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Comparative analysis of EMG activity of Vastus Medialis and Vastus Lateralis during two vertical jump variations in long jumpers

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Abstract
Electromyography (EMG) provides critical insights into neuromuscular function during explosive movements like vertical jumping. This study aimed to investigate the surface EMG activity of the Vastus Medialis (VM) and Vastus Lateralis (VL) muscles on both right and left sides during countermovement jumps (CMJ) with and without hand swing among trained national-level male long jumpers. Ten right-leg take-off athletes aged 18-25 years participated in the study. EMG data were collected using a wireless Trigno system and analyzed for muscle activation patterns and symmetry. Results revealed that the VM showed higher and more consistent activation than the VL across both conditions, indicating its primary role in knee extension and stabilization during vertical jumps. Greater overall muscle activation was observed in the hand-swing condition, suggesting the contribution of arm motion to improved jump performance. Paired sample t-tests revealed no statistically significant differences between right and left VM or VL, although the left VL showed a trend toward higher activation. These findings suggest that elite long jumpers demonstrate symmetrical lower limb muscle function with effective neuromuscular coordination. The data support the value of EMG analysis in optimizing jump training, detecting asymmetries, and guiding performance enhancement strategies.

Keywords: Surface electromyography (EMG)**,** Vastus Medialis**,** Vastus Lateralis and countermovement jump (CMJ)

1. Introduction

The long jump is a highly dynamic athletic discipline that necessitates a harmonious integration of speed, muscular strength, coordination, and explosive power. Among the various factors influencing performance, vertical jumping ability plays a pivotal role, particularly in enhancing the effectiveness of the take-off phase, which directly contributes to the overall jump distance. To augment performance in the long jump, it becomes imperative to develop a comprehensive understanding of the underlying muscular mechanisms involved in force generation and transmission.

Electromyography (EMG) has emerged as a vital tool in the domain of biomechanics and sports science, facilitating the evaluation of muscle activity patterns during complex athletic movements such as jumping. It enables both researchers and practitioners to assess the recruitment, timing, and intensity of muscle activation, thereby providing valuable insights into neuromuscular coordination. Among the various muscle groups contributing to vertical jump performance, the Vastus Medialis (VM) and Vastus Lateralis (VL) integral components of the quadriceps Femoris group play a crucial role in facilitating knee extension and generating the requisite propulsive force. These muscles are especially active during the concentric phase of a vertical jump, thus making their analysis essential for performance evaluation. Vertical jump variations, such as the countermovement jump performed with and without arm swing, impose differing neuromuscular and biomechanical demands on the lower limb musculature. Therefore, examining the activation patterns of VM and VL under these conditions can offer meaningful insights into tailoring training strategies for long jumpers and enhancing their explosive power during take-off (Goodwin, 1999).

In the sport of long jump, vertical jumping ability significantly influences the athlete's overall performance, particularly during the critical take-off phase. This phase requires the rapid and forceful engagement of lower limb muscles, especially within a short ground contact duration. To optimize performance during this explosive action, a precise understanding of neuromuscular activity is essential. Electromyography (EMG), particularly surface EMG, provides a reliable and non-invasive method for measuring the electrical activity of muscles, such as the Vastus Medialis and Vastus Lateralis, during vertical jump tasks.

The use of EMG in performance analysis enables athletes and coaches to identify specific muscles that may be underactive or inefficient during the jumping motion. This data can be utilised to develop targeted training programmes including resistance training, plyometric exercises, and neuromuscular facilitation drills focused on strengthening those muscles that exhibit suboptimal activation. Technique optimisation is achievable through comparative EMG analyses of different jump variations, such as countermovement jumps with and without arm swing. These comparisons reveal which technique elicits greater muscle activation, thereby guiding adjustments that can improve take-off mechanics and maximise jump height and distance.

EMG also plays a crucial role in monitoring training adaptation. Repeated EMG assessments over a training cycle allow practitioners to observe changes in muscle recruitment patterns. Improvements in activation efficiency and power output can indicate successful training outcomes and neuromuscular development. The integration of EMG into biofeedback systems provides athletes with real-time visual or auditory cues about their muscle activity. This immediate feedback enhances motor learning, promotes better coordination, and supports the fine-tuning of technical execution.

EMG serves as a powerful tool in enhancing vertical jump performance among long jumpers by enabling data-driven training interventions, technique refinement, adaptation tracking, and real-time feedback. Its application contributes meaningfully to the scientific optimization of athletic performance in track and field sports.

Electromyography (EMG) has provided evidence that the timing and activation pattern of muscles such as the gluteus Maximus, hamstrings, quadriceps, and gastrocnemius significantly influence jump dynamics. In elite long jumpers, proper sequencing is essential for maximizing ground reaction force and minimizing energy leaks. However, in many cases, discrepancies in muscle activation- whether due to fatigue, improper technique, or neuromuscular inhibition—can result in compromised performance.

This paper investigates the impact of muscle activation sequence on vertical jump performance in long jumpers using surface EMG analysis. The goal is to identify activation patterns.

1.1 Objectives of the Study

- To assess the electromyographic (EMG) activity of selected lower leg during vertical jumps performed by long jumpers.
- To compare muscle activation levels across two different types of the vertical jump.
- To analyze differences in EMG activity based on leg dominance (dominant vs non-dominant leg) during the vertical jump.

1.2 Hypothesis

- There is no significant difference in EMG activity between the right and left Vastus Medialis during CMJ with and without hand swing.
- There is no significant difference in EMG activity between the right and left Vastus Lateralis during CMJ with and without hand swing.
- There is no significant difference in muscle activation (EMG) of VM and VL between CMJ with and without hand swing.

1.3 Delimitations

- The study is delimited to male high jumpers aged 18-25 years.
- Only right-leg take-off jumpers were included.
- Data was collected in a laboratory setting under controlled conditions.
- Only selected lower limb muscles were assessed: Right and Left Vastus Medialis (VM) and Vastus Lateralis (VL).

1.4 Limitations

- The small sample size may limit generalizability.
- Fatigue levels and psychological factors were not controlled.
- The use of surface EMG can sometimes include cross-talk from adjacent muscles.

2. Materials and Methods

2.1 Participants

Ten national-level male high jumpers (mean age = 21.3±2.1 years; mean height = 182.4±6.3 cm; mean weight = 70.8±5.6 kg) volunteered.

2.2 Instrumentation

A wireless surface EMG system (Trigno Sensor System, Delsys Inc., Natick, MA, USA: inter electrode distance=10 mm, 80 dB common mode rejection rate) was used to record lower extremity muscle activity. EMG data were sampled at 2000 Hz, and maximal voluntary isometric contractions and vertical jump performance were exported using AD Instruments analysis software.

2.2.1 Muscles Monitored

- Right and Left Vastus Medialis (VM).
- Right and Left Vastus Lateralis (VL).

2.2.2 Preparation Stage

Before EMG measurements were taken, each athlete was asked to identify their both leg, and electrodes were placed accordingly. The selected skin area for electrode placement was inspected to ensure it was free of injury, in accordance with Hill (1970) [17]. Although several studies have utilized EMG evaluations during functional activities (Wilkie, 1968) [18] and specifically during jumping tasks (Hill, 1968) [19], there remains a scarcity of research investigating EMG data during maximal concentric and eccentric contractions, particularly within sports where jumping is a key component. This gap highlights the relevance of the present study in exploring the relationship between vertical jump height and EMG activity during maximal effort contractions.

2.2.3 Electrodes Placement

Before electrode placement, each subject was thoroughly familiarized with the study procedures. Participants were instructed on the correct techniques for the muscle tests and exercises to be performed, including vertical jumping and proper movement patterns. Each subject practiced these tasks under supervision until the research team was confident that they could perform them correctly and consistently. This familiarization process ensured accurate EMG recordings by minimizing variability due to technical errors or improper execution. The target skin area was shaved and cleaned with alcohol to reduce skin impedance. Surface electrodes (Delsys brand) were then applied to the both legs. The belly of the Right and Left Vastus Medialis (VM) and Lateralis (VL) muscles were identified by manual palpation during muscle contraction. Electrodes were placed longitudinally along the muscle fiber, the electrodes were secured using medical bandages or plaster, following protocols described by SENIAM recommendations, Guyton and Hall (2001), Maughan and Gleeson (2010), and others (Halson *et al.*, 2002) [20, 21, 22].

Table 1: Electrodes placements of muscles

Muscles	Electrodes Placement
Right and Left Vastus Lateralis (VL)	Place the sensor at approximately 2/3 of the distance between the Anterior Superior Iliac Spine (ASIS) and the lateral border of the patella. This corresponds to the muscle belly of the Vastus Lateralis, located on the outer side of the thigh
Right and Left Vastus Medialis (VM)	Place the surface EMG sensor at approximately 4/5 of the distance between the Anterior Superior Iliac Spine (ASIS) and the joint space just anterior to the Medial Collateral Ligament (MCL). This point corresponds to the muscle belly of the Vastus Medialis Oblique (VMO) portion.

2.2.4 Normalization: The EMG data were normalized for each individual to the exercise that produced the greatest amount of EMG amplitude for each muscle. This muscle contraction represented 100% of muscle activity and was then designated as the MVIC below table. Then, the average EMG envelope over a time window of one second (moving average filter) was calculated during each MVIC trial for each muscle. The activation level of each muscle was then defined as the peak value of the processed signal among the three MVIC trials. The muscle activation level during each MVIC trial was then expressed as a percentage of the maximum activity found among all the MVIC trials.

Table 2: Maximum Voluntary Isometric Test of Each Muscles

Muscles	Positions	MVIC Test
Right and Left Vastus Lateralis and (VL)Vastus Medialis (VM)	Seated Knee Extension Posture	The MVIC tests of the VM were based on knee extensions. The subject was seated on an adjustable leg extension bench with the hip flexed at approximately 90 degrees and the back supported. (Simsek, 2016) [23]. The tested leg was fixed in place at a knee angle of 65 degrees (from full extension) using a padded strap just above the ankle. This angle is commonly used to elicit peak torque from the quadriceps without causing joint discomfort. By attempting to extend the knee maximally against an immovable resistance.

2.2.5 Vertical Jump Measurement(CMJ)

Vertical jump performance was assessed using the New Test Jump Mat. Athletes were permitted to use arm swing to maximize performance. Each participant began the test by standing side-on to a wall with a knee angle of approximately 90 degrees. While keeping their feet flat on the ground, they extended the arm closest to the wall upward to mark the standing reach height. Following this, the athlete moved slightly away from the wall and performed a maximal vertical jump, using both arm and leg movements to aid upward propulsion. The three jump could be performed a countermovement.

2.2.6 Vertical Jump Protocol

Vertical jump hand swing

Vertical jump without hand swing

Prior to testing, each participant undergoes a structured warm-up consisting of light aerobic exercise, dynamic stretching, and practice trials. This preparation is intended to activate the muscles. The jump protocol involves a specific movement sequence starting from an upright stance with feet shoulder-width apart and arms at the sides. For CMJ without hand swing, participants were instructed to keep their hands firmly placed on their hips throughout the movement. The jump was performed by executing a rapid downward motion through flexion of the hips, knees, and ankles (eccentric phase), immediately followed by a powerful upward motion (concentric phase) to lift off the ground. The jump was to be performed smoothly without pausing, and landing was to be done with knees slightly bent for balance and safety.

In contrast, the CMJ with hand swing allowed participants to use their arms freely. During the downward phase, arms were swung backward, and during the upward phase, they were forcefully swung forward and upward to assist the jump. This technique mimics more natural sport-specific jump actions and enables evaluation of how upper limb movement contributes to jump height and muscle activation.

Each participant performed 3 to 5 trials of both jump variations, with a rest period of 30 to 60 seconds between each attempt to avoid fatigue. The best trial or the average of the two highest jumps was used for analysis. EMG recordings focused specifically on the activity and coordination of the Vastus Medialis and Vastus Lateralis muscles during the different jump conditions. The best or average of the performances is selected for final analysis and the EMG amplitudes of the three repetitions were averaged for each muscle.

2.2.7 EMG Measurement

Surface electromyographic (EMG) activity was recorded using a Delsys EMG system. The EMG signals were collected from the muscles Right and Left Vastus Lateralis and (VL) Vastus Medialis (VM of the dominant and non-dominated leg. Four channels were used in the setup. Raw EMG signals were pre amplified using the lab chart pro Acquisition software, with a band-pass filter set between 20-450 Hz. The signals were amplified, then converted from analog to digital format at a sampling rate of 1 kHz (1000 Hz). These recordings allowed for precise temporal and amplitude-based analysis of muscle activity during the vertical jump phases. EMG signals were synchronized with video capture. Real-time tracking allowed identification of muscle activity during specific movement phases. Each vertical jump attempt was saved with labelled trials. Data was later exported for statistical and comparative analysis. This short window was selected to capture peak activity during the vertical jump of long jumpers.

2.2.8 Statistical Analysis
Data analysis was performed using SPSS (version 26.0; IBM Corp., Armonk, NY, USA). Descriptive statistics, including means and standard deviations (mean ±SD), were calculated for vertical jump height and EMG activation levels for each muscle. The following statistical tests were used to assess the differences across jump types:
Paired sample t-tests were used to compare the differences in EMG activation levels between the vertical jump hand swing and vertical jump without hand swing for each muscle (Right and Left Vastus Lateralis and (VL) Vastus Medialis (VM). This test was used to assess within-subject differences between the two legs. Level of statistical significance was set at $p<0.05$ for all analyses. Statistical analyses were conducted with a confidence interval of 95%.All statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

3. Results (Data Interpretation)

Table 3: Normalized RMS peak value of vertical jump CMJ Hand Swing

Muscle	Mean	Std Dev	Min	Max
Vastus Medialis Right	243.49	58.39	150.04	326.34
Vastus Medialis Left	244.86	24.29	206	287.87
Vastus Lateralis Right	193.67	83.46	110.21	393.31
Vastus Lateralis Left	230.37	34.78	189.42	300.89

Above table presents the mean, standard deviation (Std Dev), minimum (Min), and maximum (Max) values of the normalized EMG activity recorded from the Vastus Medialis and Vastus Lateralis muscles on both the right and left sides.

Vastus Medialis (VM) Right Side (VMR): The mean EMG activity is 243.49, indicating a high level of muscle activation during the jump. The standard deviation (58.39) shows moderate variability among participants. The minimum and maximum values range from 150.04 to 326.34, reflecting differences in muscle recruitment levels across individuals.

Left Side (VML): The mean is 244.86, almost identical to the right side, indicating symmetry in activation. The lower standard deviation (24.29) suggests more consistent activation across subjects. Values range from 206.00 to 287.87, with less variation than the right side.

Vastus Lateralis (VL) Right Side (VLR): Mean activation is 193.67, lower than both VM muscles. A high standard deviation (83.46) indicates large variability in activation patterns among participants. The wide range from 110.21 to 393.31 suggests some individuals used this muscle much more than others.

Left Side (VLL): The mean activation is 230.37, higher than the right VL and closer to VM levels. The standard deviation (34.78) indicates moderate variability. The range is from 189.42 to 300.89, suggesting more stable recruitment compared to the right VL.

Table 4: Normalized RMS peak value of vertical jump CMJ without Hand Swing

Muscle	Mean	Standard Deviation	Minimum	Maximum
Vastus Medialis Right	205.94	32.95	163.41	276.60
Vastus Medialis Left	220.55	33.63	157.81	259.86
Vastus Lateralis Right	169.50	51.25	101.81	269.13
Vastus Lateralis Left	206.56	37.76	139.69	263.77

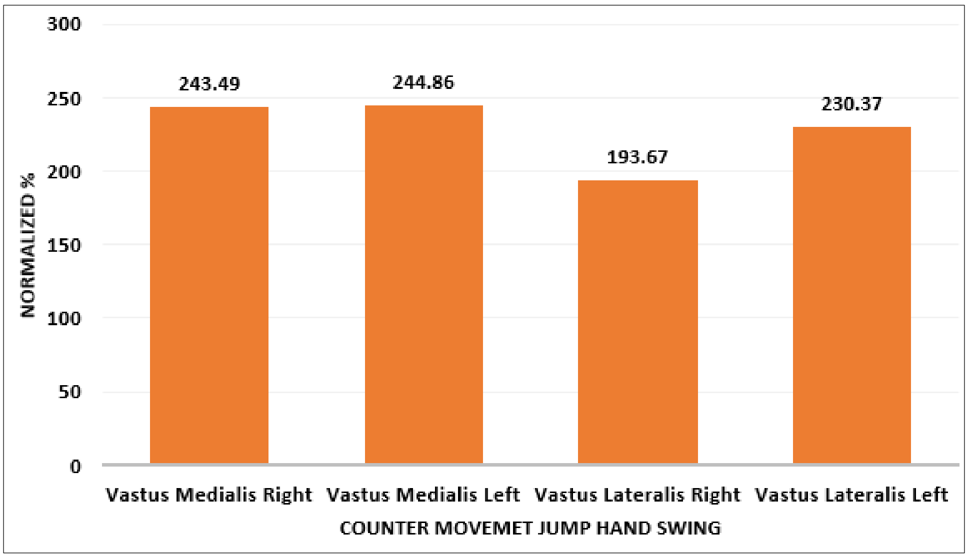
Above table shows that the mean, standard deviation, minimum, and maximum values of the normalized EMG activity (%MVIC) in microvolts of four lower limb muscles involved in vertical jump performance among long jumpers.

Vastus Medialis (VM) Right Side (VMR): The mean EMG activity is 205.94, indicating substantial activation during the jump. The standard deviation of 32.95 shows moderate variation among participants. Muscle activity ranged from 163.41 to 276.60, suggesting differences in individual performance or muscle recruitment efficiency.

Left Side (VML): The mean is slightly higher at 220.55, suggesting marginally greater muscle engagement on the left side. A similar standard deviation (33.63) indicates consistent muscle activation across participants. Minimum and maximum values range from 157.81 to 259.86, showing moderate variability.

Vastus Lateralis (VL) Right Side (VLR): The mean activation is 169.50, which is lower than both VM sides, indicating relatively less involvement. A higher standard deviation (51.25) points to significant variation in usage among athletes. The activity ranges widely from 101.81 to 269.13, suggesting differences in neuromuscular strategy or strength.

Left Side (VLL): The mean activation increases to 206.56, indicating a higher contribution of the left VL compared to the right. The standard deviation of 37.76 reflects moderate variation. EMG values range from 139.69 to 263.77, suggesting somewhat more consistent activation than the right VL.



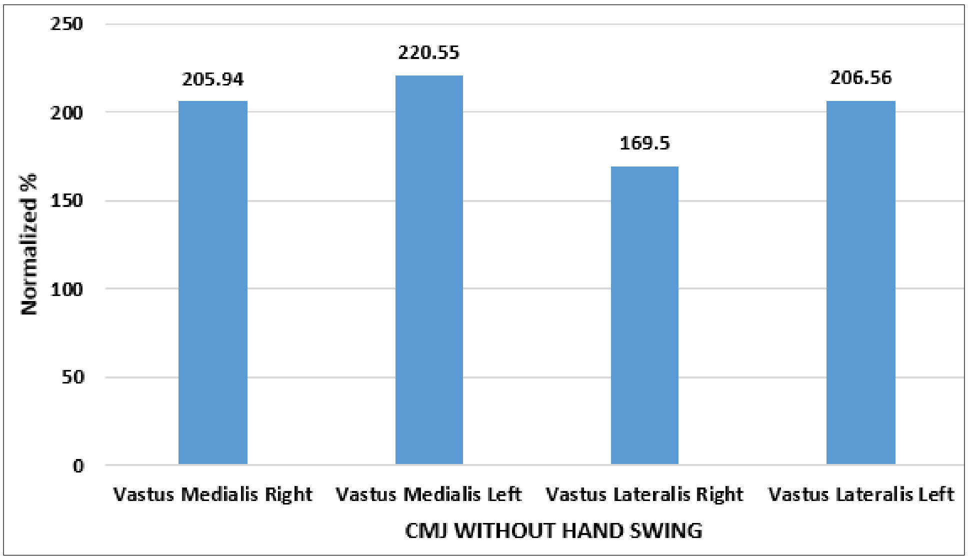


Fig 1: EMG activation of Vastus Medialis (right and left) and Vastus Lateralis (right and left) muscles during countermovement jump (CMJ) with and without hand swing.

Table 5: Paired Samples t test for paired muscles on the right and left extremity during- CMJ with Hand Swing

		Paired Differences		t	df	Sig.(2- Tailed)
		Mean	Std. Deviation			
Pair 1	VMR-VML	-0.07	55.41	-0.007	9	0.994
Pair 2	VLR-VLL	-37.29	87.62	-1.448	9	0.183

Table 5 presents the paired samples t-test results comparing the EMG activity of the Vastus Medialis and Vastus Lateralis muscles between the right and left limbs during the countermovement jump (CMJ) with hand swing among trained long jumpers.

For Pair 1 (Vastus Medialis Right vs. Left - VMR and VML), the mean difference was -0.07, indicating that the average EMG activity between the two limbs was nearly identical. The p-value of 0.994, which is well above the 0.05 level of significance, confirms that this difference is not statistically significant. This finding suggests symmetrical neuromuscular activation of the Vastus Medialis on both sides, with either limb demonstrating dominance or deficiency in muscle engagement. Therefore, during CMJ with hand swing, the Vastus Medialis muscles functioned in a balanced and coordinated manner, contributing equally to the explosive movement.

For Pair 2 (Vastus Lateralis Right vs. Left - VLR and VLL), the mean difference was -37.29, indicating relatively greater EMG activity in the left Vastus Lateralis compared to the right. However, the p-value of 0.183 exceeds the 0.05 threshold, indicating that this difference is not statistically significant. Although there appears to be a trend toward asymmetry, with the left muscle showing higher activation, this variation does not reach statistical significance in the present sample. It may reflect individual variability or minor neuromuscular imbalances that are not uncommon among athletes, but not strong enough to suggest a consistent pattern.

Table 6: Paired Samples t test for paired muscles on the right and left extremity during - CMJ without Hand Swing

		Paired Differences		t	df	Sig.(2- Tailed)
		Mean	Std. Deviation			
Pair 1	VMR-VML	-14.13	40.61	-1.096	9	0.299
Pair 2	VLR-VLL	-36.37	56.99	-2.014	9	0.074

Table 4 presents the paired samples t-test analysis comparing the electromyographic (EMG) activity of the Vastus Medialis and Vastus Lateralis muscles between the right and left limbs during CMJ without hand swing among trained long jumpers. For Pair 1 (VMR vs. VML), the mean difference in EMG activity was -14.13, suggesting slightly higher activation in the left Vastus Medialis compared to the right. However, the p-value of 0.299 is well above the significance level of 0.05, indicating that the observed difference is not statistically significant. This implies that there was no meaningful asymmetry in Vastus Medialis activation between limbs during the CMJ without arm involvement, and both muscles contributed relatively equally.
For Pair 2 (VLR vs. VLL), the mean difference was -36.37, with higher activation recorded in the left Vastus Lateralis. The p-value of 0.074, while still above the 0.05 significance threshold, is closer to significance and may suggest a trend toward asymmetry in Vastus Lateralis activation. Though not statistically conclusive, this result could indicate a tendency for greater reliance on the left Vastus Lateralis during the jump, potentially due to side dominance, movement pattern compensation.

4. Discussion

The present study aimed to investigate the electromyographic (EMG) activity of the Vastus Medialis and Vastus Lateralis muscles on the right and left sides during countermovement vertical jumps (CMJ) with and without hand swing among trained long jumpers. The findings offer insights into neuromuscular activation patterns, symmetry of muscle recruitment, and the potential influence of arm swing on lower limb muscle performance.
The descriptive statistics (Table 1 & 2) revealed that in both jump conditions, the Vastus Medialis on both sides showed higher and more consistent EMG activity compared to the Vastus Lateralis. This suggests that the Vastus Medialis plays a more dominant and stable role during the take-off phase of vertical jumping tasks, which aligns with its primary role in knee extension and stabilization during explosive lower limb actions.
Interestingly, muscle activation was generally higher in all four muscles during CMJ with hand swing than in the no-arm-swing condition. This could be attributed to the increased momentum and coordination provided by the use of the upper limbs, which aids in enhancing jump height and efficiency, as seen in prior biomechanical research.
The paired samples t-tests (Table 3 & 4) were used to compare the activation between the right and left limbs for each muscle. In both jumping conditions, no statistically significant differences were found between the right and left Vastus Medialis muscles. This indicates a high level of bilateral symmetry in neuromuscular coordination of this muscle group, which is a desirable trait in well-trained athletes, as it reflects balanced strength and technique.
For the Vastus Lateralis, although the left side consistently showed higher average EMG activity, the differences were not statistically significant, with the p-values being 0.183 (hand swing) and 0.074 (without hand swing). However, the near-significant result in the no-hand-swing condition may indicate a trend toward side dominance or compensatory activation. This could be due to an athlete's preferred leg during take-off or subtle imbalances in training or technique. Further investigation with a larger sample size or inclusion of kinetic data may clarify this finding.
Overall, the results demonstrate effective neuromuscular coordination and bilateral activation balance in the lower limb muscles critical for jumping, particularly in the Vastus Medialis, which appears to function symmetrically across conditions.

5. Conclusion

This study concludes that trained long jumpers exhibit balanced muscle activation between the right and left Vastus Medialis muscles during vertical jumps, regardless of arm swing usage. The Vastus Lateralis showed a trend toward higher activation on the left side, but this difference was not statistically significant. The use of hand swing in the jump appears to enhance overall muscle recruitment, likely due to better momentum and coordination.
These findings suggest that.

- Arm swing enhances lower limb muscle activation during vertical jumps.
- Vastus Medialis is a more consistently activated muscle across limbs and jump styles.
- Long jumpers generally display symmetrical neuromuscular performance, with minimal imbalances.

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