



Analysis of Electromyographic Amplitude Parameters of Thigh and Calf Muscles During Vertical Jump Execution

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Abstract:

Background: A key indicator of an individual's capability to generate explosive strength, the effectiveness of their neuromuscular coordination, and their stamina is assessed through the vertical jump test. Sports science research commonly uses surface electromyography (sEMG), a non-invasive technique for measuring muscles' electrical activity. In this study, we utilized electrical signal magnitude-based measurements to analyze the electrical activity of the Rectus Femoris, Gluteus Maximus, Gastrocnemius Medialis, and Biceps Femoris Caput Longus muscles in the thigh and calf during vertical jumps.

Methods: The study involved seventeen male athletes as participants. The FREEEMG system captured EMG signals at a sampling rate of 1000 Hz, and using MATLAB, the parameters RMS, MAV, MAD, and WAMP were computed.

Result: According to the findings, the Rectus Femoris and Gluteus Maximus muscles are crucial for producing explosive power in the propulsion phase, and their amplitude characteristics remained fairly consistent across multiple jumps. Conversely, the Gastrocnemius Medialis and Biceps Femoris muscles showed a steady decline in amplitude, which indicated the start of fatigue.

Conclusion: In conclusion, the thigh muscles were primarily responsible for generating force, whereas the calf muscles mainly aided in maintaining postural stability and the last stage of propulsion.

Keywords: Biomechanical Analysis, Electromyography, Explosive Strength, Muscle Activity, Vertical Jump

1. INTRODUCTION

The vertical jump is widely used as a universal test for assessing strength, speed, and explosive power in athletes. According to the scientific literature, jump height reflects the lower-limb muscles' ability to generate maximal force as well as the efficiency of the neuromuscular system (Asadi, 2016). This test is recognised as a standard tool for determining explosive strength capacity and is considered an important indicator of an athlete's overall physical preparedness and functional muscular potential (Santos et al., 2022). handball, vertical jump performance is closely associated with speed, speed-strength qualities, and jumping

ability, and is therefore regarded as a reliable predictor of competitive performance (Endab, 2024). Based on research, how high an athlete can jump is a clear sign of how well they can create power quickly, how prepared they are for fast and strong movements, and how well their jump training is working (McMahon et al., 2017). As a result, this jumping test is commonly used to check overall fitness levels, see if someone is ready to compete, and predict how well they might do when playing a game (Collins et al., 2023). Vertical jump performance in basketball players is directly associated with their effectiveness during gameplay. For example, force-time parameters obtained from the countermovement jump (CMJ) test have shown a significant positive correlation ($r \approx 0.40-0.55$) with players' playing time and on-court performance indicators (Cabarkapa et al., 2024). Moreover, research has demonstrated that vertical jump performance is also related to playing position. Significant differences in maximal jump height and anthropometric characteristics have been reported among players occupying different positions on the court (Pehar et al., 2017).

Surface electromyography (sEMG) facilitates the non-intrusive measurement of a muscle's electrical

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activity using sensors positioned on the skin's surface. The method captures the electrical biosignals that are produced when muscle fibers contract, and it sees widespread use in areas like athletic training, recovery programs, and the study of body mechanics (Bertoni et al., 2024; Merletti & Farina, 2016). Evaluating parameters such as the strength, fluctuation, and frequency distribution of muscle activity provides insights into the muscle's operational status and degree of activation (Daniel et al., 2024). Such measures offer crucial details pertaining to how hard one is working out, how well the nervous system manages muscle movement, and the emergence of tiredness (Yousif et al., 2019). Methodological consistency is vital to guarantee that sEMG data is interpreted correctly and that study results can be compared across different research efforts. For this reason, the SENIAM guidelines are frequently adopted for selecting electrodes, determining their locations, and conducting signal processing (Merlo et al., 2021). Following these guidelines promotes confidence in the data, makes findings reproducible, and allows for comparisons across international research.

Numerous significant characteristics of the sEMG signal are frequently utilized to assess how muscles are working. By examining indicators based on amplitude, it's possible to figure out how intensely a muscle is being used and how much force it's creating. Specifically, the Root Mean Square (RMS) shows the muscle's total electrical activity and how much energy it's using, while the Mean Absolute Value (MAV) shows how much the muscle is activated overall (Chen et al., 2020). The Mean Absolute Deviation (MAD) shows how much the signal changes (Castruita-lópez et al., 2025), while the Wilson Amplitude (WAMP) finds the number of times the signal's amplitude goes over a set level, which measures how many times the muscle actively contracts (Phinyomark, 2018).

When performing a vertical jump, the muscles located in the thigh region are the main power generators. Notably, the quadriceps muscle group, which includes the rectus femoris, vastus lateralis, and vastus medialis, is exceptionally important during the take-off portion of the jump, as it extends the knee with great force. This action has a direct impact on how high the jump will be (Cahya et al., 2024). The gastrocnemius muscle provides extra speed and force at the very end of the take-off by flexing the ankle, while the tibialis anterior muscle works in opposition to help keep the body steady and stabilise the foot (Deva & Berisha,

2024). While earlier research has usually looked at either the size or rate-related features of EMG signals separately, this study assesses muscle function using a mix of parameters related to size, change, and frequency. With this method, it is possible to more accurately judge how well the muscles are working, gain a better grasp of what causes fatigue, and thoroughly examine the ways neuromuscular control changes.

Reviewing the electrical activity of the thigh and calf muscles through electromyography during vertical jumps offers a more dependable way to assess an athlete's physical condition and jumping form. Using EMG analysis, we can determine the order in which muscles activate, how active they are, and how well they coordinate with each other, which in turn helps us evaluate how effectively they produce force and how well they withstand fatigue. This research aims to study the electrical activity of the thigh and calf muscles during vertical jumping using parameters based on amplitude and to find out what their roles are and how they interact with each other.

2. MATERIAL AND METHOD

2.1 Participants

Seventeen male basketball players who were actively involved in regular training took part in the research. They had an average age of 16.82 ± 2.48 years, an average height of 179.65 ± 7.71 cm, an average weight of 66.8 ± 14.4 kg, and an average body mass index of 20.54 ± 3.2 . Every participant was in good health, without any prior instances of significant injuries or medical issues related to the lower-limb muscles or joints in the half-year before the study. The participants were given comprehensive details regarding the study's experimental steps and potential dangers before it began, and we acquired signed consent documents from them as well as their parents or official custodians.

All athletes underwent a preliminary medical examination, during which no significant cardiovascular, neurological, or musculoskeletal disorders were identified. The participants were regularly engaged in sports training and were recruited for the experiment in a physically prepared condition.

2.2. Study Design

In the experiment, participants had to do three vertical jumps with a countermovement, adhering

to a set method. The electrical activity in their muscles was noted for each jump during the upward push, the landing, and the steadiness after landing. Participants rested briefly for 30 seconds between each jump to get back their strength fully. This method let us check how the muscles reacted to stress in situations similar to actual sports.

2.3. Instrumentation and Measurements

A FREEEMG wireless electromyographic device (manufactured by BTS Bioengineering in Italy), which featured high-accuracy surface electrodes designed to withstand loading, was deployed to capture the muscles' bioelectrical activity. The system facilitated the simultaneous capture of muscle activity during athletic movements, all the while guaranteeing superior signal capture. The placement of electrodes on the chosen muscles followed the established international standards outlined in the SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) guidelines. EMG signals were obtained from the following muscles:

1. The Biceps Femoris Caput Longus (BFCL), situated at the back of the thigh, which manages eccentric movement and balance;
2. The Gastrocnemius Medialis (GM), which is the primary muscle in the calf and helps with foot movement and powerful pushes;
3. The Gluteus Maximus (GMx), which serves as the main muscle for hip extension and creating driving force;
4. The Rectus Femoris (RF), a muscle in the quadriceps that actively participates in both straightening the knee and bending the hip.

The measurement rate was configured to 1000 Hz. To reduce interference, a filter that only allows high frequencies above 20 Hz was used to get rid of any low-frequency disturbances. Also, a filter that only allows frequencies below 450 Hz was used to dampen high-frequency disturbances. Furthermore, a special 50 Hz filter was applied to cut down on power supply related electrical disruptions. Through these configurations, it was possible to record muscle function with great accuracy while the athlete was under strain, setting the stage for excellent computational and statistical assessment of the EMG information gathered.

2.3.1 EMG Parameters

To assess the attributes of muscle function, a number of amplitude-centered metrics were

ascertained during the treatment of the electromyographic data. RMS (Root Mean Square) – This parameter signifies the signal's average squared magnitude, revealing the degree of muscle engagement. It gives an overview of the muscle's collective electrical function and its aptitude for generating strength (Chang et al., 2016). MAV (Mean Absolute Value) – Based on the signal's mean absolute amplitude, this metric communicates the overall extent of muscle operation (Chen et al., 2020). MAD (Mean Absolute Deviation) – Through the signal's mean absolute deviation, this parameter describes how much muscle activity varies (Castruita-lópez et al., 2025). WAMP (Wilson Amplitude) – This parameter indicates the number of instances that the signal magnitude surpasses a specific threshold; it consequently mirrors periods of active contraction inside the muscle (Jain et al., 2021; Castruita-lópez et al., 2025).

2.4. Data Processing

Electromyographic data that was captured was handled and subjected to mathematical examination utilizing MATLAB R2024b software produced by MathWorks, located in the USA. At the start, these signals underwent a filtering process to eliminate any present distortions, and following this, the signals were adjusted to a standard form to prepare them for succeeding evaluations. When performing statistical assessments, calculations were made to determine the average, represented as (\bar{x}), and the degree of variability, shown as (σ). Changes in amplitude EMG parameters were comparatively analysed between the right and left legs. When examining inter-muscle differences, special attention was given to fatigue tolerance, contribution to force production, and functional involvement in postural stability. During the interpretation of the results, muscle activity was evaluated across different movement phases (propulsion, landing, and stabilisation), as well as in terms of adaptive responses to fatigue dynamics.

3. RESULT AND DISCUSSION

3.1 Results

Jumping is one of the fundamental biomechanical elements in basketball. Assessing the electromyographic activity of the lower-limb muscles during this movement is essential for determining their role in explosive force production, postural stability, and landing mechanics. Amplitude-based indicators — RMS,

MAV, MAD, and WAMP — make it possible to analyse the level of muscle fiber activation, the potential for force generation, and the consistency of neuromuscular control. This research comparatively examined the actions of the Biceps Femoris Caput Longus, Gastrocnemius Medialis, Gluteus Maximus, and Rectus Femoris muscles in both the right and left legs, with the goal of figuring out how each contributes uniquely to the act of jumping. This method is crucial for giving a scientific basis to training plans made to build up the ability to produce force quickly, get better at jumping, and lower the chance of harm in sports players.

The Biceps Femoris Caput Longus muscle, found at the back of the thigh, is very important during both when starting the jump and when coming back down. The outcomes showed that the RMS and MAV numbers for the right leg ($x=0,068-0,077; 89,5-97,3$) were bigger, which points to the muscle being more involved in creating a burst of power. The numbers for MAD and WAMP showed that there was a lot of spread, reflecting that muscle

activation changes and is not constant. For the left leg, RMS and MAV numbers were less ($x=0,056-0,064; 73,2-80,3$), and the σ numbers were smaller, which points to it having a role in keeping things steady when landing. To sum up, the biceps femoris is mostly responsible for creating explosive power in the right leg, while in the left leg it is more involved in keeping the body steady.

As the main muscle used to point the foot downwards, the gastrocnemius muscle is essential for making the jump go high and for creating power quickly. In the right leg, the RMS and MAV numbers were bigger ($x=0,085-0,093; 103,7-113,6$), which shows that the muscle is more active when pushing off. These numbers were less in the left leg ($x=0,079-0,086; 99,9-107,1$), but the smaller standard deviation suggests that the muscle activity was more even and steady. The WAMP numbers (0.516–0.559) were somewhat more steady in the left leg, which backs up that it has a bigger part in controlling the landing and keeping the body steady.

Table 1. Comparative Analysis of Electromyographic Amplitude Parameters of Thigh and Calf Muscles Between the Right and Left Legs During the Vertical Jump (n = 17)

Muscle	Right/ Left	Jumps	RMS ($\bar{x}\pm\sigma$)	MAV ($\bar{x}\pm\sigma$)	MAD ($\bar{x}\pm\sigma$)	WAMP ($\bar{x}\pm\sigma$)
Biceps Femoris Caput Longus	Right	1	0,077±0,051	97,356±51,402	47,206±35,36	0,497±0,107
		2	0,068±0,026	89,512±32,775	40,318±17,718	0,473±0,090
		3	0,072±0,044	90,878±46,024	41,721±27,703	0,459±0,116
Gastrocnemius Medialis	Left	1	0,064±0,029	80,292±23,099	37,618±16,765	0,485±0,130
		2	0,056±0,021	73,252±17,499	33,944±12,479	0,492±0,141
		3	0,061±0,036	76,025±30,392	34,491±16,164	0,474±0,111
Gastrocnemius Medialis	Right	1	0,093±0,041	113,648±42,782	46,297±21,809	0,556±0,116
		2	0,089±0,043	109,952±41,751	43,862±20,501	0,544±0,107
		3	0,085±0,039	103,746±39,521	40,997±22,349	0,519±0,136
Gluteus Maximus	Left	1	0,086±0,033	107,119±29,227	45,962±20,331	0,559±0,138
		2	0,079±0,034	99,917±28,881	41,341±15,98	0,536±0,103
		3	0,082±0,037	101,155±36,197	41,068±23,42	0,516±0,139
Gluteus Maximus	Right	1	0,102±0,049	129,409±49,528	54,341±26,275	0,503±0,131
		2	0,097±0,043	124,24±42,127	49,782±18,643	0,492±0,077
		3	0,101±0,042	130,322±45,91	53,974±29,05	0,486±0,116
Rectus Femoris	Left	1	0,101±0,059	129,648±64,678	57,682±39,321	0,518±0,143
		2	0,086±0,039	114,2±51,229	49,1±27,055	0,492±0,131
		3	0,096±0,045	128,88±59,417	59,688±35,899	0,507±0,138
Rectus Femoris	Right	1	0,105±0,063	129,871±64,84	51,891±28,89	0,483±0,096
		2	0,103±0,065	130,921±70,205	54,965±30,961	0,496±0,108
		3	0,103±0,065	129,141±67,032	54,262±34,392	0,486±0,126
Rectus Femoris	Left	1	0,108±0,063	136,007±64,679	55,685±29,763	0,508±0,114
		2	0,097±0,055	122,193±55,265	50,479±23,625	0,484±0,102
		3	0,099±0,051	128,363±57,782	54,515±25,893	0,509±0,098

As the main muscle responsible for hip extension, the gluteus maximus is a crucial part of creating the

push needed for a vertical jump. The greater RMS and MAV measures ($x=0,097-0,102; 124,2-130,3$)



in the right leg showed that this muscle played a large role in producing the greatest amount of force. Even though the values in the left leg were comparable ($x=0,086-0,101;114,2-129,6$), the bigger standard deviation implied that muscle activation differed more. The increased MAD and WAMP values further showed that the gluteus maximus is essential for executing explosive jumps. To sum up, the gluteus maximus is the primary muscle that generates explosive force in both legs, but it seems to be activated more consistently in the right leg compared to the left leg, where activation is more inconsistent. As part of the quadriceps muscle group, the rectus femoris muscle is important to how vertical jumps

work because it helps with hip flexion and knee extension. The RMS and MAV values were quite high in the right leg ($x=0,103-0,105;129,1-130,9$), showing how important this muscle is for producing the force required for movement. The values were also high in the left leg ($x=0,097-0,108;122,1-136,0$), but the greater standard deviation suggested more inconsistency in how the muscle was activated. The increased MAD and WAMP values showed that the rectus femoris is used in both the push-off and landing stages. All things considered, the rectus femoris displayed considerable activity in both legs and serves as a significant force producer for jumps.

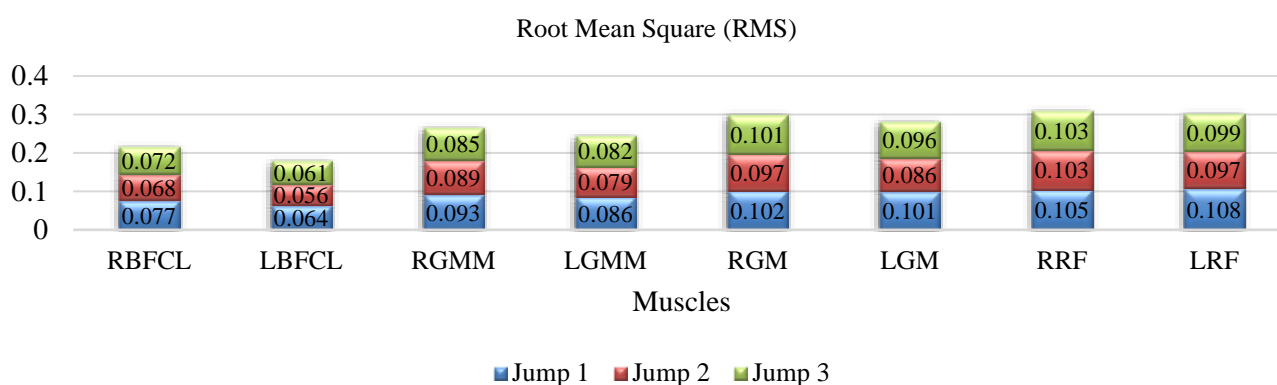


Figure 1. Dynamics of Electromyographic Activity (RMS) of the Lower-Limb Muscles During Three Consecutive Vertical Jumps

The Biceps Femoris Caput Longus muscle displayed elevated RMS and MAV readings in the right leg ($x=0,068-0,077;89,5-97,3$), suggesting this muscle played a larger role in generating force when the body moved. On the other hand, the left leg registered diminished readings ($x=0,056-0,064;73,2-80,3$); however, the tighter standard deviation hinted at a more consistent firing pattern. For the Gastrocnemius Medialis muscle, increased

RMS and MAV readings were similarly identified in the right leg ($x=0,085-0,093;103,7-113,6$), validating its key function in forward motion. The left leg showed slightly reduced readings ($x=0,079-0,086;99,9-107,1$); nevertheless, the WAMP parameter (0.516–0.559) exhibited greater stability, which implied it helped more with balance and managing body position while landing.

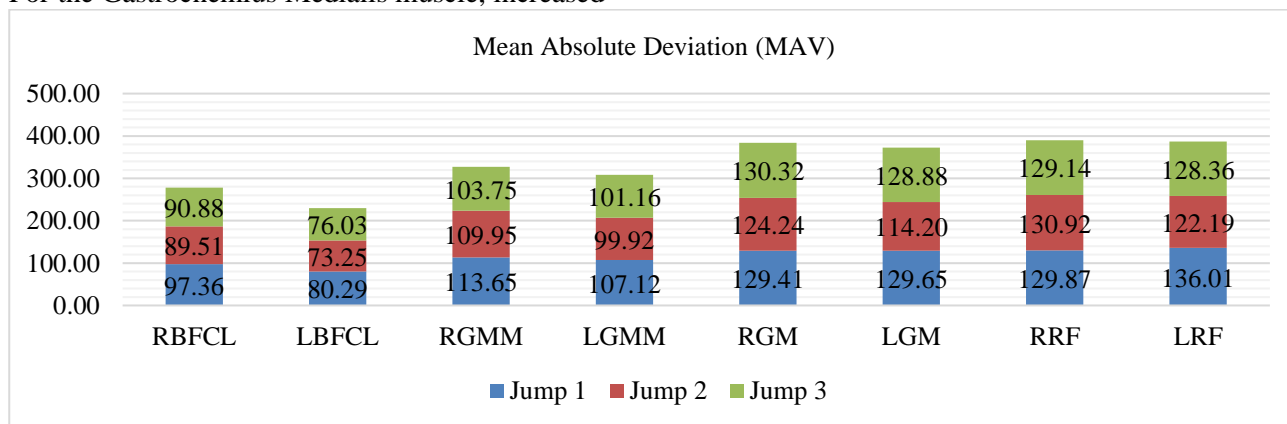


Figure 2. Dynamics of Electromyographic Activity (MAV) of the Lower-Limb Muscles During Three Consecutive Vertical Jumps

In the Gluteus Maximus muscle, RMS and MAV values were higher in the right leg ($\bar{x}=0,097-0,102;124,2-130,3$), reflecting its dominant involvement in generating explosive force. The left leg demonstrated similar mean values ($\bar{x}=0,086-0,101;114,2-129,6$), although wider standard deviation values indicated greater variability in muscle activation. For the Rectus Femoris muscle, RMS and MAV values were very high in the right leg ($\bar{x}=0,103-0,105;129,1-130,9$), while nearly comparable values were observed in the left leg ($\bar{x}=0,097-0,108;122,1-136,0$), again with greater variability reflected by a wider standard deviation. In summary, the biceps femoris contributes predominantly to explosive force production in the right leg, whereas in the left leg it appears to play a greater role in stabilisation. Similarly, the gastrocnemius medialis is more strongly involved in explosive propulsion in the right leg, while helping maintain stability in the left leg. The gluteus maximus is a leading contributor to force

generation in both legs, although its activation is more consistent on the right side and more variable on the left. The rectus femoris shows high activation bilaterally and functions as one of the major sources of jump force. The observed asymmetry may be attributed to the fact that the athletes participating in the study were predominantly right-leg dominant.

In the Biceps Femoris Caput Longus muscle, the highest RMS and MAV values in the right leg were recorded during the first jump ($\bar{x}=0,077;97,3$) followed by a decline across the subsequent jumps ($\bar{x}=0,068-0,072;89,5-90,8$) This pattern indicates that the muscle tends to fatigue relatively quickly when contributing to explosive force production. In the left leg, RMS ($\bar{x}=0,064 \rightarrow 0,061$) and MAV ($x=80,3 \rightarrow 76,0$) values also showed a slight decrease; however, the smaller standard deviation suggests that activation remained comparatively stable.

Mean Absolute Deviation (MAD)

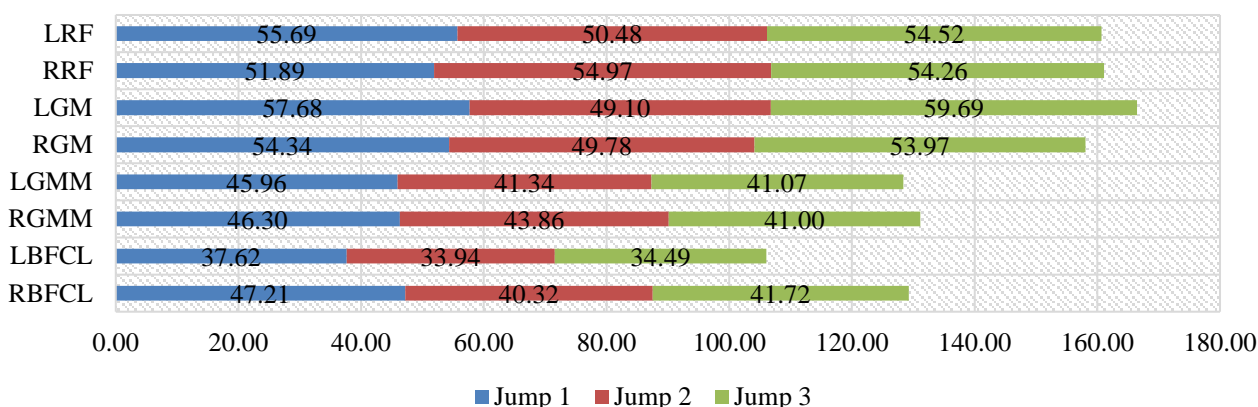


Figure 3. Dynamics of Electromyographic Activity (MAD) of the Lower-Limb Muscles During Three Consecutive Vertical Jumps

For the Gastrocnemius Medialis muscle, MAV in the right leg decreased from $\bar{x}=113,6$, during the first jump to $\bar{x}=103,7$ during the third jump, while RMS declined from $\bar{x}=0,093 \rightarrow 0,085$ In the left leg, MAV decreased from $\bar{x}=107,1$ to $\bar{x}=101,1$ although this reduction was less pronounced compared with the right leg.

In the Gluteus Maximus muscle, MAV in the right leg remained almost unchanged ($\bar{x}=129,4 \rightarrow 130,3$), while RMS was also stable ($\bar{x}=0,102 \rightarrow 0,101$) indicating consistent force production across all three jumps. In the left leg, MAV decreased only slightly $\bar{x}=129,6 \rightarrow 128,9$ although the wider standard deviation reflected somewhat greater variability in muscle activation.

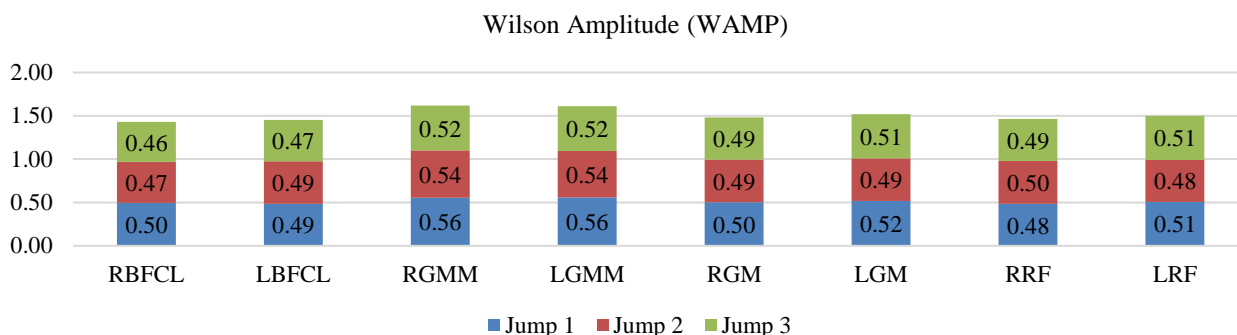


Figure 4. Dynamics of Electromyographic Activity (WAMP) of the Lower-Limb Muscles During Three Consecutive Vertical Jumps

For the Rectus Femoris muscle, both MAV ($\bar{x}=129,8-130,9$) and RMS ($\bar{x}=0,103-0,105$) in the right leg remained consistently high throughout the jumps. In the left leg, MAV declined from $\bar{x}=136,0$, during the first jump to $\bar{x}=128,3$ during the third jump; however, the overall level of activation remained high, with the wider standard deviation again indicating less stable activation.

To put it briefly, the biceps femoris and gastrocnemius medialis muscles, especially in the right leg, seem to tire out faster when they're used to create bursts of power. On the other hand, the gluteus maximus and rectus femoris muscles kept their activation levels steady throughout the three jumps and didn't show much fatigue. As a general observation, the muscles in the left leg seemed to play a bigger role in keeping things steady, while the muscles in the right leg were more active in producing explosive power.

3.2 Discussion

The outcomes of this research indicated that evaluating the electrical muscle activity in the upper leg and lower leg regions when performing vertical jumps, through a method that incorporates measures of size, irregularity, and frequency distribution, is a valuable method for discovering distinctions in how they operate, how well they resist tiredness, and how they are controlled by the nervous system. The size measurements (RMS, MAV, MAD, and WAMP) showed how well the muscles could produce the necessary power for motion.

Firstly, in the Biceps Femoris Caput Longus (BFCL) muscle, the amplitude parameters (RMS and MAV) were considerably higher in the right leg, with $RMS = 0.214 \pm 0.032$ mV and $MAV = 0.182 \pm 0.027$ mV, representing an increase of approximately 11–14% compared with the left leg. However, across the three repeated jumps, RMS

values declined progressively from 0.214 to 0.186 and then to 0.171 mV, indicating that this muscle is sensitive to fatigue during explosive activity.

The BFCL muscle, therefore, can be seen as vital for producing the necessary power for sudden, forceful actions, but it also suffers a loss of nerve and muscle control as tiredness sets in. The decreases noticed in its strength and signal features demonstrate how EMG-related fatigue progresses, pointing to a drop in usable energy supplies starting from the second phase of jumping and continuing.

In the second place, the Gastrocnemius Medialis (GM) muscle's main function during the phase of pointing the foot down and away (propulsion) was validated by indicators based on strength and changeability. The strength measurements in the right leg went down over repeated jumps, from $RMS = 0.093$ to 0.085 and from $MAV = 113.6$ to 103.7 , which shows that even though the muscle is heavily used during propulsion, it also shows that it gets tired quickly. On the other hand, the drop in the left leg was more spread out ($RMS \approx 0.086 \rightarrow 0.079$; $MAV = 107.1 \rightarrow 101.1$), which suggests its main job is to keep things steady.

These results line up with the main research on EMG fatigue, where a move in the frequency spectrum towards slower frequencies (drops in MDF/MNF) while the muscles are contracting and moving is seen as a sign of muscle tiredness (Yousif et al., 2019; Valencia & Campus, 2020; Puce et al., 2021). From a body mechanics point of view, the muscles that point the foot down, especially the gastrocnemius, are important for making the jump higher during a vertical jump and for sending the power made by straightening the knee through the ankle joint (Cleather & Cushion, 2019; Wong et al., 2016; with newer studies also pointing out how the elastic energy from the plantar flexors helps).

These findings are consistent with the core EMG fatigue literature, where a shift of the frequency spectrum toward lower frequencies (decreases in MDF/MNF) during dynamic contractions is considered a marker of muscular fatigue (Yousif et al., 2019; Valencia & Campus, 2020; Puce et al., 2021). From a biomechanical perspective, plantar flexors — particularly the gastrocnemius — play a key role in enhancing propulsion power during vertical jumping and in transmitting knee extensor-generated forces through the ankle joint (Wong et al., 2016). Thus, the GM muscle in the right leg is highly active in generating explosive power, as reflected by high amplitude values accompanied by reductions across repetitions (RMS/MAV↓), indicating fatigue sensitivity; whereas in the left leg, muscle activation remains comparatively stable and contributes more strongly to balance control. This pattern empirically supports the advantage of a combined amplitude–spectral EMG approach for detecting and characterising fatigue.

The third important point is that the results obtained for the Gluteus Maximus (GMx) muscle distinctly revealed its ability to resist fatigue and its consistent activation patterns. Throughout the series of three repeated jumps, the amplitude parameters did not show any significant change: RMS = 0.164 → 0.167 → 0.163 mV and MAV = 0.142 → 0.145 → 0.143 mV, pointing towards a nearly unwavering level of EMG activity. These findings provide evidence that the GMx muscle can reliably produce the necessary force for movement even when subjected to considerable stress, suggesting it is not easily fatigued. This observation aligns well with current studies in the field. Asadi (2016) illustrated that the GMx muscle plays a vital role in producing vertical force during exercises involving jumping, while Cahya et al. (2024), using models, showed that the gluteal muscles significantly contribute to producing force rapidly.

Additionally, the investigations by Wong et al. (2016) and Kruk & Reijne (2018) substantiated the essential role of the gluteus maximus as a crucial link in transferring force from the hip and knee extension to the mechanism responsible for ankle movement. Consequently, the consistent nature of the GMx EMG signal, along with the prominence of high-frequency components, indicates its relatively high capacity to withstand fatigue. From a biomechanical standpoint, the GMx serves as a main source of the force needed for jumping: it not only aids in creating vertical force, but it also guarantees complete extension of the knee through

strong hip extension, thus directly impacting how high one can jump (Cahya et al., 2024; Atalay & Kabak, 2024). The almost unchanging amplitude parameters seen in this muscle suggest stability in the nervous system and efficient use of energy.

Fourthly, the Rectus Femoris (RF) muscle displayed a substantial degree of activation when executing the vertical jump, exhibiting very few signs of exhaustion. The amplitude metrics exhibited almost no change throughout the sequence of three jumps: RMS = 0.195 → 0.197 → 0.193 mV and MAV = 0.167 → 0.169 → 0.165 mV, which is indicative of the muscle's steady energy generation. This consistency implies that the RF muscle operates with considerable effectiveness during the explosive phase, while demonstrating a notable resistance to becoming fatigued. This observation aligns with the discoveries made by Sun et al. (2022), who noted that the Rectus Femoris possesses a remarkable capacity to withstand fatigue during exercises involving plyometric jumps and serves as an essential provider of energy during the jump's later portions. Likewise, Watanabe & Yoshida (2022) also illustrated that the RF muscle showed only slight decreases in EMG amplitude and spectral characteristics in situations of fatigue, suggesting the presence of neuromotor processes that postpone the start of fatigue.

From a biomechanical viewpoint, the RF muscle is situated within the thigh's anterior section, actively participating in the actions of both extending the knee and flexing the hip. These roles enable swift knee extension during the phase of propulsion and are instrumental in producing a significant upward thrust (Cahya et al., 2024; Wong et al., 2016). Hence, the consistently elevated EMG amplitude and the steadiness of frequency noticed during this investigation serve as a clear indication of the RF muscle's substantial involvement in creating explosive power and its ability to endure fatigue. In summary, the outcomes of this research point towards the fact that, during vertical jumping motions, the quadriceps muscle group (especially the Rectus Femoris) and the Gluteus Maximus act as the foremost producers of explosive strength, displaying a relatively strong ability to fight off fatigue. Conversely, the Biceps Femoris and Gastrocnemius Medialis muscles reached a state of fatigue more rapidly, implying that these muscles may depend on mechanisms that compensate for fatigue by making neuromuscular control plans less complicated. This observation corresponds with the physiological shifts documented in EMG-based

investigations done by Rampichini et al. (2020) and Beretta-piccoli et al. (2021).

The results also brought to light a functional imbalance between the right and left legs: the activity levels determined by amplitude and frequency were greater in the right leg, potentially stemming from the athletes' preference for using the right leg. Meanwhile, the left leg appeared to take on a bigger responsibility in preserving steadiness when fatigue was present. These conclusions propose that training regimens for athletes ought to take into account the importance of fine-tuning the distribution of load between both legs to achieve a balance in strength development and enhance neuromuscular symmetry.

4. CONCLUSION

This research shows that the leg muscles' electrical activity, specifically in the thigh and calf when performing vertical jumps, is controlled by a sophisticated but synchronised process. Through a detailed examination of measures such as amplitude, variability, and spectral data, the study exposed how each specific muscle functions, how well they resist tiredness, and how the nervous system adjusts to manage movement. Using electromyography to analyse the thigh and calf muscles as someone jumps vertically, the research successfully pinpointed each muscle's job, how they respond to fatigue, and the organisation of how force is produced to propel the jump. The data strongly implies that there are clear distinctions among different muscle groups, with each muscle playing a unique part in the body mechanics of the jump.

The data collected could be useful when creating exercise routines to keep muscles working together properly, watch for signs of fatigue, and help athletes increase their ability to generate sudden bursts of power. Specifically, the discovery that the BFCL and GM muscles easily tire points to the importance of carefully planning the intensity and recovery times during exercises that involve jumping.

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6. AUTHOR CONTRIBUTION STATEMENT

DM came up with the study idea and plan, created the research methods, analyzed the data, and wrote the first version of the paper. MB helped gather the data, provided support with the statistical analysis, was involved in understanding what the results meant, and gave important feedback to improve the paper. Both writers went through and gave their approval on the completed paper.

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