, Kazemnejad A, Bahmani A. Ultrasound measurement of abdominal muscles during clinical isometric endurance tests in women with and without low back pain. Physiother Theory Pract. 2019;35(2):130–8.
14. Sutherlin MA, Gage M, Mangum LC, Hertel J, Russell S, Saliba SA, Hart JM. Changes in muscle thickness across positions on Ultrasound Imaging in participants with or without a history of low back Pain. J Athl Train. 2018;53(6):553–9.
15. Ehsani F, Arab AM, Jaberzadeh S, Salavati M. Ultrasound measurement of deep and superficial abdominal muscles thickness during standing postural tasks in participants with and without chronic low back pain. Man Ther. 2016;23:98–105.
16. Rasouli O, Shanbehzadeh S, Arab AM, ShahAli S, Sarafraz H. The effect of respiratory phase on abdominal muscle activity during stable and unstable sitting positions in individuals with and without chronic low back Pain. J Manipulative Physiol Ther. 2020;43(3):225–33.
17. Wang H, Zheng J, Fan Z, Luo Z, Wu Y, Cheng X, Yang J, Zhang S, Yu Q, Lo WLA, et al. Impaired static postural control correlates to the contraction ability of trunk muscle in young adults with chronic non-specific low back pain: a cross-sectional study. Gait Posture. 2022;92:44–50.
18. Rasouli O, Arab AM, Amiri M, Jaberzadeh S. Ultrasound measurement of deep abdominal muscle activity in sitting positions with different stability levels in subjects with and without chronic low back pain. Man Ther. 2011;16(4):388–93.
19. Arab AM, Shanbehzadeh S, Rasouli O, Amiri M, Ehsani F. Automatic activity of deep and superficial abdominal muscles during stable and unstable sitting positions in individuals with chronic low back pain. J Bodyw Mov Ther 2017.
20. Ota M, Ikezoe T, Kaneoka K, Ichihashi N. Age-related changes in the thickness of the deep and superficial abdominal muscles in women. Arch Gerontol Geriatr. 2012;55(2):e26–30.
21. Fragala MS, Kenny AM, Kuchel GA. Muscle quality in aging: a multi-dimensional approach to muscle functioning with applications for treatment. Sports Med. 2015;45(5):641–58.
22. Deursen LLJMV, Snijders CJ, Patun J. Influence of Daily Life activities on Pain in patients with low back Pain. J Orthop Med. 2002;24(3):74–6.
23. Stanton TR, Latimer J, Maher CG, Hancock MJ. How do we define the condition 'recurrent low back pain'? A systematic review. Eur Spine J. 2010;19(4):533–9.
24. Boonstra AM, Schiphorst Preuper HR, Reneman MF, Posthumus JB, Stewart RE. Reliability and validity of the visual analogue scale for disability in patients with chronic musculoskeletal pain. Int J Rehabil Res. 2008;31(2):165–9.
25. da Silva RA, Vieira ER, Léonard G, Beaulieu LD, Ngomo S, Nowotny AH, Amorim CF. Age- and low back pain-related differences in trunk muscle activation during one-legged stance balance task. Gait Posture. 2019;69:25–30.
26. Antoniadou E, Kalivioti X, Stolakis K, Koloniari A, Megas P, Tyllianakis M, Panagiotopoulos E. Reliability and validity of the mCTSIB dynamic platform test to assess balance in a population of older women living in the community. J Musculoskelet Neuronal Interact. 2020;20(2):185–93.
27. Teyhen DS, Gill NW, Whittaker JL, Henry SM, Hides JA, Hodges P. Rehabilitative ultrasound imaging of the abdominal muscles. J Orthop Sports Phys Ther. 2007;37(8):450–66.
28. Teyhen DS, Bluemle LN, Dolbeer JA, Baker SE, Molloy JM, Whittaker J, Childs JD. Changes in lateral abdominal muscle thickness during the abdominal drawing-in maneuver in those with lumbopelvic pain. J Orthop Sports Phys Ther. 2009;39(11):791–8.
29. Mew R. Comparison of changes in abdominal muscle thickness between standing and crook lying during active abdominal hollowing using ultrasound imaging. Man Therap. 2009;14(6):690–5.
30. Klimstra M, Dowling J, Durkin JL, MacDonald M. The effect of ultrasound probe orientation on muscle architecture measurement. J Electromyogr Kinesiol. 2007;17(4):504–14.
31. Bunce SM, Hough AD, Moore AP. Measurement of abdominal muscle thickness using M-mode ultrasound imaging during functional activities. Man Ther. 2004;9(1):41–4.
32. Ehsani F, Arab AM, Salavati M, Jaberzadeh S, Hajihasani A. Ultrasound Measurement of Abdominal muscle thickness with and without transducer fixation during standing postural tasks in participants with and without chronic low back Pain: Intrasession and Intersession Reliability. Pm r. 2016;8(12):1159–67.
33. Ainscough-Potts AM, Morrissey MC, Critchley D. The response of the transverse abdominis and internal oblique muscles to different postures. Man Ther. 2006;11(1):54–60.
34. Nakai Y, Kawada M, Miyazaki T, Kiyama R. Trunk muscle activity during trunk stabilizing exercise with isometric hip rotation using electromyography and ultrasound. J Electromyogr Kinesiol. 2019;49:102357.
35. Granacher U, Zahner L, Gollhofer A. Strength, power, and postural control in seniors: considerations for functional adaptations and for fall prevention. Eur J Sport Sci. 2008;8(6):325–40.
36. Horlings CG, van Engelen BG, Allum JH, Bloem BR. A weak balance: the contribution of muscle weakness to postural instability and falls. Nat Clin Pract Neurol. 2008;4(9):504–15.
37. Parreira RB, Amorim CF, Gil AW, Teixeira DC, Bilodeau M, da Silva RA. Effect of trunk extensor fatigue on the postural balance of elderly and young adults during unipodal task. Eur J Appl Physiol. 2013;113(8):1989–96.
38. Houdijk H, Brown SE, van Dieën JH. Relation between postural sway magnitude and metabolic energy cost during upright standing on a compliant surface. J Appl Physiol (1985). 2015;119(6):696–703.
39. Kochanowicz A, Niespodziński B, Marina M, Mieszkowski J, Biskup L, Kochanowicz K. Relationship between postural control and muscle activity during a handstand in young and adult gymnasts. Hum Mov Sci. 2018;58:195–204.
40. Bergmark A. Stability of the lumbar spine. A study in mechanical engineering. Acta Orthop Scand Suppl. 1989;230:1–54.

41. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. Spine (Phila Pa 1976). 1996;21(22):2640–50.

42. Costa LO, Maher CG, Latimer J, Hodges PW, Shirley D. An investigation of the reproducibility of ultrasound measures of abdominal muscle activation in patients with chronic non-specific low back pain. Eur Spine J. 2009;18(7):1059–65.

43. Hodges PW, Richardson CA. Altered trunk muscle recruitment in people with low back pain with upper limb movement at different speeds. Arch Phys Med Rehabil. 1999;80(9):1005–12.

44. Koppenhaver SL, Hebert JJ, Parent EC, Fritz JM. Rehabilitative ultrasound imaging is a valid measure of trunk muscle size and activation during most isometric sub-maximal contractions: a systematic review. Aust J Physiother. 2009;55(3):153–69.

45. ShahAli S, Shanbehzadeh S, ShahAli S, Ebrahimi Takamjani I. Application of ultrasonography in the assessment of abdominal and lumbar trunk muscle activity in participants with and without low back pain: a systematic review. J Manipulative Physiol Ther. 2019;42(7):541–50.

46. Shanbehzadeh S, ShahAli S, Hides J, Ebrahimi-Takamjani I, Rasouli O. Effect of Motor Control Training on Trunk Muscle Morphometry, Pain, and disability in people with chronic low back Pain: a systematic review and Meta-analysis. J Manip Physiol Ther 2022.

47. Ferreira PH, Ferreira ML, Hodges PW. Changes in recruitment of the abdominal muscles in people with low back pain: ultrasound measurement of muscle activity. Spine (Phila Pa 1976). 2004;29(22):2560–6.

48. Blanchard TW, Smith C, Grenier SG. In a dynamic lifting task, the relationship between cross-sectional abdominal muscle thickness and the corresponding muscle activity is affected by the combined use of a weightlifting belt and the Valsalva maneuver. J Electromyogr Kinesiol. 2016;28:99–103.

49. Hodges PW, Moseley GL. Pain and motor control of the lumbopelvic region: effect and possible mechanisms. J Electromyogr Kinesiol. 2003;13(4):361–70.

50. Kato S, Murakami H, Demura S, Yoshioka K, Shinmura K, Yokogawa N, Igarashi T, Yonezawa N, Shimizu T, Tsuchiya H. Abdominal trunk muscle weakness and its association with chronic low back pain and risk of falling in older women. BMC Musculoskelet Disord. 2019;20(1):273.

51. Russo M, Deckers K, Eldabe S, Kiesel K, Gilligan C, Vieceli J, Crosby P. Muscle control and non-specific chronic low back Pain. Neuromodulation. 2018;21(1):1–9.

52. Ishak NA, Zahari Z, Justine M. Muscle Functions and Functional Performance among Older Persons with and without Low Back Pain. *Curr Gerontol Geriatr Res* 2016, 2016:8583963.

53. Hodges PW, Richardson CA. Delayed postural contraction of transversus abdominis in low back pain associated with movement of the lower limb. J Spinal Disord. 1998;11(1):46–56.

54. Hodges PW, Pengel LH, Herbert RD, Gandevia SC. Measurement of muscle contraction with ultrasound imaging. Muscle Nerve. 2003;27(6):682–92.

55. Teyhen DS, Rieger JL, Westrick RB, Miller AC, Molloy JM, Childs JD. Changes in deep abdominal muscle thickness during common trunk-strengthening exercises using ultrasound imaging. J Orthop Sports Phys Ther. 2008;38(10):596–605.

56. Richardson C, Jull G, Hodges P, Hides J. Therapeutic exercise for spinal segmental stabilization in low back pain. Edinburgh: Churchill Livingstone 1999, 10.

57. Saliba SA, Croy T, Guthrie R, Grooms D, Weltman A, Grindstaff TL. Differences in transverse abdominis activation with stable and unstable bridging exercises in individuals with low back pain. N Am J Sports Phys Ther. 2010;5(2):63–73.

58. Ehsani F. Effect of exercise therapy in an unstable surface on muscle activity pattern in patients with low back pain: a systematic review. Koomesh. 2015;16:495–504.

59. Farley BG, Koshland GF. Trunk muscle activity during the simultaneous performance of two motor tasks. Exp Brain Res. 2000;135(4):483–96.

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