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ORIGINAL RESEARCH

Left–Right Differential Erector Spinae Muscles Activation in Prone and Quadruped Positions

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Left–right differential erector spinae (ES) muscle strengthening is required to correct ES muscle imbalances. The objective was to test the effect of 6 body positions on the differential activation of the ES muscles. In 14 able-bodied young women, using a surface electromyography system, the bilateral ES muscles activity at the third lumbar (ES_{L3}) and the 10th (ES_{T10}) and 6th (ES_{T6}) thoracic vertebral levels was measured with the contralateral arm and leg lifted in the prone and quadruped conditions and with a single arm lifted in the quadruped position. Results showed that the activity of the ES_{L3} was symmetrical ($P > .05$) and significantly smaller than that of the thoracic ES muscles in all body positions ($P < .01$). The ES_{T10} and ES_{T6} were differentially activated in all tests ($P < .001$). Besides, the differential activation was higher in the contralateral-arm and -leg lift in the quadruped position than in the other positions. In conclusion, contralateral-arm and -leg lift and single-arm lift in the quadruped and prone positions are capable of differentially activating the ES muscles on one side more than the other side. Further studies are recommended to examine the effectiveness of these exercises on the correction of ES muscle imbalances in clinical populations.

***Keywords*:** unilateral muscle activity, electromyography, exercises

Trunk muscle stabilizers are important to maintain adequate posture in standing or during movement. Erector spinae (ES) muscles are the main trunk stabilizers that run vertically along both sides of the spine from the pelvis to the skull. Normally, the origins/insertions, cross-sectional area, muscle fiber types, muscle volume, muscle activation pattern, and strength of the ES muscles on the right and left sides of the spine are symmetrical (balanced).[1] Muscle imbalance is referred to as a condition wherein one (or more) of these items is greater or smaller on one side than the other side of the spine. In an ideal normal musculoskeletal system, during a given symmetrical flexion/extension task, the electromyography (EMG) and the generated force on the right and left ES muscles are expected to be similar. Therefore, when activated bilaterally, the ES muscles are considered the main extensor of the trunk,[1,2] whereas a unilateral muscle contraction generates an ipsilateral side flexion of the trunk. Regardless of the underlying cause, imbalanced ES muscles may produce an altered or asymmetrical EMG pattern and muscle force, which impose asymmetrical forces on the discs and facet joints of the spine. The imbalanced ES muscle activity might be associated with low back pain, postural deficits, and spinal deformities, such as scoliosis, and its correction has clinical value.[3–8] In such circumstances where imbalanced ES muscles activity exists, the specific exercises that can differentially strengthen the weaker side are needed to create balance and cure the abnormality.

It is suggested that trunk exercises strengthen and increase the thickness of the ES and abdominal muscles.[9] However, in high-load trunk exercises, the dominant side muscles are more activated than the nondominant side.[10] Therefore, ES muscles imbalance could be developed in professional athletes, especially among those who often use their dominant limb to perform sports skills.[11] A prolonged poor posture, job tasks requiring an asymmetrical posture, neurological diseases, or structural deformity could also result in asymmetrical ES activity, leading to muscle strength imbalance and spinal deformity.[3,4,9,12–14] It was shown in scoliosis that the ES muscle on the convex side of the scoliotic curvature is weaker than on the concave side, as demonstrated by higher electrical activity in the weaker side.[3,4] Therefore, a better understanding of specific exercises that can strengthen one side of the ES muscles more than the other side has clinical value and can help to develop rehabilitation programs for improving the muscle balance and minimizing the asymmetrical mechanical forces imposed on the spine in various physical activities.

Muscle force cannot be directly measured. However, it is positively correlated with the level of muscle activity, which can be measured by EMG. To generate a greater muscle force, a higher electrical activity is required (involving larger motor units and a higher firing rate).[15,16] A weaker muscle displays a greater activation level than the stronger muscle to produce the same force.

Surface EMG during various exercises is widely used to identify a possible asymmetrical muscle activity, identify the muscle activity pattern in a given performance, improve rehabilitation techniques, optimize exercise selection, overcome training stagnation, or identify the risk of injuries.[17–20] After identification of the weaker side of the ES muscle, exercises with the capacity of activating the weaker side more than the opposite side are required for rehabilitation of the imbalance condition, such as scoliosis.[4,21,22] However, it is still unknown which exercises can highly activate ES muscles of a particular region (upper thoracic, lower thoracic, or lumbar) only at the designated side while keeping the opposite side with minimal activation. Furthermore, it is not clear which body position (prone, bipedal, or quadrupedal) stance is best to perform these exercises.

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In practice, the prone and quadruped positions are well accepted by many physical therapists to strengthen the ES muscles because in these positions the compression forces on the spine are greatly reduced.[2,23–26] Contralateral-arm and -leg lift in prone and quadruped positions are utilized to solicit unilateral activation of the lumbar ES muscles.[2,23]

There are numerous studies on muscle strengthening exercises,[27,28] therapeutic and trunk stabilization training,[24,29] and body posture realignment.[23,25] But most of these exercises are proposed for strengthening of the global back muscles. Kim et al[23] examined the selective activation of the ES in trunk extension in prone and quadruped positions.[23] However, they recorded the lumbar ES and multifidus muscles of the left side only at L2 and L5 vertebral levels, respectively. In most of the previous studies, the EMG activity of ES muscles is reported only at one level or in one side of the vertebral level.[23,30–32] Therefore, their results could not show the capacity of the applied exercises for differential activation of the right versus left ES muscles or selectivity between the thoracic and lumbar region. Ko et al[29] recorded bilateral ES muscles at T7, T12, and L3 vertebral levels in a few exercises, including hand and leg raise in prone position,[29] but they only reported the raw data (in microvolts) without normalizing the signals.

Despite the fact that differential strengthening of the ES muscles is required in most of the clinical conditions, such as low back pain, scoliosis, and strokes, the previous studies suffer from serious limitations. To the best of our knowledge, no study addressed the differential activation of the ES muscles at the lumbar and thoracic regions. Both factors, the symmetry/asymmetry (right vs left) and the region (thoracic, thoracolumbar, and lumbar), are important. Sometimes in clinical conditions, such as in scoliosis, we may need to strengthen only the right thoracolumbar region. Therefore, based on the previous base of knowledge, it is impossible to suggest a particular exercise to differentially and selectively strengthen the ES muscles. Understanding of which exercise can strengthen a particular side and region of the spine is essential for successful rehabilitation and treatment of clinical conditions with imbalanced ES muscles. Physical therapists often position the patient in the prone or the quadruped positions for the treatment of low back pain and scoliosis.[25,26,29,31] In scoliosis, the highest imbalanced ES muscle activity is at the apex (the most deviated vertebra from the midline) zone of the curvature, which is usually located between T5 to T11 in thoracic scoliosis and L2 to L4 in the lumbar scoliosis. So, the ES muscles at T6, T10, and L3 levels could represent the apex zone for the upper thoracic, lower thoracic, and lumbar curvatures, respectively. Therefore, in this study, the EMG activities of bilateral ES_{L3}, ES_{T10}, and ES_{T6} muscles were measured during 3 exercises in prone position to provide baseline data for healthy individuals to assess their effectiveness on the left–right differential activation of the ES muscles at the selected spinal levels.

The objective of this study was to test the result of contralateral-arm and -leg raise in the prone and quadruped positions as well as the single-arm raise in a quadruped position on the activation of the ES_{L3}, ES_{T10}, and ES_{T6} muscles bilaterally. The first aim was to determine whether the activity of the ES muscle is similar at 3 spinal levels. The second aim was to examine whether the testing positions are capable of left–right differentially activating the ES in a different region. It was hypothesized that these testing positions activate the ES muscles more in the thoracic region than in the lumbar. The positions impose asymmetrical torque, demanding higher ES muscle activity in the lifted arm side than on the opposite side.

Methods

Fourteen nonathletic symptom-free female university students voluntarily participated in this study (age: 23.5 [3.5] y; height: 164.7 [5.2] cm; mass: 60.1 [7.7] kg; and body mass index: 22.1 [2.3] kg/m^2). All subjects were right handed and right footed, determined by throwing and kicking a ball. A subject was excluded if she had any pain, neuromuscular disorder, asymmetrical shoulder height or limb length discrepancies of more than 5 mm, spinal deformity, history of surgery, or if she was on any medication. Subjects were advised to avoid any serious physical activity during the 3 days before the experiments. The protocol was approved by the ethical committee of Hamedan University of Medical Sciences (ID: p/16/35/9/5851–10/2/2015). All subjects agreed to join the study and signed an informed consent form before their participation.

Six body positions (Figure 1A–1F), including the prone and quadruped positions with the contralateral-arm and -leg raise and the quadruped with single-arm raise, were selected to evaluate the bilateral third lumbar (ES_{L3}), 10th thoracic (ES_{T10}), and sixth thoracic (ES_{T6}) muscles in this study. The first 2 conditions were in a prone lying position with (A) the right arm and left leg lift (P-RALL) and with (B) the left arm and right leg lift (P-LARL). The others were in the quadruped position; the third and fourth were positioned with (C) the right arm and left leg lift (Q-RALL) and with (D) the left arm and right leg lift (Q-LARL). Finally, the fifth and sixth positions were with (E) the right arm lift (Q-RA), and (F) the left arm lift (Q-LA).

A portable EMG system (BTS FREEEMG 300–BTS Bioengineering Corp) with 6 pairs of bipolar pregelled Ag/AgCl surface electrodes (circular with 11 mm in diameter; 25-mm center-to-center distance; input impedance of 100 MΩ; and common-mode rejection ratio of >110 dB at 50–60 Hz) was used to measure the EMG activity of the muscles in the previously explained body positions.

The electrodes were placed vertically, parallel to the muscle fibers orientation, on the skin over the right and the left ES_{L3}, ES_{T10}, and ES_{T6} vertebral levels with a 30-mm distance from the respective spinous process (Figure 1H).[33,34] Based on the SENIAM recommendations,[33] the skin on the target area on both sides of the spine was shaved, cleaned with alcohol (70% ethanol—C_2H_5OH), and abraded smoothly to reduce the skin impedance before placing the electrodes. A ground electrode was also positioned over the right acromion, as shown in Figure 1H. To our knowledge, this study was the first that compared the bilateral ES muscles at 3 spinal levels in these positions.

In this study, the EMG activities of the ES muscles for the 6 prone and quadruped positions were recorded at 2000 Hz and gain of 1000. For baseline reference, the maximum voluntary isometric contraction (MVIC) test lasting 5 seconds was performed in the Sorensen position at the end of testing sessions shown in Figure 1G. During the MVIC test, the participant was verbally instructed to extend her trunk against the examiner's resistance with maximum effort.[35] The examiner's resistance is shown with an arrow in Figure 1G.

In the quadruped condition, the participant was advised to keep her limb(s) horizontal as best as possible. In the prone tests, the upper and lower limbs were lifted as much as possible. In all the prone and quadruped positions, the testing conditions were held for 15 seconds.

Before the experiments, participants had 5 minutes for warming up and practicing trials. During the trials, the participant's

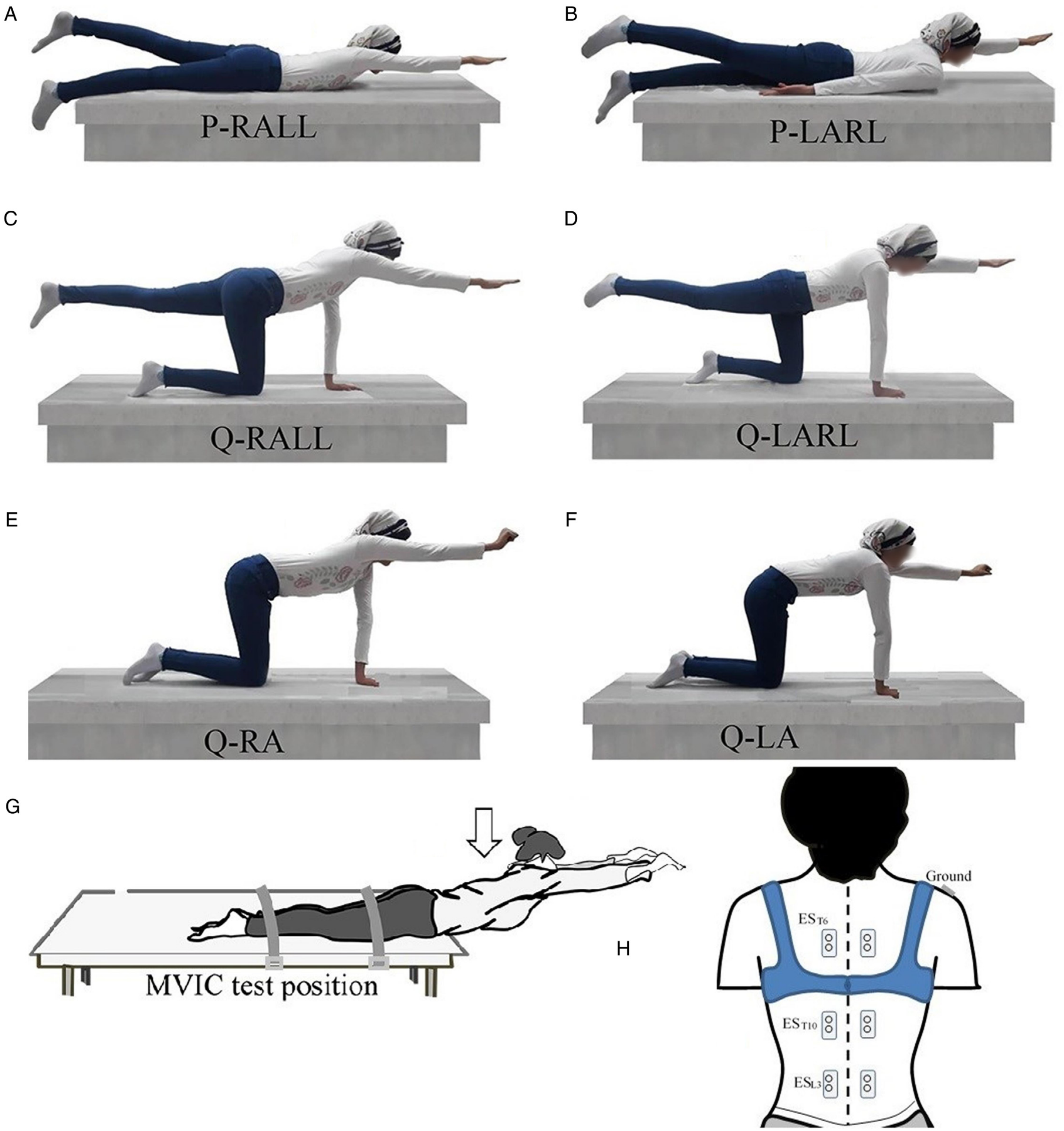

Figure 1 — The 6 different testing positions for ES muscle activation, the position for MVIC test, and electrode placement are presented (A–H): (A) P-RALL, (B) P-LARL, (C) Q-RALL, (D) Q-LARL, (E) Q-RA, (F) Q-LA, (G) Sorensen testing position for quantifying the ES muscles activity in MVIC used for normalization of the ES activities, and (H) surface electrode locations over the bilateral ES_{L3}, ES_{T10}, and ES_{T6} muscles as well as the ground electrode. ES indicates erector spinae; ES_{L3}, ES_{T10}, and ES_{T6}, erector spinae muscles at L3, T10, and T6 vertebral levels; MVIC, maximum voluntary isometric contraction; P-LARL, prone position with the left arm and the right leg lift; P-RALL, prone position with the right arm and the left leg lift; Q-LA, quadruped position with the left arm lift; Q-LARL, quadruped position with the left arm and the right leg lift; Q-RA, quadruped position with the right arm lift; Q-RALL, quadruped position with the right arm and the left leg lift.

performances were visually inspected by the examiner, and feedback was given to the participant if necessary. The order of the 6 testing positions was chosen randomly. Each test was repeated 3 times, making a total of 21 trials, which included the reference baseline position for the MVIC test. There was a 1-minute resting time between trials. During the resting time, subjects were to remain relaxed or walked in the laboratory according to their preference.

The raw EMG signals were band-pass filtered using a zero-lag Butterworth filter with a cutoff frequency of 10 to 500 Hz, followed by a 50-Hz notch filter and full-wave rectification. Linear envelope was created by applying moving-root mean square (RMS) with a 0.2-second time window. For each testing trial, signals of a 5-second window were taken from the middle of the EMG traces. For the MVIC trials, the maximum RMS value was taken in the middle 3-second window of the EMG traces of each of the 3 repetitions and for each muscle area. Then the maximum value of the RMS of the EMG traces was recorded for each trial, and the average of the 3 trials was calculated. The MVIC trials were processed accordingly, and the maximum value of the linear envelope over 3 repetitions for each muscle area was used to normalize each trial (%MVIC). To normalize the signals of each muscle section, the peak RMS value of each trial was divided by the maximum RMS value of the MVIC tests of the same muscle section. Then the mean of the normalized values (%MVIC), obtained from the 3 repetitions of each task, was presented as muscle activity and used in the statistical analysis.

First, a Kolmogorov–Smirnov test was conducted, and all data were found to be normally distributed. The mean and SD for the RMS of each muscle for each body position were calculated. For each of the 3 testing conditions (prone, quadruped with and without leg involvement), a separate repeated-measures analysis of variance with 3 factors ($2 \times 2 \times 3$), namely, lifted arm side (right and left arms), muscle side (right and left), and muscle levels (ES_{L3}, ES_{T10}, and ES_{T6} muscles), was conducted, and for the post hoc comparisons, Tukey test was applied (to compare 3 muscle levels). The statistical analysis was performed using SPSS (version 19). The significance level was set at $P < .05$ for all comparisons.

Results

The results of the testing positions are presented in Figures 2 to 4. Figure 2 presents the activity of the right and left ES_{L3}, ES_{T10}, and ES_{T6} muscles as %MVIC for the prone lying position tests P-RALL and P-LARL.

In repeated measure analysis of variance, the within-subject design multivariate test for P-RALL revealed significant effects for the "side" (left and right; $F = 71.59$; $P = .0001$) and "muscles" (ES_{L3} and ES_{T10} and ES_{T6}; $F = 28.40$; $P = .0001$) factors. These implied that, generally, the activity of the ES muscles in the right and left sides and between the 3 spinal levels was different. However, the significant interaction "side × muscle" ($F = 26.23$; $P = .0001$) showed that the pattern of "right and left" differences varied in different muscle groups. In P-RALL position, the right ES_{T6} ($P = .0001$) and right ES_{T10} ($P = .0001$) muscles displayed higher activity than their counterparts on the left side by 5.0 and 1.8 times, respectively. However, at the ES_{L3} level, the muscle activity between the right and left side was not significantly different ($P = .25$).

In this position, the right ES_{T6} muscle displayed higher activity than the right ES_{T10} and right ES_{L3} by 1.5 and 3.2 times, respectively ($F = 26.75$; $P = .0001$). The right ES_{T10} also displayed higher activity than the right ES_{L3} by 2.2 times ($F = 26.75$; $P = .0001$; Figure 2).

In the P-LARL testing position, significant effects for the "side" (left and right; $F = 87.10$; $P = .0001$) and "muscle" ($F = 34.92$; $P = .0001$) factors and a significant interaction "side × muscle" ($F = 29.77$; $P = .0001$) were also observed. In this position test, the left ES_{T6} ($P = .0001$) and left ES_{T10} ($P = .0001$) muscles

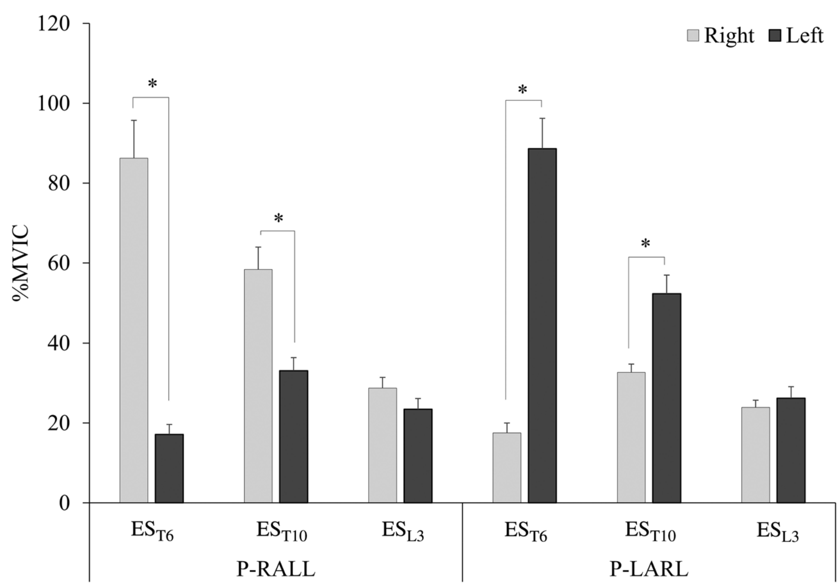

Figure 2 — The peak RMS of the electrical activity of the right and left ES_{L3}, ES_{T10}, and ES_{T6} muscles is illustrated for the P-RALL and P-LARL. Values are presented as the percent of the maximum RMS displayed during the MVIC test (%MVIC). *$P < .05$. ES_{L3}, ES_{T10}, and ES_{T6} indicate erector spinae muscles at L3, T10, and T6 vertebral levels; MVIC, maximum voluntary isometric contraction; P-LARL, prone position with the left arm and the right leg lift; P-RALL, prone position with the right arm and the left leg lift; RMS, root mean square of the electromyography signals.

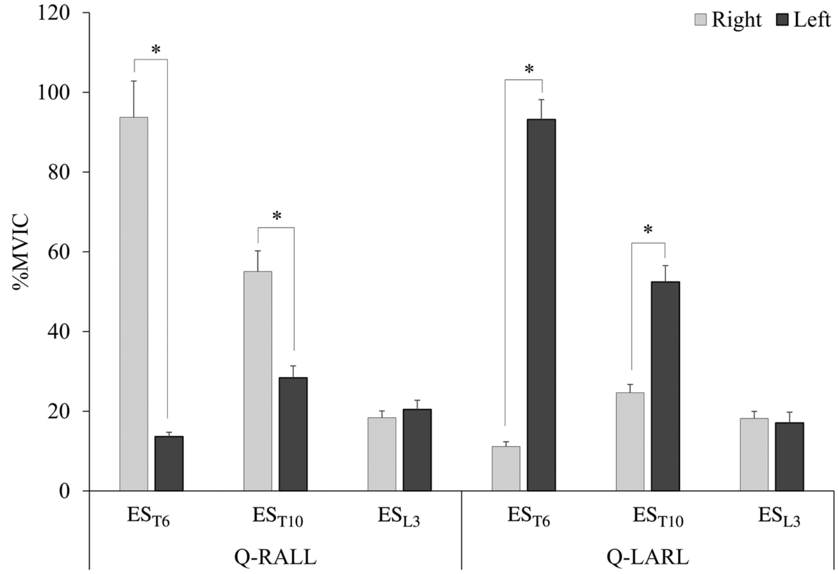

Figure 3 — The peak RMS of the electrical activity of the right and left ES_{L3}, ES_{T10}, and ES_{T6} muscles is illustrated for the Q-RALL and Q-LARL. Values are presented as the percent of the maximum RMS displayed during the MVIC test (%MVIC). $*P < .05$. ES_{L3}, ES_{T10}, and ES_{T6} indicate erector spinae muscles at L3, T10, and T6 vertebral levels; MVIC, maximum voluntary isometric contraction; Q-LARL, quadruped position with the left arm and the right leg lift; Q-RALL, quadruped position with the right arm and the left leg lift; RMS, root mean square of the electromyography signals.

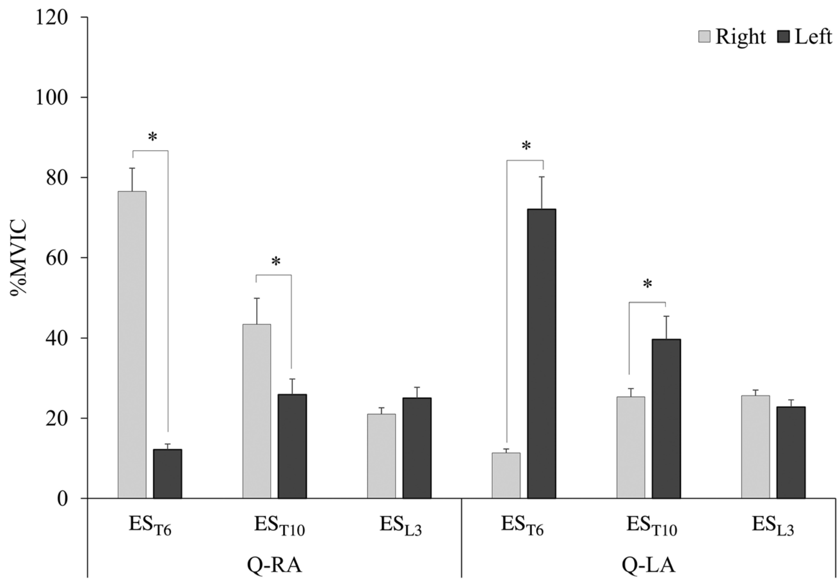

Figure 4 — The peak RMS of the electrical activity of the right and left ES_{L3}, ES_{T10}, and ES_{T6} muscles is illustrated for the Q-RA and Q-LA. Values are presented as the percent of the maximum RMS displayed during the MVIC test (%MVIC). $*P < .05$. ES_{L3}, ES_{T10}, and ES_{T6} indicate erector spinae muscles at L3, T10, and T6 vertebral levels; MVIC, maximum voluntary isometric contraction; Q-LA, quadruped position with the left arm lift; Q-RA, quadruped position with the right arm lift; RMS, root mean square of the electromyography signals.

displayed higher activity than their corresponding right side by about 5.1 and 1.6 times, respectively. However, the activity of the left and right ES_{L3} was not statistically different ($P > .05$). The activity of the left ES_{T6} was higher than the activity of the left ES_{T10} and left ES_{L3} muscles by 1.7 and 3.4 times, respectively ($F = 33.31$; $P < .001$). The activity of the left ES_{T10} muscle was about 1.8 times higher than that of the left ES_{L3} muscle ($P = .001$).

Figure 3 illustrates the EMG activity of the right and left ES_{L3}, ES_{T10}, and ES_{T6} muscles for the Q-RALL and Q-LARL positions. Similar to the prone test, in quadruped position, the activity of the ES_{T6} and ES_{T10} was also much higher in the side ipsilateral to the lifted arm side, whereas ES_{L3} displayed a symmetrical activity.

In the Q-RALL position, significant effects for "side" ($F = 126.91$; $P = .0001$) and "muscle" ($F = 50.48$; $P = .0001$) factors and "side × muscle" ($F = 86.58$; $P = .0001$) interaction were also observed. The right ES_{T6} ($P = .0001$) and right ES_{T10} ($P = .0001$) muscles displayed higher activity than their counterpart muscles on the left side by about 6.9 and 1.9 times, respectively.

However, the activity of the ES_{L3} muscle was similar on both sides of the spine ($P = .27$). The right ES_{T6} ($P = .0001$) and right ES_{T10} ($P = .0001$) muscle displayed higher activity than the right ES_{L3} muscle by about 5.1 and 3.0 times, respectively (Figure 3).

In the Q-LARL position, significant effects for the "side" ($F = 75.07$; $P = .0001$) and "muscle" ($F = 32.5$; $P = .0001$) factors and "side × muscle" ($F = 41.7$; $P = .0001$) interaction were also observed. The activities of the left ES_{T6} ($P = .0001$) and left ES_{T10} ($P = .0001$) muscles were higher than their counterparts on the right side by about 8.4 and 2.1 times, respectively ($P < .01$). However, the ES_{L3} muscle showed symmetrical activity on the right and left sides ($P = .56$). The activity of the left ES_{T6} was higher than that of the left ES_{T10} muscle by 1.8 ($P < .0001$).

The activity of the right and left ES_{L3}, ES_{T10}, and ES_{T6} muscles in Q-RA and Q-LA testing positions is illustrated in Figure 4. In the Q-RA position, the effects of the "side" ($F = 41.55$; $P = .0001$) and "muscle" ($F = 15.32$; $P = .0001$) factors and "side × muscle" ($F = 25.52$; $P = .0001$) interaction were also significant. The activities of both the ES_{T6} ($P = .0001$) and ES_{T10} ($P = .0001$) muscles were higher on the lifted arm side (right side) than those on the opposite side by 6.3 and 1.7 times, respectively. But, the ES_{L3} muscle displayed similar activity on both sides of the spine ($P > .05$). In the lifted arm side, the ES_{T6} was activated more than the ES_{T10} and ES_{L3} muscles by about 5.1 and 1.7 times, respectively ($F = 19.89$; $P = .007$). Also, the right ES_{T10} displayed 2.0 times greater activity than the right ES_{L3} muscle ($P = .007$; Figure 4).

In the Q-LA position (left arm lifted in quadruped), significant effects for "side" ($F = 41.5$; $P = .0001$) and "muscle" factors as well as "side × muscle" interaction ($F = 25.5$; $P = .0001$) were also observed. The activity of the ES_{T6} ($P = .0001$) and ES_{T10} ($P = .0001$) muscles on the lifted arm side (left side) was higher than those on the opposite side by about 6.4 and 1.6 times, respectively. Like other positions, in Q-LA, the ES_{L3} muscle also displayed relatively low and symmetrical activity on both sides of the spine ($P = .31$). In the lifted arm side, the activity of the ES_{T6} was higher than that of the ES_{T10} and ES_{L3} by 1.8 and 3.2 times, respectively ($F = 32.39$; $P = .0001$). On this side, the ES_{T10} also displayed higher activity than the ES_{L3} by 1.7 times ($P = .001$).

Overall, without regard to the right or left arm raise, only the thoracic muscles (ES_{T6} and ES_{T10}) were activated much more highly in the lifted arm side than on the opposite side. The activity of the lumbar ES muscles was symmetrical and lower than that of the thoracic region.

Discussion

The first aim of this study was to investigate the outcome of the prone and quadruped positions with contralateral-arm and -leg raise as well as the quadruped with single-arm raise on the activation of the ES muscles to test whether the activity of the ES muscle is similar at the ES_{L3}, ES_{T10}, and ES_{T6} levels. Results of the present study showed that for all the body position conditions, the ES_{L3} displayed relatively lower activity than the thoracic ES muscles, and it was similar on both sides of the spine (symmetrical). The activity of ES_{T10} and ES_{T6} was higher on the lifted arm side than on the opposite side. Nonetheless, on the lifted arm side, the activity of the ES_{T6} was higher than that of the ES_{T10}. This indicates that the arm position has a high capacity to activate the ipsilateral upper and lower thoracic ES muscles. These results are in agreement with McGill and Karpowicz[36] and Ekstrom et al,[26] who also studied ES activity in the quadruped and prone positions in healthy individuals. McGill and Karpowicz[36] compared various quadruped tests and showed that the arm position has significant effects on enhancing the ES muscle activity.[36]

The second aim was to examine whether the testing positions are capable of differentially activating the ES (more in one side while keeping the other side in minimal activation level) at different spinal regions. In the prone lying position test, the lumbar (lower trunk) rests symmetrically on the ground, and therefore, less muscle effort is required to stabilize the lumbar spine. This could explain, in part, the low and symmetrical activity of the ES_{L3}. During the prone lying test condition, lifting the chest off the ground (trunk extension) is performed mainly by the trunk extensors. This position acts as a third class lever wherein stretching the arm displaces the center of mass and increases the load arm. This requires greater muscle force to hold the trunk and the arm in the extended position, which is provided by the ipsilateral extensors. The ES_{T6} activity was higher than that of the ES_{T10} and $ES_{L3.}$ Consequently, the opposite arm, which is placed on the ground, partially supports the ipsilateral trunk, requiring less muscle activity at this site. The same analogy can be applied to the higher activity of the ipsilateral ES_{T10} and ES_{T6} muscles concerning the lifted arm side in the quadruped positions.[37]

The lower EMG activity recorded on the ES_{L3} can also be explained, in part, by the fact that the required stabilizing forces in the lower back are shared by many muscle groups, including the iliocostalis, longissimus, multifidus, spinalis,[38] the transverse abdominis, the internal and external oblique muscles,[39] quadratus lumborum,[14] the pelvic floor muscles,[40] the gluteus (maximus and medius), and latissimus dorsi muscles.[41] However, we only measured ES activity at L3 level. While, in the thoracic region, the ES muscles, including iliocostalis, longissimus, and spinalis, are the primary spinal stabilizer which require higher activity to perform the required work.

Against resistance, the weaker muscle develops a higher activity level.[42] Therefore, the higher activity of ES_{T6} could be interpreted in 2 ways. It can be indicative of a weaker ES_{T6} compared with the other muscles[37]; it might also be due to the greater demand for stabilizing the upper thoracic when the base of support is decreased by removing the hand support and stretching it forward.

Guo et al[2] found that quadruped position with contralateral-arm and -leg lift is more susceptible to producing unilateral selectivity in the ES_{L1} muscle than the prone test.[2] However, they used a single pair of electrodes located at the L1 level, whereas our study documented the ES activity at 3 other spinal levels. Besides, in their study, the unilateral selectivity of ES muscle activation was relatively very low compared with the present study because of the much smaller right–left difference. Ekstrom et al[26] also recorded the activity of ES at the L1 and multifidus at L5 levels with only the right arm and left leg raise in the quadruped and prone positions.[26] They observed that in the quadruped position, the ES muscles display an asymmetrical activity. But they could not discuss the selective activation of the ES muscles in quadruped position because they measured only ES_{L1}.

Kim et al[23] measured the EMG activity of ES_{L2} and ES_{L5} muscles in the quadruped position with contralateral-arm and -leg lifts and for the Sorensen tests.[23] They concluded that unilateral activation of ES muscles in quadruped was greater than in the Sorensen test. These studies are in agreement with our study where the ES unilateral muscle activity is greater in the quadruped than in the prone position.

Unilateral muscle activation could correct muscle strength imbalance and activity in professional athletes as well as in some clinical populations, such as in scoliosis. In scoliosis treatment, the main focus for the therapists is strengthening the muscles on the convex side of the spinal curvature.[43,44] Schmid et al[45] tested the possibility of unilateral activation of the back muscles of scoliotic patients in symmetrical and asymmetrical weight training exercises.[45] They reported that the asymmetrical roman chair and front press exercises preferentially activated the muscles on the concave side of the spinal deformity. Our proposed body position to perform exercises, especially the quadruped position with both single-arm and contralateral-arm and -leg lift could be considered for patients with a thoracic idiopathic scoliosis wherein the ES muscle is weaker on the convex side of the thoracic spine.[3,4,44,45] Thus, for right thoracic scoliosis, the Q-RA and Q-RALL are recommended. Likewise, the Q-LA and Q-LARL are suggested for the left thoracic spinal deformity. Although the prone position exercises are also beneficial for scoliosis, the effectiveness of the quadruped exercises is greater than that of the prone position exercises. Still, further studies are required to examine the extent of the effectiveness of long-term quadruped exercises for patients with thoracic scoliosis.

There are some limitations to this study. The unilateral activation of ES muscles was only investigated at 3 spinal levels. Monitoring the ES muscle activity at more spinal levels and including the latissimus dorsi and multifidus muscles could have led us to a better understanding of the outcome of these exercises. However, thoracic scoliosis is defined by the location of the apex between T4 and T11, and therefore, our electrodes, at T6 and T10, cover this zone for the ES muscle activity. Another limitation is that the skinfold thickness of the lumbar and thoracic regions was not assessed, and this underlying fat acts as a low-pass filter. However, this limitation has little influence on the results and the interpretations because the data were normalized by the MVIC. Moreover, this effect should be identical on both the left and right sides.

The activation of the ES is modified by the body positions in able-bodied women. Furthermore, the ES activity was shown to vary at 3 spinal levels during the testing positions. In both prone and quadruped positions, the ES was unilaterally and selectively activated in the thoracic at the 6th and 10th vertebral levels. ES_{T6} displayed greater unilateral activation than ES_{T10} in all testing positions. The unilateral activation of ES in the quadruped position with single-arm raise was greater than the other positions. It appears that single-arm raise and contralateral-arm and -leg raise in quadruped position are potentially suitable to strengthen the ES muscle in an exercise program where dorsal muscle imbalances are a concern.

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