

Original Article

Effect of Asymmetrical Versus Symmetrical Extremity Exercises on Erector Spinae Co-Contraction: A Pilot Study in Healthy Adults

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Abstract

Background. Idiopathic scoliosis (IS) is commonly associated with asymmetrical erector spinae (ES) muscle activity, contributing to impaired spinal stability and postural imbalance. Physiotherapy exercise programmes are widely used in the conservative management of IS; however, limited evidence exists regarding the comparative effects of symmetrical and asymmetrical upper limb (UL) and lower limb (LL) exercises on ES muscle co-contraction at specific vertebral levels. Therefore, this pilot experimental study aimed to compare the effects of symmetrical and asymmetrical extremity exercises on ES muscle co-contraction at vertebral levels T7, T12, and L3 in healthy adults using surface electromyography (sEMG). **Methods.** A quantitative pilot experimental study was conducted with 21 healthy participants (16 males, 5 females). Bilateral ES muscle activity was recorded using sEMG at vertebral levels T7, T12, and L3 during four exercises: barbell shoulder press, dumbbell shoulder press, weighted squat, and dumbbell single-leg squat. Electromyographic signals were normalized using maximum voluntary isometric contraction (MVIC). **Results.** Symmetrical UL exercises produced significantly greater right ES muscle co-contraction than asymmetrical UL exercises at T7, T12, and L3 (all $p = 0.001$). Median right ES activation at T7 was higher during the barbell shoulder press compared to the dumbbell shoulder press (64.09 vs. 34.81). Similarly, symmetrical LL exercises demonstrated greater right ES activation at T7 and T12 compared to asymmetrical LL exercises (both $p = 0.001$), with median T7 activation values of 73.51 versus 50.67, respectively. Asymmetrical exercises demonstrated relatively greater contralateral ES activation, particularly at T7 and T12, although left-side differences between exercise categories were not statistically significant across most comparisons. **Conclusion.** Symmetrical extremity exercises elicited greater erector spinae co-contraction, whereas asymmetrical exercises preferentially activated the contralateral erector spinae, providing preliminary evidence to inform exercise selection for trunk muscle rehabilitation pending validation in individuals with idiopathic scoliosis.

Keywords: erector spinae; surface electromyography; asymmetrical exercise; symmetrical exercise; co-contraction; pilot study; idiopathic scoliosis; physiotherapy; spine

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Introduction

Scoliosis is a medical condition resulting in deformity of the spinal column, which is three-dimensional in nature and characterised by a spinal curvature equal to or greater than ten degrees (10°). Its global prevalence rate is estimated at 2%. Idiopathic scoliosis (IS) is the most common form, occurring in approximately 75 to 85% of all cases, with no single identifiable cause (Wang et al., 2025a; Li et al., 2024).

Adolescent idiopathic scoliosis typically manifests as a paraspinal muscular imbalance, particularly affecting the erector spinae (ES) muscle between the right and left sides of the spine, leading to reduced activity on the concave side and increased activity on the convex side (Becker et al., 2023; Park et al., 2021). Physiotherapy exercises are an important intervention in the treatment of scoliosis, with the goal of halting its progress, decreasing spinal deformity, stabilising curve growth and reducing the likelihood of requiring a scoliotic brace or surgery (Romano et al., 2024). Physiotherapy Scoliosis-Specific Exercises (PSSE) involving asymmetrical resistance exercises are frequently used to specifically target the concave side of the curve and improve muscular strength and activation (Wang et al., 2025b).

However, some authors have highlighted limitations in the current PSSE evidence base, including the lack of objective compliance oversight and uncertainty regarding the extent to which PSSE reliably activates the ES muscle compensatory mechanism (Tolo and Herring, 2020). Research by Crommert et al. (2015) demonstrated that upper limb movement can elicit trunk muscle activation through anticipatory postural adjustments, while Kim and Zhang (2017) showed that asymmetric lifting tasks substantially influence trunk muscle forces and spinal loading. Together, these findings suggest that extremity

movement may affect trunk muscle co-contraction. Varrecchia et al. (2022) provided evidence demonstrating that co-contraction of back muscles can impact upon spinal stability. While many studies have sought to determine the association between extremity movement and trunk muscle co-activation, there is a lack of comparative evidence linking symmetrical versus asymmetrical lifting exercises with ES muscle co-contraction measured by sEMG.

A review by Ghofrani et al. (2017) confirmed the reliability of sEMG on trunk muscle measurements, reporting Intra Class Correlation Coefficients (ICC) of 0.73 to 0.97, indicating good reliability. The reliability of sEMG for trunk muscles was further supported by Dankaerts et al. (2004), who reported excellent within-day and between-day reliability (ICC 0.75 to 0.98 and 0.78 to 0.97 respectively) and by Danneels et al. (2001), who reported good reliability (ICC > 0.75) for paraspinal muscle assessment. Therefore, sEMG was selected as the measurement tool for the present study.

Based on the above, this pilot experimental study was designed to address an identified research gap: to the authors' knowledge, limited evidence exists directly comparing the effects of symmetrical and asymmetrical UL and LL extremity exercises on ES muscle co-contraction at specific vertebral levels. The study aims to: (1) determine whether a disparity exists in ES muscle co-contraction between symmetrical and asymmetrical exercises; and (2) ascertain which form of exercise prompts greater ES muscle activation at vertebral levels T7, T12 and L3, which demonstrate the most prevalent patterns of curves in IS (Wang et al., 2025a). It was hypothesised that asymmetrical exercises would produce greater ES co-contraction than symmetrical exercises, given their capacity for selective unilateral loading.

Materials and Methods

Study Design

A quantitative pilot experimental study design was employed. Pilot studies are useful for evaluating intervention safety, improving researcher familiarity with methods and facilitating assessment of exercise strategy and experimental instruments (Blatch-Jones et al., 2018). This design was considered appropriate for the aims of the present study, as it enabled preliminary testing of methods and generation of data to inform a future full-scale trial.

Participants

A convenience sample of 21 participants (16 males, 5 females) was recruited from staff and students at Cardiff University. Healthy participants were selected rather than IS patients for two methodological reasons: first, to establish baseline ES activation patterns in a controlled population before applying the protocol to a clinical group; and second, to ensure participant safety during a novel exercise protocol without prior evidence of feasibility. The gender imbalance reflects the nature of convenience sampling from a university setting and is acknowledged as a limitation. Inclusion criteria required participants to be aged 20 to 50 years, in good health, free from musculoskeletal problems preventing them from lifting weights and to have had no low back pain in the previous six months. Participants were excluded if they had severe spinal conditions (e.g., osteoporosis, spinal canal stenosis, tumors, fibromyalgia, spine fractures, rheumatoid arthritis), restricted range of motion, balance disorders, cardiovascular conditions, skin conditions or self-reported dermal allergies on the back.

Ethical Approval

The Research Governance and Ethics Committee of Cardiff University granted ethical approval prior to

data collection. Participants were provided with an information sheet detailing the study aims and methods and were informed they could withdraw at any time without explanation. Written informed consent was obtained from all participants. Data were kept anonymous using unique participant codes and stored on a password-encrypted computer for no more than five years, in keeping with Cardiff University's data protection policy.

Instrumentation

A wireless sEMG DTS 58616710 device with a six-channel configuration (Noraxon Inc., AZ, USA) was used to measure ES muscle activity. This device was linked to a portable computer with Noraxon software version MR3.8. The reliability of this device type has been confirmed: Ghofrani et al. (2017) reported ICC values of 0.73 to 0.97; Dankaerts et al. (2004) reported ICC 0.75 to 0.98 within-day and 0.78 to 0.97 between-day; and Danneels et al. (2001) reported ICC > 0.75 for paraspinal muscles. To minimise electrode placement variability, all electrode positions were identified using consistent anatomical landmarks, marked prior to placement and verified between exercises. Bipolar Ag/AgCl electrodes were placed in pairs on each side of the ES muscle, separated by a 2 cm space (Young Ko et al., 2018). Electrodes were positioned bilaterally at vertebral levels T7, T12 and L3. Participants' backs were shaved and cleaned with alcohol swabs prior to electrode placement (Krekoukias et al., 2009).

EMG Normalisation

Prior to the resistance training session, EMG data normalisation was performed using the Maximum Voluntary Isometric Contraction (MVIC) technique applied to the ES muscles at levels T7, T12 and L3. Participants lay prone with their xiphoid process aligned with the margin of the table and performed an isometric back hyperextension based on body

weight, with arms crossed at chest level and lower extremities strapped at hip, knee and ankle level to prevent movement. Participants were required to flex their muscles as much as possible with a five-second hold (Park et al., 2015). The percentage value was obtained by dividing the sEMG signals from each exercise by the MVIC signals and multiplying by 100.

Exercise Protocol

The Rate of Perceived Exertion (RPE) scale was applied to assess lifting capacity and determine the optimal weight for each participant, targeting a score of 5 to 6 (Pfeiffer et al., 2002). The use of a participant-selected RPE-based load, rather than a

fixed absolute load, was a deliberate methodological choice to ensure safety across a heterogeneous sample and to reflect typical clinical practice. This approach introduces subjectivity in load selection, which is acknowledged as a limitation. Participants performed four exercises in a randomised, counterbalanced order to prevent learning effects. A five-repetition protocol per exercise was selected as sufficient to generate stable average EMG amplitude data (Burden et al., 2003), while minimising fatigue risk. A warm-up procedure was implemented prior to testing and a three-minute rest period was applied between exercises (Saraiva et al., 2017). The exercises are described in Table 1.

Table 1. Description of the four exercises performed by participants.

Exercise	Type	Description
1. Barbell Shoulder Press	Symmetrical – upper limbs	Lifting of a weighted barbell and performance of an overhead shoulder press with five repetitions
2. Dumbbell Shoulder Press	Asymmetrical – upper limbs	Lifting of a dumbbell with the right upper limb and performance of an overhead shoulder press with five repetitions
3. Dumbbell Single Leg Squat	Asymmetrical – lower limbs	Five-repetition single leg squat with the right leg whilst holding a dumbbell in the right arm, with the left foot resting on a platform behind
4. Weighted Squat (WS)	Symmetrical, lower limbs	Performance of squatting exercise with barbell positioned on the shoulders, with five repetitions

BSP = barbell shoulder press; DSP = dumbbell shoulder press; DSLS = dumbbell single leg squat; WS = weighted squat.

Potential Biases and Confounders

Several potential sources of bias and confounding are acknowledged. First, convenience sampling from a single university introduces selection bias and limits generalisability. Second, all participants were right-hand dominant, and all asymmetrical exercises were performed exclusively on the right side. This introduces a limb dominance confound: the greater right ES activation observed during symmetrical exercises and the preferential left ES activation during asymmetrical exercises may partly reflect the neuromuscular characteristics of dominant versus non-dominant limb loading rather than, or in addition to, the effect of exercise symmetry per se. These two

factors cannot be separated in the current design and the findings should be interpreted accordingly. Future studies should recruit participants with mixed handedness or counterbalance the side of asymmetrical exercise to isolate these contributions. Third, the wide variation in participant weight (51.8 to 114.2 kg) and BMI (20.9 to 35.13 kg/m²) may have influenced sEMG amplitude, as higher BMI has been associated with greater muscle activity (Cho et al., 2018; Green and Gabriel, 2012). Fourth, the gender imbalance (76% male) limits applicability to female populations. These confounders were partially mitigated through MVIC normalisation, randomised exercise order and use of

non-parametric statistical methods.

Statistical Analysis

Data were entered into an Excel spreadsheet and analysed using the Statistical Package for Social Sciences (SPSS), version 25. Normality was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. As data were revealed to lack normal distribution, a non-parametric Wilcoxon signed-rank test was applied (Field, 2017). Descriptive analysis of the median and interquartile range (IQR) was used as the primary reporting metric, as these measures are more appropriate and resistant to outliers in non-normally distributed data (Plichta and Kelvin, 2013). Mean and standard deviation are reported only for participant demographics (Table 2), where data were approximately normally distributed. Statistical significance was set at $p < 0.05$. Effect sizes were calculated using the formula $r = Z$ divided by the square root of N , where Z is the Wilcoxon test statistic and N is the sample size, following the convention of Cohen (1992): $r \geq 0.10$ = small; $r \geq 0.30$ = medium; $r \geq 0.50$ = large. It should be noted that when multiple between-exercise comparisons yield the same p -value ($p = 0.001$) with identical sample size ($N = 21$), the formula $r = Z$ divided by the square root of N will produce identical r values, as identical Wilcoxon Z statistics with identical sample sizes produce identical p -values and effect sizes, and repeated r values were therefore expected. The identical $r = 0.72$ values reported across between-exercise comparisons therefore reflect mathematically equivalent statistical outcomes, not an error in calculation. Given the exploratory pilot nature of the study, no correction for multiple testing was applied, to avoid inflating Type II error and suppressing potentially meaningful signals in a small sample. Findings should therefore be interpreted cautiously as preliminary and hypothesis-generating rather than confirmatory.

Results

Participant Demographics

Twenty-one participants completed the study. Demographic characteristics are presented in Table 2.

Table 2. Demographic characteristics of study participants ($N = 21$).

Characteristic	Mean	SD	Range
Age (years)	30.4	6.7	18 – 50
Height (cm)	170.4	8.9	154 – 186
Weight (kg)	79.5	15.7	51.8 – 114.2
BMI (kg/m^2)	27.17	3.57	20.9 – 35.13
Gender	16 males, 5 females	–	–

SD = standard deviation; BMI = body mass index.

Tests of Normality

The Kolmogorov-Smirnov and Shapiro-Wilk normality tests revealed that data lacked normal distribution across the majority of conditions. Therefore, non-parametric analysis using the Wilcoxon signed-rank test was applied throughout.

Effect of Individual Exercises on ES Muscle Co-Contraction

Barbell Shoulder Press (BSP, Symmetrical Upper Limb)

Assessment of the BSP (Table 3) at levels T7, T12 and L3 demonstrated no statistically significant differences between left and right ES co-activation (T7: $p = 0.068$; T12: $p = 0.876$; L3: $p = 0.131$), with corresponding effect sizes of $r = 0.40$, $r = 0.03$ and $r = 0.33$ respectively. However, the median values of the right side were consistently greater than the left across all three levels (Right T7 Median = 64.09 > Left T7 Median = 55.33; Right T12 Median = 31.47 > Left T12 Median = 29.60; Right L3 Median = 29.92 > Left L3

Median = 24.57). Full data are presented in Table 3 and Figure 1.

Table 3. Wilcoxon test results for barbell shoulder press, right vs. left ES co-contraction at T7, T12, and L3.

Level	Side	Median (%MVC)	Q1	Q3	Z	p-value	r
T7	Right	64.09	41.9	83.8	1.825	0.068	0.40
T7	Left	55.3	30.28	73.57			
T12	Right	31.47	22.14	38.93	0.156	0.876	0.03
T12	Left	29.60	15.15	41.63			
L3	Right	29.92	20.94	37.16	1.512	0.131	0.33
L3	Left	24.57	15.80	30.84			

Q1 and Q3 = first and third quartile; r = effect size. No statistically significant differences ($p > 0.05$).

Figure 1. BSP: Right vs. Left ES Co-Contraction at T7, T12 and L3

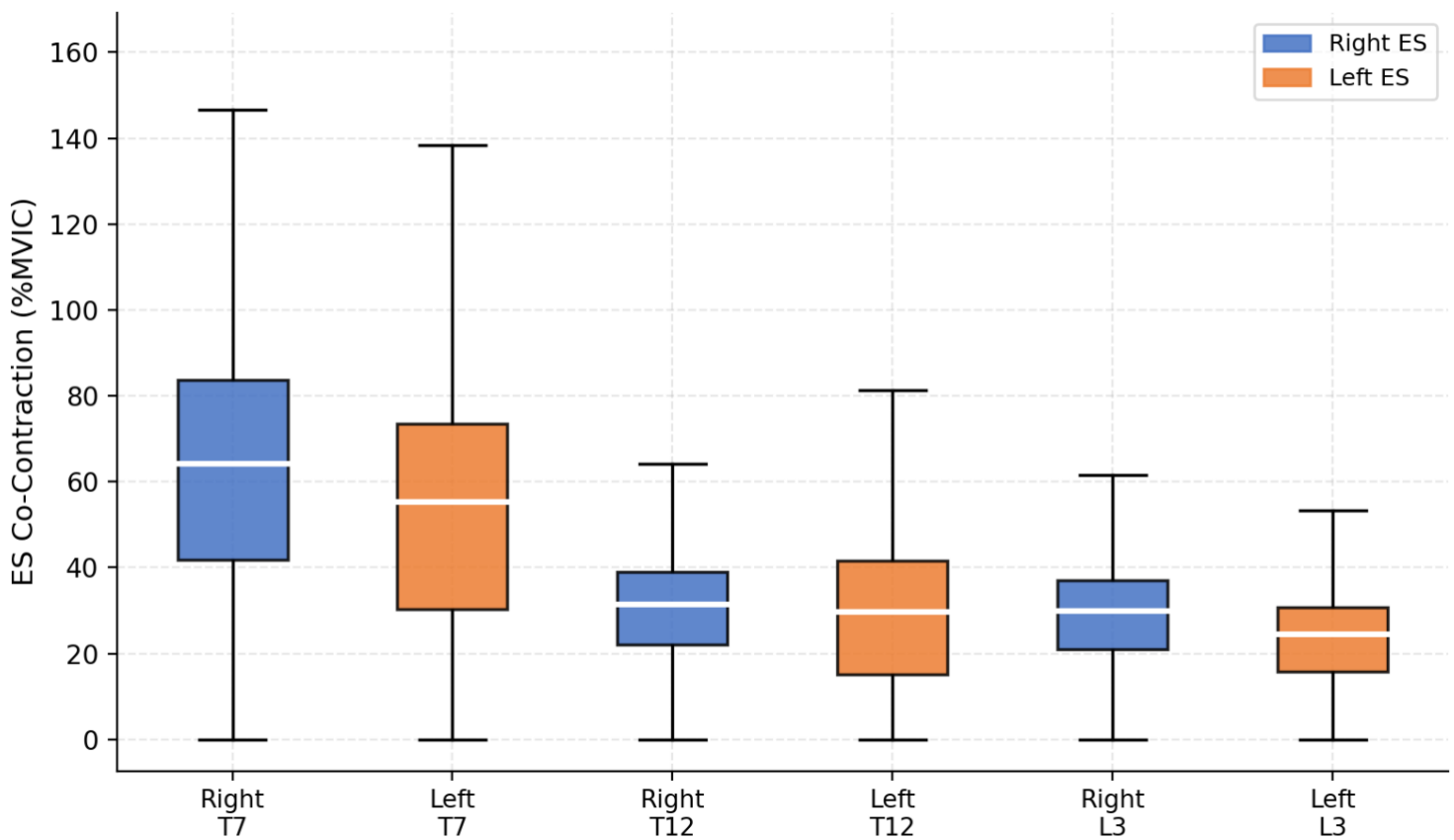


Figure 1. Boxplot of right and left ES muscle co-contraction (%MVIC) during BSP at T7, T12 and L3. White line = median; box = IQR (Q1 to Q3); whiskers = 1.5 x IQR. No statistically significant differences.

Dumbbell Shoulder Press (DSP, Asymmetrical Upper Limb)

The DSP, performed with the right arm only, produced statistically significant differences between left and right ES activation at T7 ($Z = 2.902$, $p = 0.004$, $r = 0.63$, large effect) and T12 ($Z = 3.771$, p

$= 0.001$, $r = 0.82$, large effect). At both levels, the left-side median was significantly greater than the right, with T7 values of 59.11 (left) versus 34.81 (right) and T12 values of 36.80 (left) versus 16.91 (right). At L3, no significant difference was found ($Z = 1.894$, $p = 0.058$, $r = 0.41$), though the left median (30.79) remained higher than the right (17.46). Full data are

in Table 4 and Figure 2.

Table 4. Wilcoxon test results for dumbbell shoulder press, right vs. left ES co-contraction at T7, T12 and L3.

Level	Side	Median (%MVC)	Q1	Q3	Z	p-value	r
T7	Right	34.81	20.32	49.86	2.902	0.004*	0.63
T7	Left	59.11	38.67	68.25			
T12	Right	16.91	11.35	21.75	3.771	0.001*	0.82
T12	Left	36.80	20.13	47.73			
L3	Right	17.46	15.45	30.55	1.894	0.058	0.41
L3	Left	30.79	16.33	37.28			

*p < 0.05. Q1 and Q3 = first and third quartile; r = effect size.

Figure 2. DSP: Right vs. Left ES Co-Contraction at T7, T12 and L3

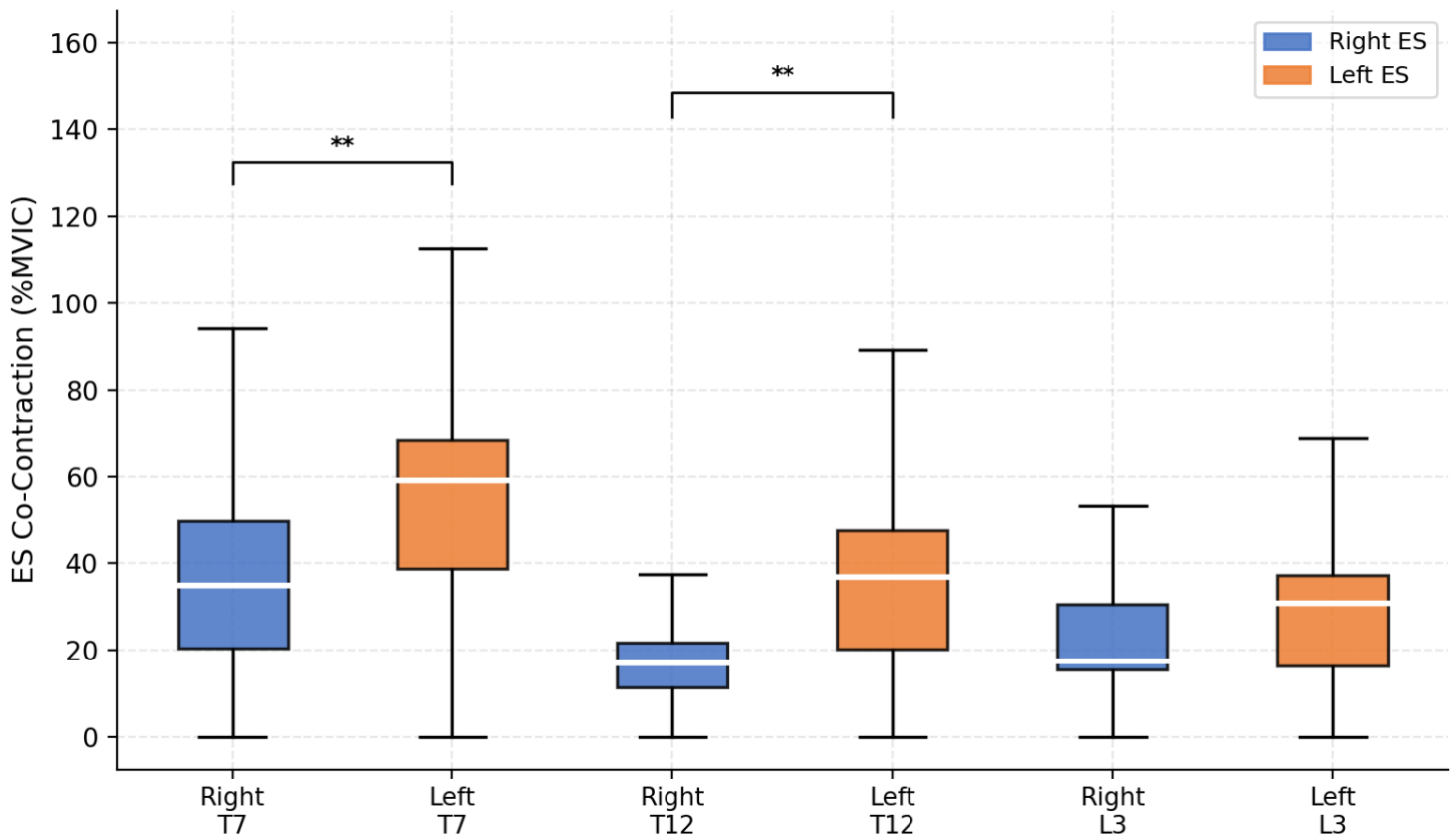


Figure 2. Boxplot of right and left ES muscle co-contraction (%MVIC) during DSP at T7, T12 and L3. ** p < 0.01.

Dumbbell Single Leg Squat (DSLS, Asymmetrical Lower Limb)

The DSLS, performed on the right leg, produced statistically significant differences at T7 (Z = 3.076, p = 0.002, r = 0.67, large effect) and T12 (Z = 3.250, p =

0.001, r = 0.71, large effect), with the left-side median significantly greater than the right at both levels: T7 values of 66.30 (left) versus 50.67 (right); T12 values of 69.14 (left) versus 37.78 (right). No significant difference was found at L3 (Z = 0.087, p = 0.931, r = 0.02, negligible effect). Full data are in Table 5 and

Figure 3.

Table 5. Wilcoxon test results for dumbbell single leg squat, right vs. left ES co-contraction at T7, T12 and L3.

Level	Side	Median (%MVC)	Q1	Q3	Z	p-value	r
T7	Right	34.81	20.32	49.86	2.902	0.004*	0.67
T7	Left	59.11	38.67	68.25			
T12	Right	16.91	11.35	21.75	3.771	0.001*	0.71
T12	Left	36.80	20.13	47.73			
L3	Right	17.46	15.45	30.55	1.894	0.058	0.02
L3	Left	30.79	16.33	37.28			

* p < 0.05. Q1 and Q3 = first and third quartile; r = effect size.

Figure 3. DSLS: Right vs. Left ES Co-Contraction at T7, T12 and L3

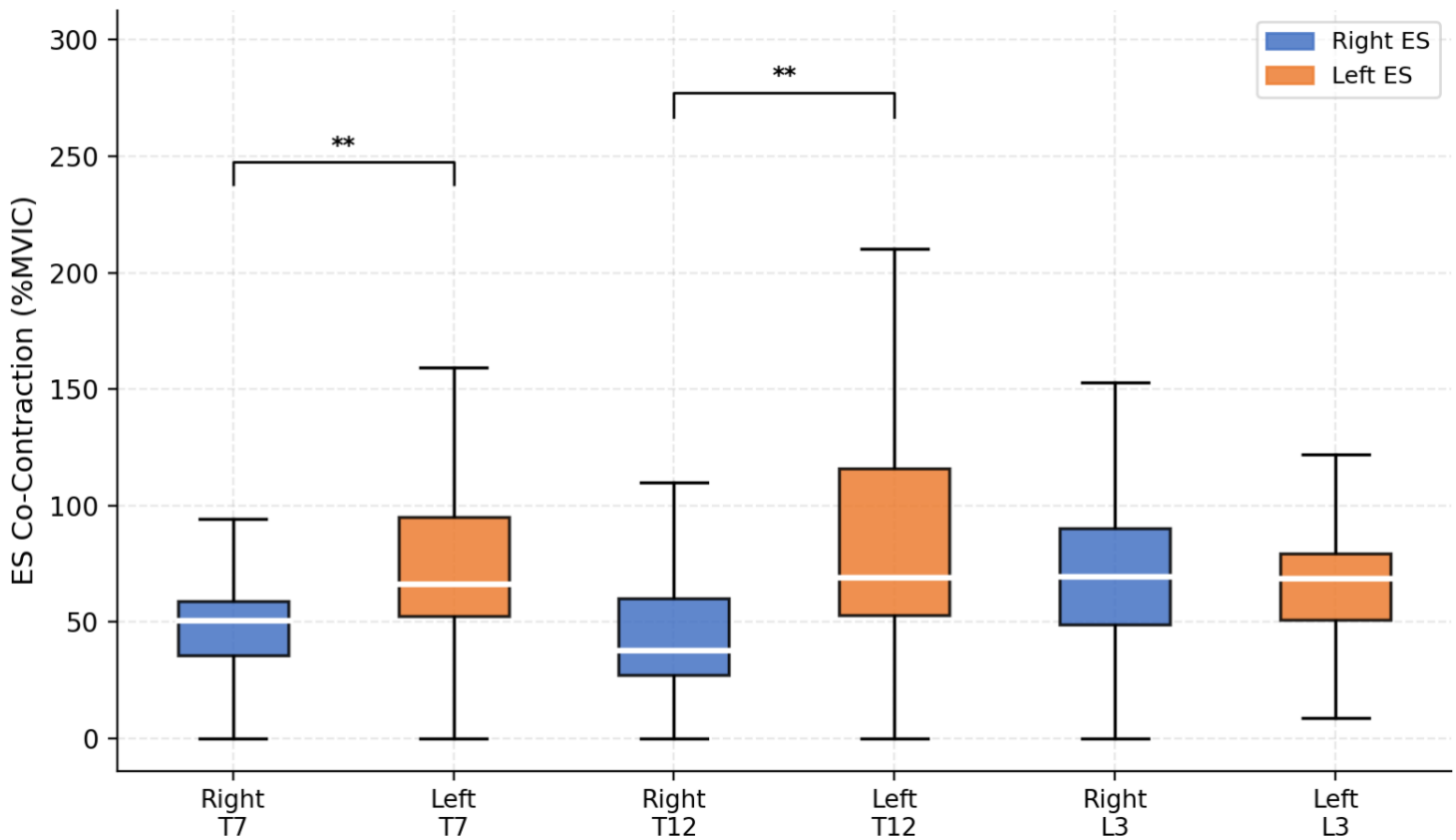


Figure 3. Boxplot of right and left ES muscle co-contraction (%MVIC) during DSLS at T7, T12 and L3. ** p < 0.01.

Weighted Squat (WS, Symmetrical Lower Limb)

No statistically significant differences were observed between left and right ES activation at any level in response to the WS (T7: Z = 0.556, p = 0.578, r = 0.12; T12: Z = 1.147, p = 0.251, r = 0.25; L3: Z = 0.226, p =

0.821, r = 0.05). At T7 and L3 the right-side median was moderately greater than the left (T7: 73.51 vs. 71.78; L3: 67.33 vs. 64.69), while at T12 the left (79.16) was greater than the right (66.24). Full data are in Table 6 and Figure 4.

Table 6. Wilcoxon test results for weighted squat, right vs. left ES co-contraction at T7, T12 and L3.

Level	Side	Median	Q1	Q3	Z	p-value	r
T7	Right	34.81	20.32	49.86	2.902	0.004*	0.12
T7	Left	59.11	38.67	68.25			
T12	Right	16.91	11.35	21.75	3.771	0.001*	0.25
T12	Left	36.80	20.13	47.73			
L3	Right	17.46	15.45	30.55	1.894	0.058	0.05
L3	Left	30.79	16.33	37.28			

Q1 and Q3 = first and third quartile; r = effect size. No statistically significant differences ($p > 0.05$).

Figure 4. WS: Right vs. Left ES Co-Contraction at T7, T12 and L3

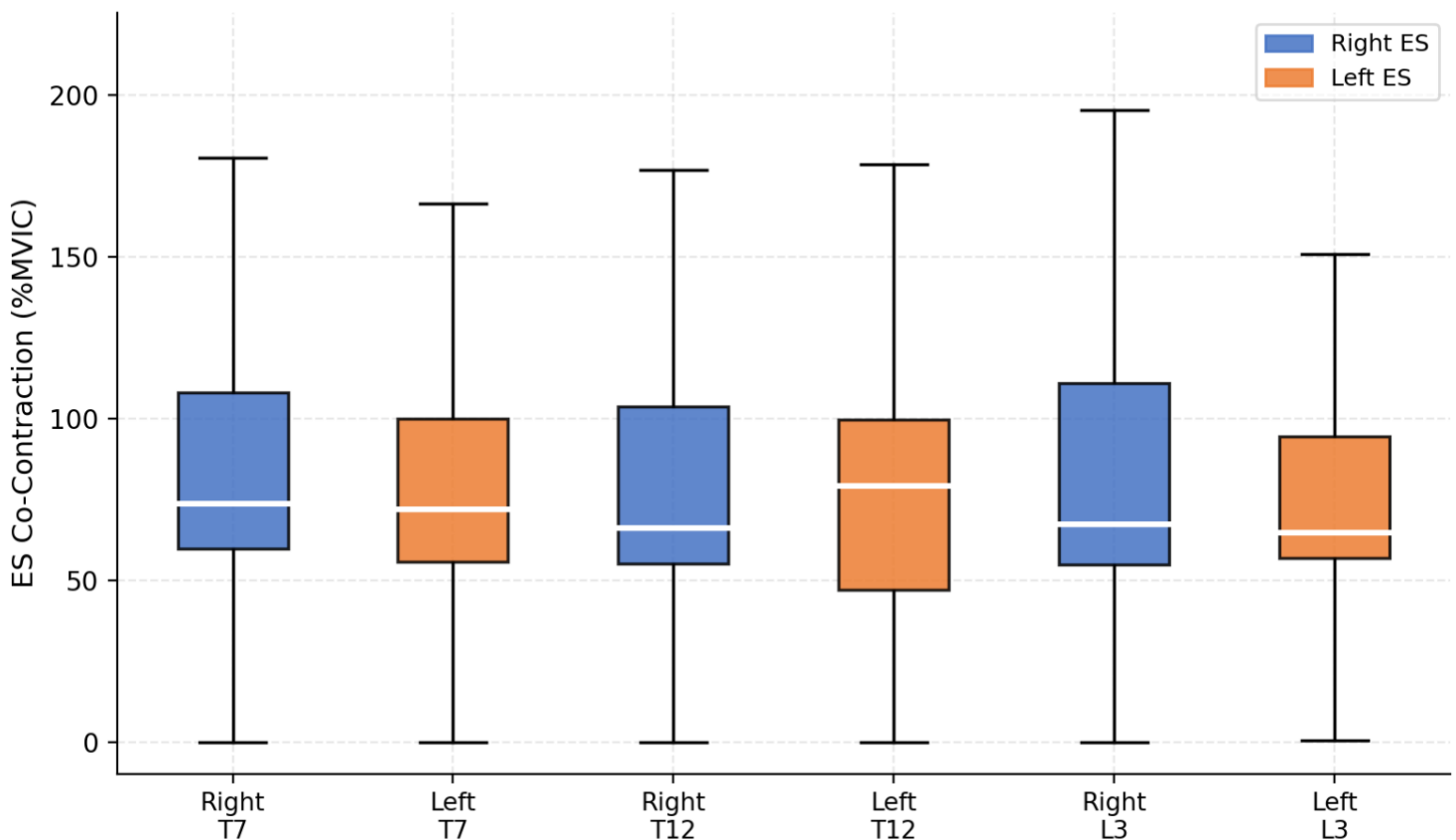


Figure 4. Boxplot of right and left ES muscle co-contraction (%MVIC) during WS at T7, T12 and L3. No statistically significant differences.

Comparison: Symmetrical vs. Asymmetrical Upper Extremity Exercises (BSP vs. DSP)

Comparison of BSP versus DSP (Table 7) revealed statistically significant differences in right ES co-contraction at all three levels (T7: $p = 0.001$, $r = 0.72$;

T12: $p = 0.001$, $r = 0.72$; L3: $p = 0.001$, $r = 0.72$), all indicating large effects. In all cases, BSP produced greater right ES activation: at T7, 64.09 (BSP) versus 34.81 (DSP); at T12, 31.47 (BSP) versus 16.91 (DSP); at L3, 29.92 (BSP) versus 17.46 (DSP). For the left ES muscle, no statistically significant differences were

observed (T7: $p = 0.779$; T12: $p = 0.058$; L3: $p = 0.114$). However, moderately higher left-side activation was noted with DSP at all levels: T7, 59.11 (DSP) versus

55.33 (BSP); T12, 36.80 (DSP) versus 29.60 (BSP); L3, 30.79 (DSP) versus 24.57 (BSP). Full data are in Table 7 and Figure 5.

Table 7. BSP vs. DSP, right and left ES co-contraction at T7, T12 and L3.

Exercise, Level	Right Median	Q1	Q3	p-value (Right)	r	Left Median	Q1	Q3	p-value (Left)	r
BSP, T7	64.09	41.92	83.77	0.001**	0.72	55.33	30.28	73.57	0.779	n/a
DSP, T7	34.81	20.32	49.86			59.11	38.67	68.25		
BSP, T12	31.47	22.14	38.39	0.001**	0.72	29.60	15.15	41.63	0.058	n/a
DSP, T12	16.91	11.35	21.75			36.80	20.13	47.73		
BSP, L3	29.92	20.94	37.16	0.001**	0.72	24.57	15.80	30.84	0.114	n/a
DSP, L3	17.46	15.45	30.55			30.79	16.33	37.28		

** Significant at the 0.001 level. BSP = barbell shoulder press; DSP = dumbbell shoulder press; r = effect size; n/a = not applicable.

Figure 5. BSP vs. DSP: ES Co-Contraction at T7, T12 and L3

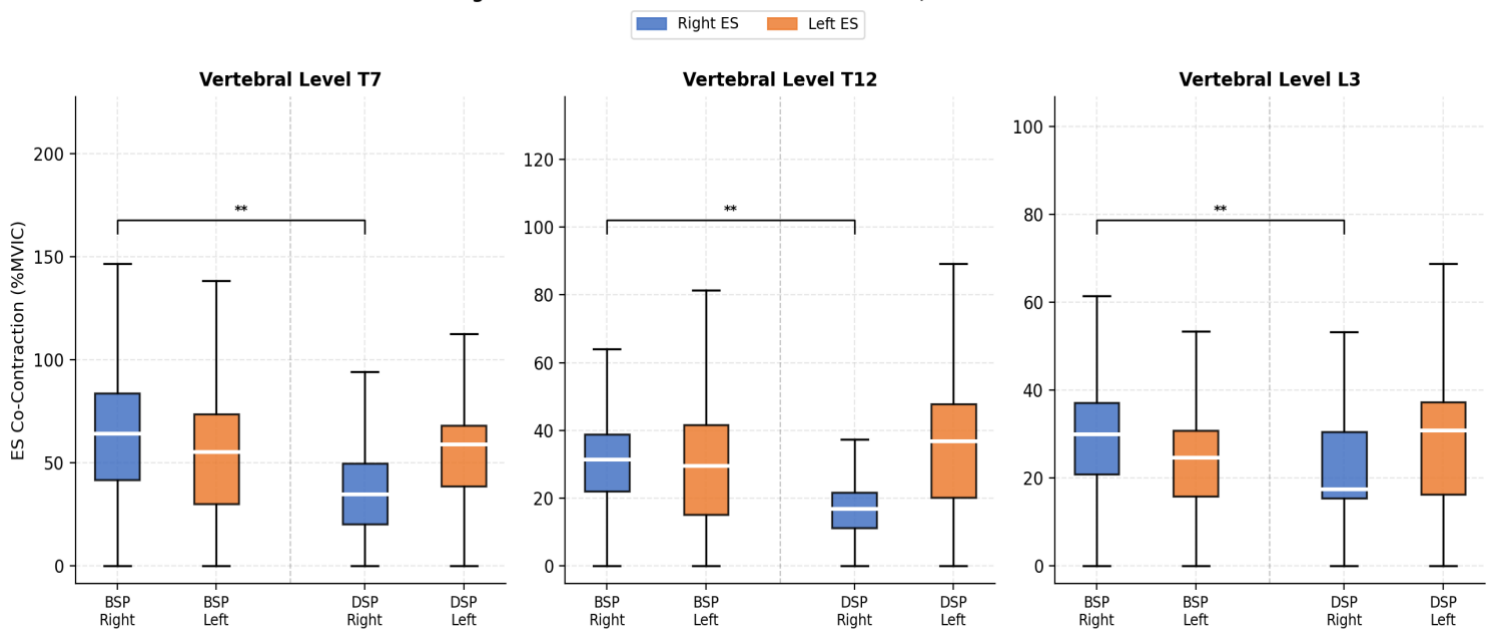


Figure 5. Boxplot comparison of BSP vs. DSP ES co-contraction (%MVIC) at T7, T12 and L3. ** Significant at the 0.001 level. Dashed vertical line separates exercise conditions..

In summary, symmetrical upper limb exercise (BSP) produced significantly and substantially greater ipsilateral (right) ES co-contraction across all three levels, with large effect sizes ($r = 0.72$). Asymmetrical upper limb exercise (DSP) produced relatively greater contralateral (left) ES activation, though this did not reach statistical significance in the between-exercise comparison.

Comparison: Symmetrical vs. Asymmetrical Lower Extremity Exercises (WS vs. DSLS)

Comparison of WS versus DSLS (Table 8) revealed statistically significant differences in right ES co-contraction at T7 ($p = 0.001$, $r = 0.72$, large effect) and T12 ($p = 0.001$, $r = 0.72$, large effect), with WS producing greater right-side activation: at T7, 73.51

(WS) versus 50.67 (DSLS); at T12, 66.24 (WS) versus 37.78 (DSLS). No significant difference was found at L3 ($p = 0.444$). For the left ES muscle, no statistically

significant differences were observed at any level (T7: $p = 0.217$; T12: $p = 0.305$; L3: $p = 0.289$). Full data are in Table 8 and Figure 6.

Table 8. WS vs. DSLS, right and left ES co-contraction at T7, T12 and L3.

Exercise, Level	Right Median	Q1	Q3	p-value (Right)	r	Left Median	Q1	Q3	p-value (Left)	r
BSP, T7	73.51	59.64	108.07	0.001**	0.72	71.78	55.62	99.95	0.217	n/a
DSP, T7	50.67	35.52	59.11			66.30	52.47	95.24		
BSP, T12	66.24	55.19	103.86	0.001**	0.72	79.16	47.20	99.75	0.305	n/a
DSP, T12	37.78	27.16	60.33			69.14	52.77	115.79		
BSP, L3	67.33	54.72	110.92	0.444	0.72	64.69	56.86	96.41	0.289	n/a
DSP, L3	69.29	49.02	90.49			68.48	51.10	79.39		

** Significant at the 0.001 level. BSP = barbell shoulder press; DSP = dumbbell shoulder press; Q1 = first quartile; Q3 = third quartile.

Figure 6. WS vs. DSLS: ES Co-Contraction at T7, T12 and L3

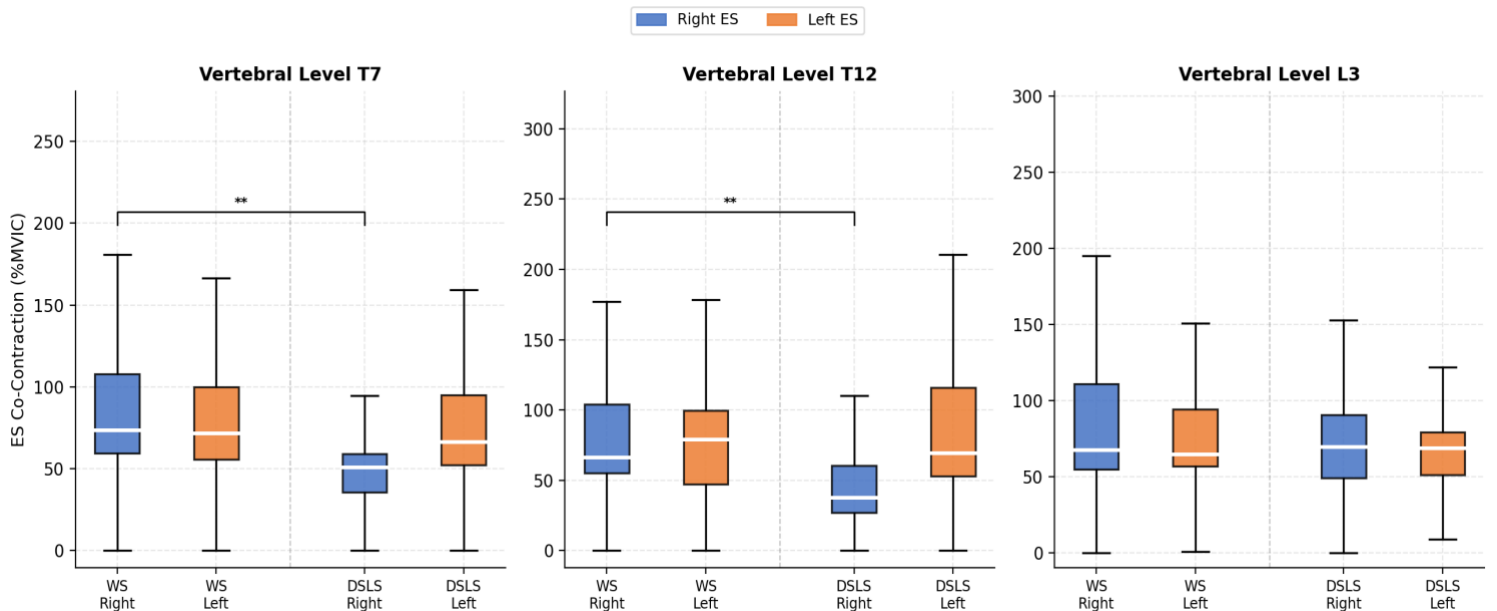


Figure 5. Boxplot comparison of BSP vs. DSP ES co-contraction (%MVIC) at T7, T12 and L3. ** Significant at the 0.001 level. Dashed vertical line separates exercise conditions.

In summary, symmetrical lower limb exercise (WS) produced significantly greater ipsilateral (right) ES co-contraction at T7 and T12 with large effect sizes ($r = 0.72$). Asymmetrical lower limb exercise (DSLS) produced relatively greater contralateral (left) ES activation at T7 and T12, though this did not reach statistical significance in the between-exercise comparison.

Discussion

This pilot experimental study compared the effects of symmetrical and asymmetrical upper limb (UL) and lower limb (LL) extremity exercises on erector spinae (ES) muscle co-contraction at specific vertebral levels (T7, T12 and L3) using sEMG in healthy adults. The study hypothesis that asymmetrical exercises would produce greater ES co-contraction was rejected. Two notable patterns emerged from the data. First, symmetrical exercises (BSP and WS)

produced significantly greater ipsilateral (right) ES co-contraction across all tested vertebral levels, with consistently large effect sizes ($r = 0.72$) in between-exercise comparisons. Second, and of greater potential clinical relevance, asymmetrical exercises (DSP and DSLS) produced preferential contralateral (left) ES activation at T7 and T12, with large effect sizes within each exercise (DSP: $r = 0.63$ at T7, $r = 0.82$ at T12; DSLS: $r = 0.67$ at T7, $r = 0.71$ at T12). Notably, this contralateral activation pattern was absent at L3 across both asymmetrical exercises, suggesting a vertebral level-dependent response that warrants mechanistic investigation.

Demographic Data

The most important demographic features of this sample are that all participants were healthy adults without IS, and that the sample was predominantly male (76%). The healthy adult population provides a controlled environment to establish baseline neuromuscular patterns, but introduces an inherent extrapolation challenge when interpreting findings in the context of IS rehabilitation, as the structural and neuromuscular environment of a healthy spine differs fundamentally from that of a scoliotic spine. The gender imbalance limits the generalisability of findings to female populations, who constitute the majority of IS cases and who may exhibit different neuromuscular recruitment strategies during loaded exercises. Additionally, the wide variation in participant BMI (20.9 to 35.13 kg/m²) is noted as a potential source of sEMG amplitude variability, since adipose tissue attenuates surface signals and overweight individuals may recruit greater trunk muscle activity independently of exercise type (Cho et al., 2018; Green and Gabriel, 2012). MVIC normalisation was applied to partially mitigate these effects, though residual confounding cannot be fully excluded.

Upper Extremity Exercises and ES Muscle Co-

Contraction

Both the BSP and DSP produced ES co-contraction across all three vertebral levels, consistent with the concept of anticipatory postural adjustment, whereby the central nervous system activates trunk muscles to pre-stabilise the spine against reactive forces during loading (Crommert et al., 2015). The magnitude of postural activation is load-dependent (Crommert et al., 2015; Varrecchia et al., 2022). Participants used heavier absolute loads during BSP than DSP to achieve the same RPE score, and this load differential cannot be excluded as a contributor to the greater right ES activation during BSP. Future studies should standardise absolute load across bilateral and unilateral conditions to isolate the independent contribution of exercise symmetry. The DSP produced significantly greater left ES activation at T7 and T12, with large effect sizes ($r = 0.63$ and $r = 0.82$ respectively), consistent with contralateral compensatory stabilisation against the lateral bending moment generated by unilateral upper limb loading (Panhan et al., 2019; Coloma et al., 2018). The present findings diverge from Saeterbakken and Fimland (2012), who examined different vertebral levels (L1, L2, L5, S1), suggesting the contralateral ES response to unilateral loading is vertebral level-specific.

Lower Extremity Exercises and ES Muscle Co-Contraction

Both the WS and DSLS produced ES co-contraction across all three vertebral levels. The WS produced significantly greater right ES activation at T7 and T12, mirroring the load-dependent pattern observed for upper limb exercises. The DSLS produced significantly greater left ES activation at T7 and T12 ($r = 0.67$ and $r = 0.71$ respectively), replicating the contralateral compensatory pattern of the DSP. The consistency of this contralateral response across two anatomically distinct exercise modalities

suggests it reflects a generalised neuromuscular strategy for spinal stabilisation during asymmetrical loading, rather than an exercise-specific effect. The absence of a similar finding at L3 in both asymmetrical exercises is a noteworthy negative finding that warrants further mechanistic investigation.

Potential Clinical Relevance and Implications for Future Research

The rejection of the study hypothesis is scientifically meaningful. The pattern of activation, rather than its magnitude, differentiates symmetrical from asymmetrical exercise: symmetrical exercises generated greater ipsilateral activation, while asymmetrical exercises generated preferential contralateral activation. Before any clinical interpretation is drawn, an important methodological caveat must be acknowledged. All participants were right-hand dominant and all asymmetrical exercises were performed on the right side. It is not possible to determine whether the preferential left ES activation reflects a true contralateral compensatory mechanism, a neuromuscular characteristic of loading the dominant limb, or a combination of both. Notwithstanding this caveat, the consistency of the pattern across two anatomically distinct exercises and the large effect sizes suggest the finding is sufficiently consistent to warrant further investigation under controlled handedness conditions.

In IS, the ES on the concave side typically exhibits reduced electromyographic activity (Park et al., 2021; Becker et al., 2023; Wilczyński, 2021). Current PSSE approaches address this imbalance through asymmetric postural exercises designed to selectively activate the concave-side musculature (Wang et al., 2025b; Romano et al., 2024). The present study introduces a potentially

complementary strategy: contralateral ES activation via asymmetrical extremity exercises. If a similar activation pattern were present in AIS populations, asymmetrical extremity exercises may have the potential to preferentially recruit the contralateral ES musculature. This possibility remains hypothetical because these findings are exploratory observations from healthy adults and cannot be directly generalised to AIS populations. Further clinical investigation in AIS populations is required before these findings can be translated into practice.

Vertebral Level Specificity and Effect Size Interpretation

A consistent finding was the absence of significant contralateral ES activation at L3, in contrast to large effects at T7 and T12. This level-specific gradient was replicated across both asymmetrical exercises and warrants further investigation. Several speculative explanations may account for this observation. It is possible that the thoracic ES, operating within the rib cage environment, responds more strongly to unilateral loading demands than the lumbar ES at L3, where stabilisation forces may be distributed across a wider range of structures including the quadratus lumborum, iliopsoas, and abdominal obliques. Alternatively, the motor control of thoracic and lumbar ES segments may be at least partly dissociable, with thoracic motor units responding preferentially to shoulder and hip loading demands. These proposed mechanisms remain speculative in the absence of direct neurophysiological evidence and should be investigated in future mechanistic studies.

Regarding effect size interpretation, the identical $r = 0.72$ values reported across all six between-exercise comparisons are a mathematical consequence of the statistical methodology rather than an error. When multiple comparisons yield identical p-values ($p = 0.001$) with identical sample size ($N = 21$), the

formula $r = Z$ divided by the square root of N produces identical r values because identical Wilcoxon Z statistics with identical sample sizes produce identical p -values and effect sizes, and repeated r values were therefore expected. These values should be interpreted as indicating large effect magnitude and direction rather than as precise population estimates. Replication in larger samples will be necessary to establish stable effect size estimates for future power calculations.

Study Limitations

The following limitations should be considered when interpreting these findings: Small convenience sample ($N = 21$) limits statistical power and generalisability. All participants were healthy adults without IS; findings cannot be directly extrapolated to IS patients. Predominantly male sample (76%) limits applicability to female populations, who represent the majority of IS cases. Participant physical activity level, resistance training experience, and familiarity with the exercise protocol were not formally assessed; exercise experience can influence neuromuscular activation patterns and represents an uncontrolled variable in this study. All participants were right-hand dominant and all asymmetrical exercises were performed on the right side; limb dominance and exercise asymmetry effects cannot be separated in this design. Wide variation in participant BMI may have influenced sEMG amplitudes despite MVIC normalisation. One above-threshold observation was identified at L3 during the DSP (observed value: 56.58; threshold: 53.2) in a participant with higher BMI; the use of median and IQR throughout limits the impact of this observation on group-level estimates. Single-session design does not capture training adaptation or longitudinal effects. No standardisation of absolute exercise load; heavier loads in symmetrical exercises may partly explain greater ipsilateral ES activation. A total of 20 Wilcoxon signed-rank tests

were conducted across individual and between-exercise comparisons. No correction for multiple pairwise comparisons was applied; the large number of comparisons increases the risk of Type I error and results should therefore be interpreted as preliminary and hypothesis-generating. Effect sizes were calculated using the Z divided by square root of N method; identical p -values with identical N necessarily yield identical r values, which should be interpreted as indicating equivalent effect magnitudes rather than as a calculation error.

Recommendations for Future Research

A load-matched mechanistic study in healthy adults comparing bilateral and unilateral exercises at identical absolute loads is the most immediate research priority, to isolate the independent contribution of exercise symmetry to ES activation patterns. This study should recruit participants of mixed handedness and counterbalance the side of asymmetrical exercise. The second priority is a controlled sEMG study in AIS patients comparing ES activation between concave and convex sides during asymmetrical exercises. Following confirmation of these findings in AIS populations through a dedicated sEMG study, a fully powered randomised controlled trial should be considered, with primary outcomes including Cobb angle change, sEMG symmetry index, and validated patient-reported quality of life measures.

Conclusion

This pilot experimental study demonstrated that both symmetrical and asymmetrical extremity exercises produce ES muscle co-contraction across multiple vertebral levels in healthy adults. The study hypothesis was rejected: symmetrical exercises generated significantly greater ipsilateral ES activation, with large effect sizes ($r = 0.72$). However, asymmetrical exercises produced a noteworthy

pattern of preferential contralateral ES activation, consistent with a possible ES compensatory activation pattern. These are exploratory findings from a small healthy sample and should not be directly generalised to IS patients. Further clinical studies in AIS populations are required before clinical recommendations can be made.

Author Contributions

Mohammad Mamdoah M. Subahi contributed to the all aspect of study, including conception, design, material preparation, data collection, analysis, manuscript initial and final draft, and critically edited for the intellectual contents.

Ethical Approval and Patient Consent

The Research Governance and Ethics Committee of Cardiff University granted ethical approval prior to data collection. This research carried on human data in compliance with Declarations of Helsinki (2010). Written informed consent was obtained from all participants.

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The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Conflicts of Interest

The authors declare no potential conflicts of interest in this study.

Declaration of generative AI and AI-assisted technologies

The author utilized AI tools to enhance the language quality and address any grammatical issues while preparing the manuscript. Following the use of this tool, the author carefully reviewed and edited the content as necessary and assumes full responsibility for the accuracy and integrity of the published work.

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