BMC Sports Science, Medicine and Rehabilitation

RESEARCH Open Access

Whole-body vibration training reduces erector spinae stiffness by ultrasound shear-wave elastography: a randomized controlled trial

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Abstract

Background Efficient methods to reduce erector spinae stiffness are important for solving lumbar spine problems, however, the trunk training positions effective for reducing erector spinae stiffness are unclear. Furthermore, it unclear whether whole-body vibration and trunk training are synergistic. Therefore, this study aimed to clarify the differences in the immediate effects on reducing erector spinae stiffness among three types of training: simple spinal flexion training, spinal neutral position training, and spinal flexion training combined with whole-body vibration.

Methods This single-blind randomized controlled trial included 36 healthy university students who were assigned to either the spinal neutral position training group, spinal flexion training group, or whole-body vibration (vibration conditions: 35 Hz, 4 mm) + spinal flexion training group. Training consisted of only one session of the assigned exercise in each group (20 s × 8 sets, rest 15 s). The outcomes measured were erector spinae stiffness, tenderness threshold of the erector spinae, lumbar proprioception, and maximum lumbar forward bending angle. All statistical analyses were performed using a split-plot design analysis of variance.

Results There were no significant group × period interactions for erector spinae stiffness; however, a significant main effect of time was observed ($p < 0.01$). Comparison of pre- and post-intervention stiffness indicated no significant differences in the spinal flexion training group. In contrast, both the spinal neutral position ($p < 0.01$, pre-intervention: 49.0 [10.6], post-intervention: 47.1 [6.4]) and whole-body vibration + spinal flexion training groups ($p = 0.02$, pre-intervention: 49.8 [12.6], post-intervention: 47.9 [9.4]) showed significantly less stiffness post-intervention compared to pre-intervention.

Conclusions Trunk training performed in the spinal neutral position or spinal flexion position combined with whole-body vibration reduces erector spinae stiffness more effectively than simple spinal flexion training.

Trial registration This study was registered in the Japan Registry of Clinical Trials as a clinical trial (ID: jRCT1042240153; registration date: 20/12/2024).

Keywords Elastography, Erector spinae, Stiffness, Training, Whole-body vibration

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Background

The erector spinae (ES) muscles are essential for lumbar motion and postural control; however, excessive ES stiffness can cause other issues. The ES is an agonist muscle of spinal extension located lateral to the lumbar multifidus that co-contracts with the antagonist muscle to produce spinal stability [1]. Conversely, excessive activation of ES muscles due to low back pain and other factors results in reduced lumbar range of motion, delayed movement, reduced movement variation for spinal load distribution, muscle fatigue, and other issues [1, 2]. Furthermore, sustained excessive ES activity can cause myofascial low back pain, increased intervertebral disc and facet joint compressive forces, and decreased proprioception [2–4], which can contribute to secondary tissue damage and transition to chronic low back pain. Therefore, effective interventions to reduce excessive ES stiffness are essential.

Trunk training is often used to improve or prevent structural and functional problems in the lumbar region. Trunk training involves various approaches, focusing on muscle strength, muscular endurance, magnitude of lumbar motion, balancing activity between the back and abdominal muscles, and other factors. From an ergonomic perspective, training to maintain a neutral spine position, such as performing plank exercises, along with muscle contraction control exercises such as hollowing and bracing that support this, are commonly performed [5–8]. Another frequently used method of trunk training is spinal flexion training, which is performed with the spine in a flexed position, such as holding the sit-up position. This training focuses on increasing the muscular activity of the abdominal muscles through concentric or isometric contractions of the rectus abdominis and other abdominal muscles.

Both spinal neutral and flexion position training focus on increasing spinal stability (not stiffness, but the ability to resist external loads and prevent misalignment), with limited research specifically focused on reducing ES stiffness. Notably, excessive muscle stiffness may inhibit proprioceptive input [9] and contribute to a lack of stability such that the muscle adapts to the load. Excessive ES stiffness itself, as observed in cases with myogenic low back pain in ES, is often a problem. However, it is not clear which trunk training method is effective in reducing direct ES stiffness. As the abdominal muscles are the antagonist muscles of ES, which increase the flexibility of the target muscle when activated [10], spinal flexion training may be more effective than spinal neutral position training towards reducing ES stiffness.

Recently, whole-body vibration (WBV), a novel training method, has gained considerable attention. WBV enhances trunk muscle activation and proprioception, which are essential for motor control [11–13], making it popular as a simple and effective training method. Additionally, WBV reduces antagonist muscle activity and improves flexibility [14, 15]. WBV has shown both long- and short-term effects on flexibility, muscle performance, and proprioception [15, 16]. Therefore, combining WBV with spinal flexion training may effectively reduce ES stiffness. However, the effects and adverse events associated with using WBV for spinal flexion training on ES stiffness have not been investigated. It is thus necessary to first clarify the effects of training with WBV in healthy individuals as a preliminary study.

Therefore, this study aimed to evaluate (1) the immediate effect of spinal flexion training on ES stiffness reduction compared to spinal neutral position training and (2) the immediate effect of combining spinal flexion training with WBV for reducing ES stiffness to identify effective training methods for reducing ES stiffness. We hypothesized that compared with spinal neutral position training, spinal flexion training was more effective for ES stiffness reduction, and combining spinal flexion training with WBV would further reduce ES stiffness.

Methods

Study design

This study was conducted in compliance with the CONSORT guidelines. This was a single-blind randomized controlled trial, where participants were randomly assigned to (1) a neutral position training (NT) group, (2) a flexion training (FT) group, or (3) a whole-body vibration training (WBVT) group. Participants performed spinal flexion training along with WBV on a WBV equipment. Randomization was performed using a random number table in Microsoft Excel, with stratification by sex to ensure equal proportions of males and females in each group. The allocation was done by a different co-author other than the one responsible for measurements and data analysis, who was blinded to the group assignments of participants.

Participants and setting

This study included healthy university students aged 18–25 years who expressed their willingness to participate in the study in response to a request for research cooperation in August 2024. All measurements and interventions were performed in September 2024. Individuals with any one of the following conditions were excluded: (1) pain that interfered with daily activities, (2) typical physical function impairment such as paralysis due to cerebrovascular disease, (3) history of surgery that substantially affected spinal or hip motion such as lumbar fusion or artificial hip replacement, (4) major spinal deformities, (5) cognitive impairments that hindered comprehension, and (6) pregnancy. All measurements and interventions were performed in the laboratory of the author's institution.

Intervention

The training session was for one day only, as only one training session was conducted. Prior to training, the training protocol was verbally explained to the participants, and they were required to understand the methods before the actual training. Training was supervised by another co-author, who was not involved in measurements and data analysis, ensuring that any incorrect methods were corrected immediately. For training, the NT group performed prone bridge, where only the elbows (forearms) and toes touched the floor with their trunk and lower limbs aligned (Fig. 1). The FT and WBVT groups held the sit-up position in a sitting position with their lower limbs elevated and the trunk flexed and tilted backward at approximately 45° (Fig. 1). Each group completed a single training session, consisting of 8 sets of 20 s each, with 15 s of rest between each set, as reported previously [17]. The NT and FT groups were trained on a normal floor surface, while the WBVT group was trained on the WBV equipment. Vibration was set at 35 Hz and 4 mm amplitude, which has been shown to be effective in previous studies [16]. The intervention consisted of one session of training for each group (one-time intervention).

Outcome measurement

The primary and secondary outcome measures were measured before and after the training. The primary outcome measure was ES stiffness measured using ultrasound shear wave elastography (SWE). Secondary outcome measures included the maximum lumbar motion angle during forward trunk bending, ES tenderness threshold, and error in active joint repositioning sense (AJRS).

Primary outcome measure

ES stiffness was measured using SWE on an ultrasound imaging system (AplioαVerifia, Canon Medical Systems) with a 14 MHz linear probe. The longissimus, which is the most likely to cause problems among the ES, was evaluated [18]. Additionally, the elasticity (kPa) of the longissimus at high levels of the spinous process of the fourth lumbar vertebra was also measured as reported previously [19]. As the participants were healthy university students, and after confirming that there were no noticeable left-right differences, the measurements were standardized to the right side to maintain measurement consistency.

Measurements were taken while the participant was in a resting prone position, with the neck tilted to the right and the upper limbs off the bed. The measurement site was the longissimus at the level of the fourth lumbar vertebra based on previous studies [19], and elasticity (kPa) was measured. The fourth lumbar vertebra was identified by palpation, and the participants were instructed to extend the trunk voluntarily, and a marking was made on the belly of the longissimus approximately 1 cm lateral to the spine. The probe was placed parallel to the muscle fibers at the marked site (Fig. 2-a). Five circular measurement regions of interest (5-mm in diameter each) were manually set in the color-coded observation box (approximately 15 mm × 15 mm) on the ultrasound images. One circle was placed at the center of the observation region of the box of interest, and the others were placed in four diagonals at the corners of the observation region of the box of interest (Fig. 2-b). The average elasticity value from these five regions of interest was used as the representative value, expressed in kPa.

Secondary outcome measure

The maximum lumbar motion angle during forward trunk bending was measured using a small accelerometer (AMWS020, ATR-Promotions, Sagara, Japan) and a receiver system (Sensor Controller, ATR-Promotions,

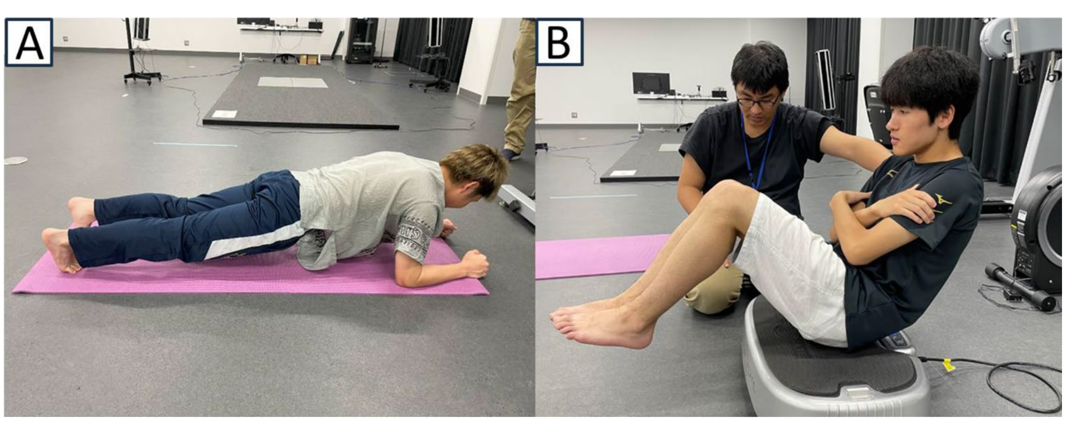

Fig. 1 Trunk training. **A**: Spinal neutral position training, **B**: Whole body vibration with spinal flexion training

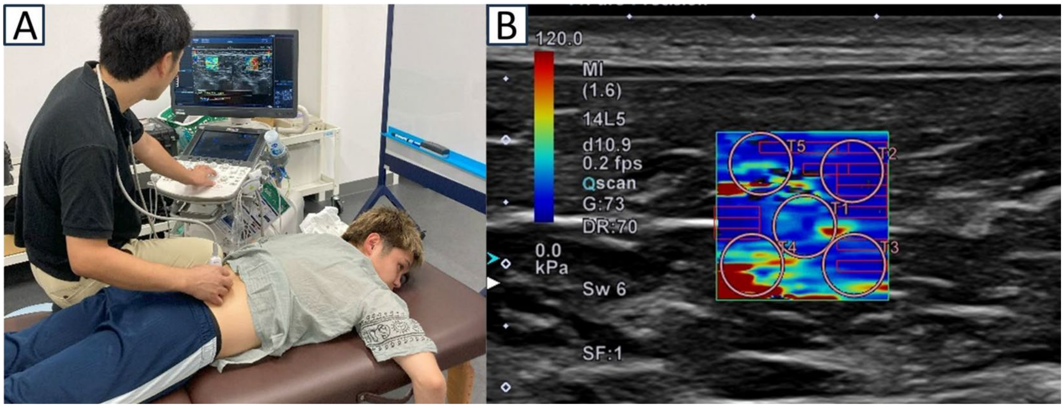

Fig. 2 Ultrasound shear-wave elastography of the erector spinae. **A**: Imaging, **B**: Region of interest

Sagara, Japan). Small accelerometers were secured to the first lumbar vertebra (thoracolumbar transition area) and the first sacral vertebra (lumbosacral transition area). The sensor at the first lumbar vertebra was positioned with its upper edge aligned with the first lumbar vertebra, and the sensor at the first sacral vertebra was similarly aligned with the upper edge of the sacrum, both placed along the midline of the body. The acceleration range was set to ± 8 G, angular velocity range of ± 1000 dps, and sampling frequency of 100 Hz to acquire data on the sensor tilt angle in the sagittal plane [20]. The lumbar motion angle was defined as the angle difference between the first lumbar sensor and the first sacral sensor, with positive values indicating motion in the flexion direction and negative values indicating motion in the extension direction. Miyachi et al. [20] reported an intra-class correlation coefficient $>$ 0.8 after two measurements. The movement task consisted of voluntary movements from a resting standing position to a maximal forward trunk bend. The verbal instruction was “Please bend your body to the limit as if you were curled up from the top to the bottom,” and the movement was performed for 2 s and held for 2 s at the end position. The average lumbar angle for 1 s from 0.5 to 1.5 s after the stop was taken as the value of one trial, and the average value of two trials was taken as the representative value.

The ES tenderness threshold was measured using a manual pressure-measuring device (AMF Digital Force Gauge AMF-300, YAHUJI, Tokyo, Japan) equipped with a 1 cm diameter probe. Pressure was applied perpendicularly to the tissue surface three times at a constant rate (1 kgf/s), as previously described [21]. The pressure was applied to the site marked during the ultrasound measurement (the right longissimus muscle belly at the level of the fourth lumbar vertebrae). The tenderness threshold was obtained by instructing the participant to say “stop” when the sensation became “uncomfortable” or “painful,” and the average threshold of three trials was taken as the representative value.

The AJRS during lumbar flexion in the sitting position was used as an index of lumbar proprioception [22]. The lumbar flexion angle was defined as the tilt angle of the thoracolumbar transitional sensor and was measured using the iPhone® inclinometer application, as previously described [23]. Participants were instructed to close their eyes with their upper limbs crossed in front of the chest at a lumbar flexion angle of 0°. The trunks were flexed voluntarily, with their pelvis fixed, and after memorizing the position where the lumbar flexion angle was 20°, they performed the trunk flexion movement again and stopped at the position where they felt the lumbar spine moved 20°. Measurements were taken three times, and the absolute error was calculated from the measured values [24].

Statistical analysis

All statistical analyses were performed using SPSS version 28 (IBM SPSS Statistics, Japan; IBM, Tokyo, Japan). The sample size was calculated using G Power v 3.1.9.7. with an effect size of 0.4, alpha of 0.05, and a power of 0.8 based on previous studies [17]. The following statistical analyses were performed after confirming normality using the Shapiro–Wilk test (Holm correction) and equal variance with the Levene test (Holm correction) for all items. This analysis included 36 participants (12 per group), and the baseline characteristics of the participants were compared using the chi-square test and one-way analysis of variance (Tukey’s multiple comparisons). Each outcome was compared using a split-plot design with the pre-intervention value as the covariate, analysis of variance (group × time), and a simple main effects test. The significance level was set at $p < 0.05$.

Results

Participants

A flowchart of participant selection is shown in Fig. 3. After excluding two participants who were unable to participate owing to scheduling conflicts, 36 participants (27

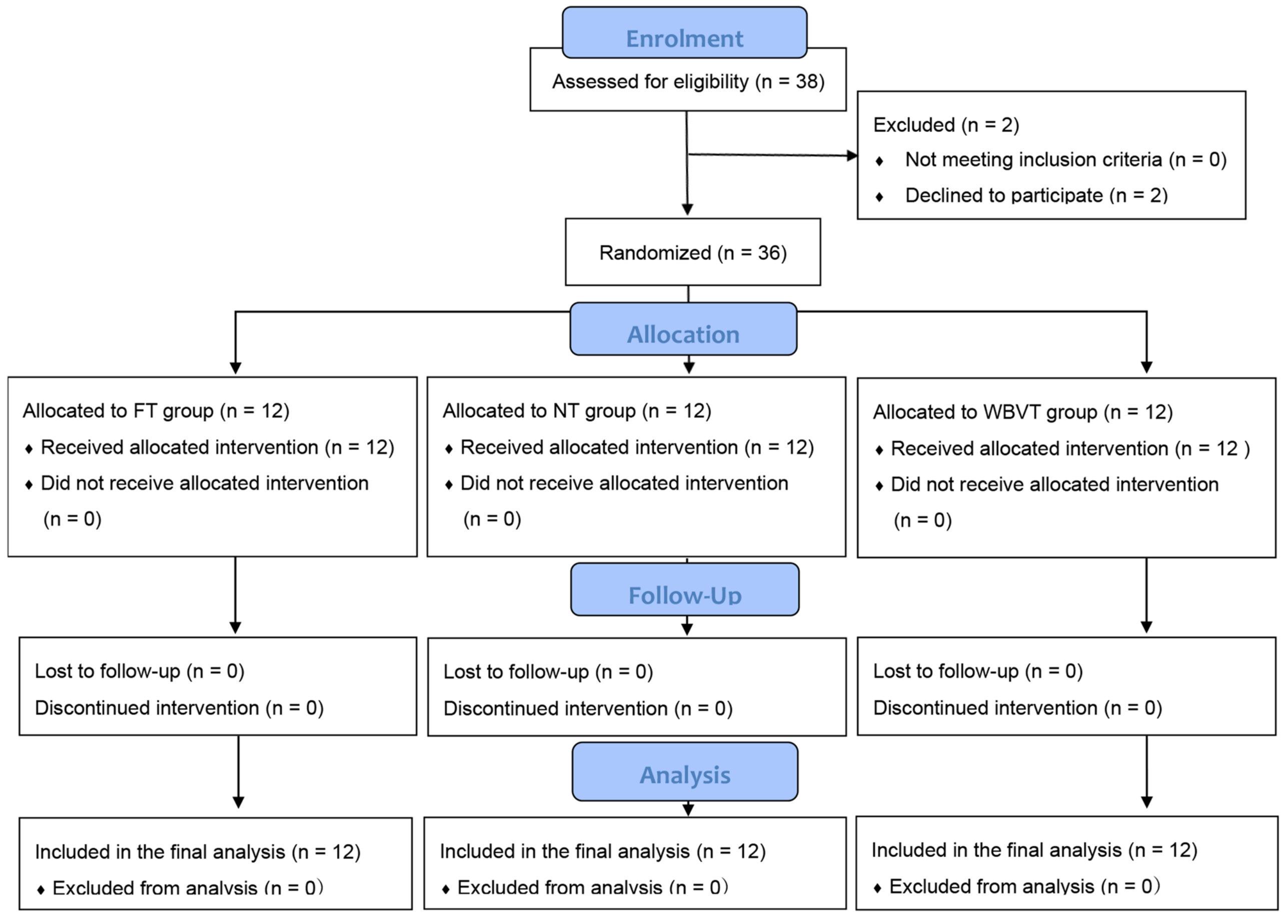

Fig. 3 Flowchart of participant selection. FT, flexion training; NT, neutral position training; WBV, whole-body vibration training

Table 1 General characteristics of the participants

Characteristic	Overall (*N* = 36)	FT group (*N* = 12)	NT group (*N* = 12)	WBVT group (*N* = 12)	*p*-value
Sex, N (%)	Male, 27 (75.0)	Male, 9 (75.0)	Male, 9 (75.0)	Male, 9 (75.0)	1.00
	Female, 9 (25.0)	Female, 3 (25.0)	Female, 3 (25.0)	Female, 3 (25.0)	
Age (years)	19.4 (1.2)	19.3 (1.1)	19.4 (0.8)	19.4 (1.2)	0.92
Height (cm)	169.4 (8.1)	167.2 (6.1)	170.3 (8.7)	170.8 (9.4)	0.52
Weight (kg)	61.0 (8.7)	56.9 (7.4)	65.1 (7.6)	60.9 (9.7)	0.07

Values are presented as number of participants (%) or mean (standard deviation)

FT, flexion training; NT, neutral position training; WBVT, whole-body vibration training

Table 2 Outcome measure results in the pre-intervention

	FT group (*N* = 12)	NT group (*N* = 12)	WBVT group (*N* = 12)
Erector spinae elasticity (kPa)	46.5 (9.9)	49.0 (10.6)	49.8 (12.6)
Maximum lumbar motion angle (degree)	41.5 (11.7)	40.4 (13.4)	36.5 (13.3)
Tender threshold (kgf)	5.4 (1.3)	4.1 (1.3)	5.5 (2.0)
AE (degree)	3.9 (3.2)	2.7 (1.2)	3.8 (2.8)

Values are presented as mean (standard deviation)

FT, flexion training; NT, neutral position training; WBVT, whole-body vibration training

AE, Absolute error in active joint repositioning sense

The motion angles are + for lumbar flexion and– for extension

males and 9 females, aged 19.4 (1.2) years, with height 169.4 (8.1) cm and weight 61.0 (8.7) kg), were included in the study. No adverse events were reported during training. All 36 participants completed the training and were included in the final analysis ($n = 12$ in each group). The general characteristics of the participants are presented in Table 1. No significant differences were observed in sex, height, or weight among the three groups. No adverse events (e.g. pain) were observed during the study.

Primary outcome measure

The pre- and post-intervention values are shown in Tables 2 and 3. No significant group × period interaction was observed for ES elasticity ($p = 0.61$, partial $\eta^2 = 0.03$), however, a significant main effect of period was evident

Table 3 Outcome measure results in the post-intervention

		Lumbar erector spinae muscle stiffness (kPa)	Maximum lumbar motion angle (degree)	Tender threshold (kgf)	AE (degree)
FT group ($N=12$)	Mean (standard deviation)	49.0 (10.6)	38.2 (14.2)	4.8 (1.3)	2.2 (1.5)
	p-value for pre/post comparisons	0.11	0.28	0.15	0.02*
	Effect size (partial η^2)	0.24	0.12	0.19	0.44
NT group ($N=12$)	Mean (standard deviation)	47.1 (6.4)	38.5 (11.5)	5.6 (1.6)	2.3 (1.9)
	p-value for pre/post comparisons	< 0.01*	0.17	0.52	0.12
	Effect size (partial η^2)	0.54	0.18	0.04	0.22
WBV group ($N=12$)	Mean (standard deviation)	47.9 (9.4)	39.8 (12.2)	6.1 (2.5)	2.1 (1.6)
	p-value for pre/post comparisons	0.02*	0.10	0.94	0.16
	Effect size (partial η^2)	0.42	0.28	< 0.01	0.19
Group and period interaction	p-value	0.61	0.16	0.61	0.85
	Effect size (partial η^2)	0.03	0.11	0.03	0.01
Main Effects	p-value	< 0.01*	0.13	0.41	0.01*
	Effect size (partial η^2)	0.37	0.07	0.02	0.22

Values are presented as mean (standard deviation)

FT, flexion training; NT, neutral position training; WBVT, whole-body vibration training

AE, Absolute error in active joint repositioning sense

The motion angles are + for lumbar flexion and– for extension

* Significant difference ($p < 0.05$)

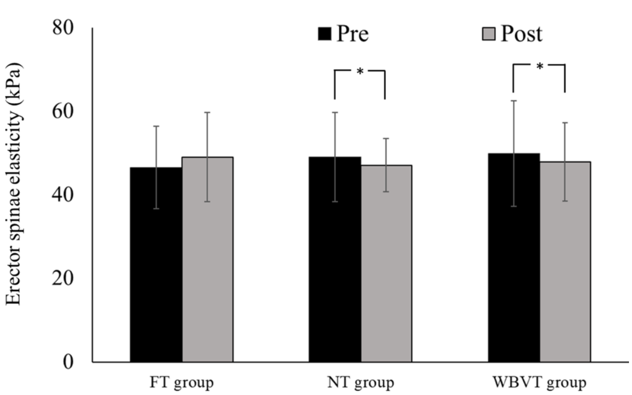

Fig. 4 Comparison of erector spinae elasticity between the groups (pre- and post-intervention). FT, flexion training; NT, neutral position training; WBV, whole-body vibration training. * Significant difference ($p < 0.05$)

($p < 0.01$, partial $\eta^2 = 0.37$). Pre- and post-intervention comparisons within each group revealed that the FT group showed no significant difference in elasticity. In contrast, the NT group showed significantly less elasticity post-intervention compared to pre-intervention ($p < 0.01$, partial $\eta^2 = 0.54$, pre-intervention: 49.0 [10.6], post-intervention: 47.1 [6.4]), and the WBVT group also showed significantly less elasticity post-intervention compared to pre-intervention (p = 0.02, partial $\eta^2 = 0.42$, pre-intervention: 49.8 [12.6], post-intervention: 47.9 [9.4]) (Fig. 4).

Secondary outcome measure

No significant group × period interaction ($p = 0.16$, partial $\eta^2 = 0.11$) or main effect of period ($p = 0.13$ partial $\eta^2 = 0.07$) was observed for the maximum lumbar motion angle during forward trunk bending (Table 3). Additionally, pre- and post-intervention comparisons within each group showed no significant differences in the maximum lumbar motion angles in all groups.

No significant group × time interaction ($p = 0.61$ partial $\eta^2 = 0.03$) or main effect of period ($p = 0.41$ partial $\eta^2 = 0.02$) was observed for the tenderness threshold of ES (Table 3). Regarding the pre- and post-intervention comparisons within each group, no significant differences in ES tenderness thresholds were observed pre- and post-intervention in all groups.

No significant group × period interaction was observed for absolute error in the AJRS ($p = 0.85$, partial $\eta^2 = 0.01$); however, a significant main effect of period was evident ($p < 0.01$, partial $\eta^2 = 0.22$).

Regarding the comparison between pre- and post-intervention outcomes for each group, only the FT group showed a significant decrease in lumbar absolute error post-intervention compared to pre-intervention ($p=0.02$, partial $\eta^2=0.44$, pre-intervention: 2.7 [1.2], post-intervention: 2.3 [1.9]).

Discussion

This study investigated the differences in the immediate effects of spinal neutral position training, spinal flexion training, and spinal flexion training combined with WBV on ES stiffness reduction.

Differences in training effectiveness between types of training

Although our findings indicated no group × time interaction, the NT group exhibited less ES stiffness post-intervention than pre-intervention. In contrast, the FT group exhibited no reduction in ES stiffness pre- and post-intervention, which contradicts the hypothesis that spinal flexion training is more effective than spinal neutral position training. The surface electromyography of the rectus and oblique abdominis muscles indicates that muscle activity levels are approximately equal in the prone bridge and sit-up positions [25]; however, the activity of transversus abdominis muscle, which plays a crucial role in controlling the deviation of the spine in the neutral zone and assists in spinal extension torque by extending the thoracolumbar fascia, was not measured [26]. Therefore, the prone bridge position in the NT group also required transversus abdominis muscle activity, which may have reduced ES activity. Another study compared the plank position, similar to the prone bridge, with the crunch position, similar to the sit-up position, and reported that the crunch position resulted in higher ES activity [27]. This is because the crunch position requires co-contraction of the hip flexors and ES to maintain anterior pelvic tilt. Similarly, in our study, the sit-up position may have led to sustained erector spinae activity and increased stiffness. Furthermore, it has been reported that passive tension increases after repetitive centrifugal contractions [28]. Therefore, it is possible that the centrifugal contraction of the ES due to the sit-up position also affected muscle stiffness in the present study. However, this study did not examine the muscle activity of the trunk muscles, including the transversus abdominis and ES, or the stiffness of the thoracolumbar fascia during training. Therefore, it is necessary to verify the mechanism of the difference in ES stiffness reduction between the NT and FT groups in the future by using electromyography and evaluating other sites.

Differences in training effectiveness following WBV training

Our findings indicated no group × time interaction; however, pre- and post-intervention comparison revealed less ES stiffness post-intervention in the WBVT group. Therefore, our findings support the hypothesis that ES stiffness reduction was higher after spinal flexion training with WBV than without WBV. Several mechanisms have been proposed to improve flexibility with WBV, including inhibition of antagonist muscles, increased blood flow, decreased pain, and increased muscle temperature [14, 29, 30]. Wirth et al. [25] reported that WBV in the sit-up position immediately increased the activity of the abdominal muscles, the antagonist muscles of the ES, which explains the reduction in ES stiffness in our study due to the activation of the abdominal muscles by WBV. These results suggest that spinal flexion training with WBV is beneficial for reducing ES stiffness.

Although increased ES stiffness is important to avoid excessive spinal motion during the acute phase of lumbar injury, prolonged excessive stiffness beyond the recovery period leads to compressive stress on the intervertebral discs and facet joints, muscle fatigue, and associated discomfort [2, 3]. Furthermore, excessive trunk muscle stiffness effectively counters small disturbances; however, this may hinder the ability to cope with more complex tasks [31–33]. Therefore, the findings of this study provide potential insights for preventing and improving low back pain and selecting training activities requiring complex trunk control in sports and other domain.

Clinical implications

The results of this study contribute to the selection of training protocols recommended for patients with symptoms such as low back pain based on increased ES stiffness. Notably, to reduce ES stiffness, spinal neutral position training or spinal flexion training combined with WBV is preferable to simple spinal flexion training. Excessive muscle stiffness is reported to contribute to pain development and hinder proprioceptive feedback [34], leading to reduced movement in surrounding areas. This reduction in movement can further exacerbate pain and proprioceptive impairments, potentially creating a vicious cycle. In contrast, the above-mentioned training immediately reduces muscle stiffness, allowing training to be conducted without the negative effects of excessive muscle stiffness, thereby breaking the vicious cycle. Moreover, the relationship between muscle stiffness and muscle injury is well-known [35]. Notably, the present findings are also useful in selecting warm-up training protocols to prevent lower back injuries and low back pain.

Limitations

Our study had several limitations. First, all the study participants were healthy young individuals, which may have caused a ceiling effect for each item. In other words, the small pre-intervention stiffness of ES and the small absolute error in AJRS may have led to a plateau effect, limiting the extent of change following the intervention. Therefore, in populations where changes are more likely to occur, such as in individuals with low back pain or older adults with higher baseline ES stiffness, the effects of each intervention may be more pronounced, and clearer differences between interventions may emerge. Hence, future studies should include participants with symptoms such as low back pain. However, when targeting individuals with structural instability of the lumbar spine, it is essential to consider the potential risks associated with reduced passive support from the muscles due to decreased ES stiffness.

Furthermore, this study focused solely on the immediate effects of the intervention, and long-term effects were not assessed. Notably, although ES stiffness decreased immediately after the intervention in the WBVT group, no significant differences in tenderness threshold or lumbar spine motion angle were observed pre- or post-intervention. This suggests that WBVT may not be effective enough to produce immediate improvement in pain or spinal mobility in the case of symptoms that would otherwise result from excessive ES stiffness. However, because WBV may show different results for immediate and long-term effects [13, 15], further validation of the effects of long-term interventions longer than 3 weeks is needed in the future [36]. In addition, in this study, WBV was only given for spinal flexion training and not for spinal neutral position training. Considering the present results, future validation is needed, as a greater ES stiffness reduction effect may occur in spinal neutral position training.

Furthermore, this study proposed the possibility of abdominal and ES muscle activity as a possible explanation for the present results. However, as muscle activity was not assessed in this study, the mechanism of the intervention effect could not be evaluated. Therefore, it is necessary to verify the results of the present study using surface electromyography and other methods to clarify the mechanism of the intervention effect.

Conclusions

This study investigated the differences in the immediate effects of spinal neutral position training, spinal flexion training, and spinal flexion training with WBV on ES stiffness reduction. The results showed that spinal neutral position training and spinal flexion training with WBV were effective in reducing ES stiffness post-intervention. Therefore, trunk training in the spinal neutral position and in the spinal flexion position using WBV may have an immediate effect in reducing ES stiffness.

Abbreviations

AJRS	Active joint repositioning sense
ES	Erector spinae
FT	Flexion training
NT	Neutral position training
SWE	Shear wave elastography
WBV	Whole-body vibration
WBVT	Whole-body vibration training

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13102-025-01167-6.

Supplementary Material 1

Author contributions

R.M contributed to conceptualization, data curation, project administration, resources, software, validation, supervision, visualization, writing - original draft. R.M, T.N, Y.F, Y.K, A.G, K.I contributed to formal analysis, investigation, methodology, project administration, resources, software, validation. T.N, Y.F, Y.K, A.G, K.I contributed to writing - review & editing. All authors have read and agreed to the published version of the manuscript.

Funding

This research was funded by JSPS KAKENHI Grant Number JP22K17543.

Data availability

The data associated with the present study are not publicly available but are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the principles of the Declaration of Helsinki. The purpose and procedures of this study were thoroughly explained to all participants both orally and in writing. Written informed consent for voluntary participation was obtained from all participants prior to the commencement of the study. This study was approved by the Hokuriku university ethics review committee for research involving human subjects (Approval No. 2024-19).

Consent for publication

Written informed consent was obtained from the participants for the publication of personal or clinical details and identification images in this study.

Competing interests

The authors declare no competing interests.

Received: 11 December 2024 / Accepted: 24 April 2025
Published online: 03 May 2025

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