Comparison of Electromyographic Characteristics of Volleyball Players in Stop-jumps: An Analysis at Different Speeds

Hua Zheng[1], Zengliang Cai[2*], Changqing Li[1]

[1]*College of Physical Education and Health Sciences*
Chongqing Normal University
Chongqing 401331, China
E-mails: zhuazhengh@outlook.com, cqli3278@163.com

[2]*Department of Physical Education*
Shanghai University of Traditional Chinese Medicine
Shanghai 201203, China
E-mail: caizlc@hotmail.com

[*]*Corresponding author*

Received: January 21, 2024 **Accepted: May 10, 2024**

Published: June 30, 2024

Abstract: *The stop-jump is a crucial skill in volleyball, and analyzing its motion can greatly benefit the training of volleyball players. This paper analyzed 30 players from the volleyball team at Chongqing Normal University. To study the impact of running speed on lower limb muscle activity during stop-jumps, the players were randomly assigned the low-speed running group, the medium-speed running group, and the high-speed running group. Surface electromyography sensors were employed to collect electromyographic signals from the rectus femoris, vastus lateralis, and gastrocnemius muscles of the players during the execution of the stop-jump. The electromyographic indicators were calculated using the surface electromyography system's built-in program, including the root-mean-square (RMS) electromyographic value and integral electromyographic (IEMG) value. The former represents the effective discharge value of motor units, which depends on the electromyographic amplitude and is related to the number of recruited motor units. The latter represents the discharge capacity of motor units involved in muscle activity per unit of time, reflecting the degree of muscle activation during exercise. Then, statistical analysis was performed on these calculated indicators using SPSS software. It was found that the stop-jump comprised three distinct stages: stop, jump, and flight. Regardless of the stage, the results indicated that the higher the speed of running, the greater the electromyographic indexes of the muscle groups. Additionally, when comparing electromyographic indexes across different stages, it was observed that the index values gradually decreased with the progression of each stage.*

Keywords: *Volleyball, Stop-jump, Electromyographic signal, Running speed.*

Introduction

Volleyball is a competitive sport played across a net, where the most technical movements require a combination of skill and quick movement. It is a sport that demands high levels of technique and rapid reactions, and the stop-jump is one commonly used technique in volleyball matches [12]. Players, whether on offence or defense, must quickly move to designated positions and then swiftly execute corresponding actions [16]. This requires players to have the ability to start running quickly and stop rapidly upon reaching their positions. For example, defensive blocking requires rushing towards the net and abruptly stopping before jumping up; similarly, offensive spiking at the net also demands quick movement towards the net followed by a stop-jump [17]. When using a stop-jump, players need to generate powerful force in a short period to change their direction of movement, especially in the lower limbs. The tremendous force generated during a stop-jump can put a strain on muscles and joints, which can frequently occur during competitions and daily training. Improper handling of such strain can lead to injuries for players [11]. The action of stop-jump involves the coordinated work of multiple muscles, and muscle activity generates electromyographic signals that can reflect muscle activation status and functional characteristics [2]. Peebles et al. [14] utilized the load collected by wireless load-sensing insoles to predict knee joint extension torque and power symmetry during bilateral stop-jump tasks for healthy recreational athletes. The experimental results validated the effectiveness of this method. Charlton et al. [3] proposed a method to quantify external loads by multiplying the number of jumps with average kinetic energy to measure the jumping ability of volleyball players. The effectiveness of this method was validated through experiments. Li et al. [9] analyzed vertical jumping to understand the movement characteristics of the legs during volleyball training. The results indicated that the duration of training significantly affected joint pressure and the risk of injury in the legs. Kuniszyk-Jóźkowiak et al. [8] investigated the relationship between muscle fatigue caused by physical labour and changes in skin temperature. Surface electromyography (sEMG) signals were used to measure muscle activity during the study, which revealed a correlation between skin temperature changes and muscle fatigue. This paper performed a case study involving 30 players from the varsity volleyball team at Chongqing Normal University.

Methods

Study subjects

The varsity volleyball team of Chongqing Normal University was used as the subject for the case study. Thirty volleyball players were selected from the varsity team. The average age was 20.3 ± 0.8 years old, the average height was 180.5 ± 3.9 cm, the average weight was 75.9 ± 8.8 kg, and the length of training was more than two years. None of the subjects had a physical injury six months before being tested. The subjects were informed about the experimental content and signed an informed consent form before formal testing.

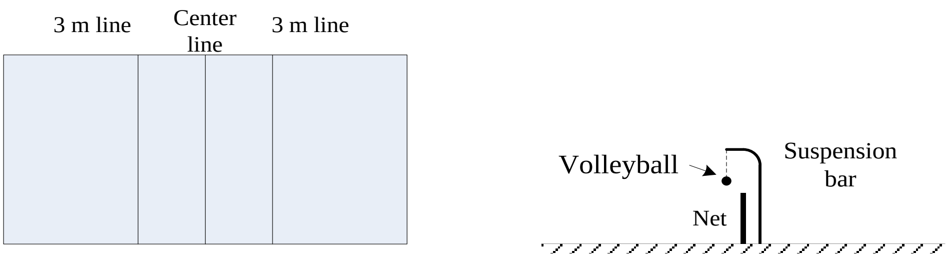
Research methods

Testing equipment

Test equipment used for the study included a Kistler three-dimensional force measuring plate [18], an infrared high-speed video camera, a wireless SEMG device PicoBlue (Cometa, Italy), a skin preparation knife used for removing dead skin and body hair from the surface of the skin in contact with the electrodes, medical alcohol, degreasing cotton balls, medical adhesive tape, and a volleyball court [6].

Testing protocol

The experiments were conducted on a volleyball court situated in a gymnasium. A visual representation of the test site is provided in Fig. 1. The volleyball court is 18 m in length and 9 m in width, with the 3 m line representing a parallel boundary situated 3 m from the centre line. A suspension bar was installed on one side of the net to suspend the volleyball, which hung above the opposite side of the net. Additionally, a force-measuring plate was positioned below the suspended volleyball [15]. Referring to the preliminary test results for the subjects' stop-jump height, the suspension height of the volleyball was established at 2.5 m, and the horizontal distance between the volleyball and the centre line was set at 10 cm.



a) top view of volleyball court b) side view of volleyball test court

Fig. 1 Schematic diagram of the test site

Theoretically, the low-speed running group is expected to maintain a speed of 2 m/s before stopping, the medium-speed running group aims for a theoretical maintenance speed of 3 m/s, and the high-speed running group targets a theoretical maintenance speed of 4 m/s. Acknowledging that individuals cannot consistently maintain precise speeds at all times, these target speeds were translated into effective speed intervals. Specifically, the low-speed group operated within the effective interval of 1.9-2.1 m/s, the medium-speed group within 2.9-3.1 m/s, and the high-speed group within 3.9-4.1 m/s. Initial training focused on enabling players in each group to consistently sustain their respective effective speed zones. For speed measurement, high-speed cameras were used.

At the initiation of the test, surface electromyographic signal sensors were affixed to the m. vastus lateralis, m. rectus femoris, and m. gastrocnemius (Fig. 2), guided by both the technical characteristics of the stop-jump and anatomical knowledge [1]. Following the commencement signal, participants initiated their movement from the 3 m line. Executing a stop at a predetermined running speed, they proceeded to jump onto the force platform beneath the volleyball, simultaneously making contact with the volleyball using their right hand. This action constituted a stop-jump. An infrared high-speed video camera was employed to concurrently capture the stop-jump process for subsequent stage division [7]. Each subject within each group executed three stop-jumps for each of the three volleyball heights. The electromyographic signals during each stop-jump at different heights were recorded.

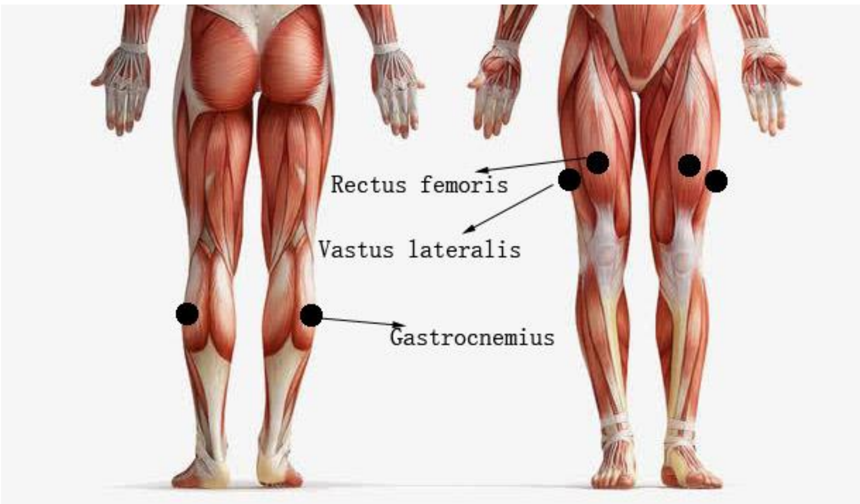
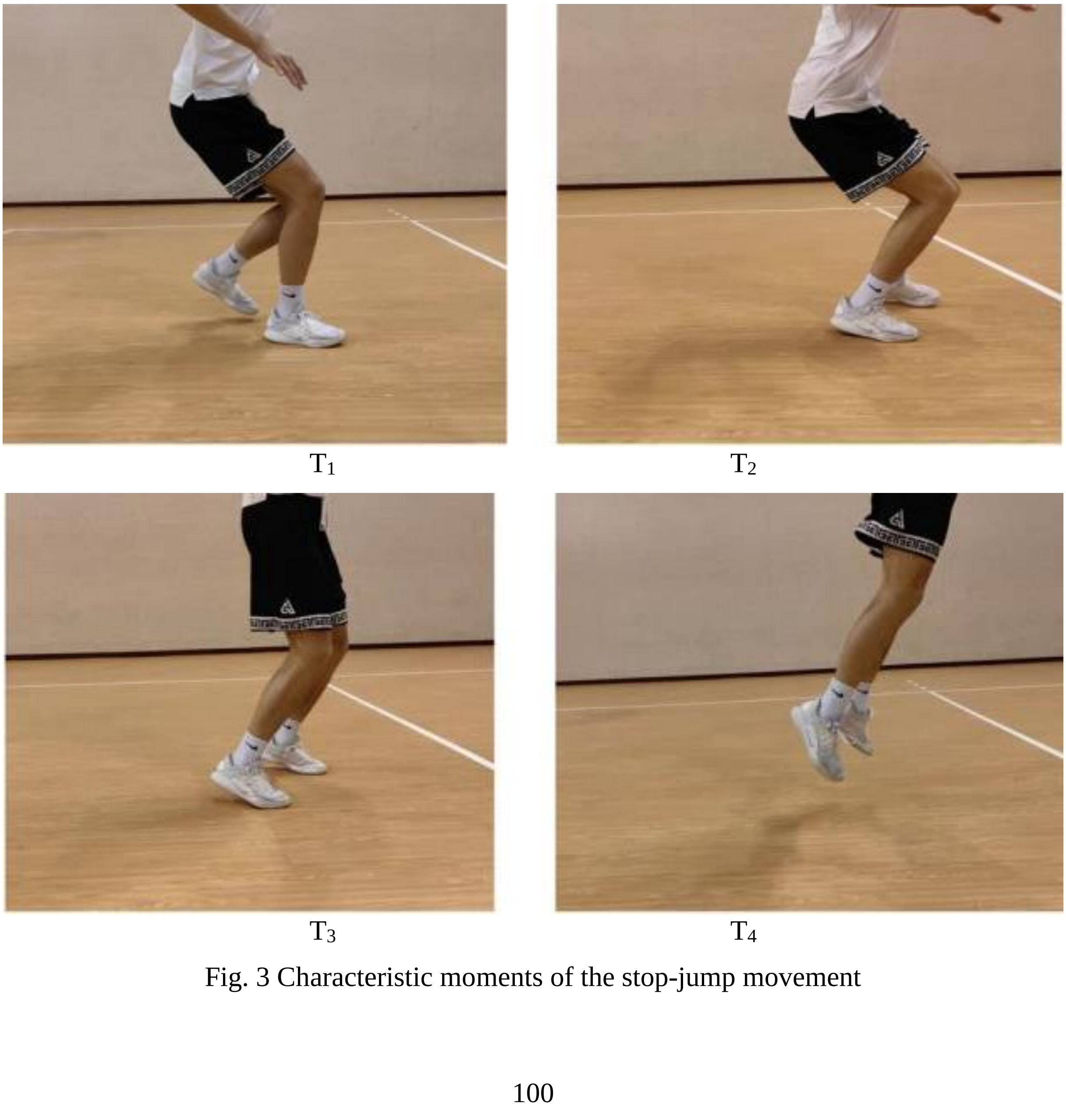


Fig. 2 A diagram illustrating the placement of sEMG electrodes

Statistical analysis

The stop-jump movement was divided into three phases: the stop phase, the jump phase, and the flight phase [4]. The division criteria of the stop phase were T_1 to T_2; the division criteria of the jump phase were T_2 to T_3; the division criteria of the flight phase were T_3 to T_4. The characteristic moments of the above three phases are shown in Fig. 3, with T_1 as the moment when the ground reaction force is more than 10 N, T_2 as the moment when the knee joints reach the maximum angle of flexion, T_3 as the moment when the ground reaction force is less than 10 N, and T_4 as the moment when the right-hand shoots the volleyball. The moments of takeoff and landing were determined by measuring the ground reaction force using the force-measuring plate, while the moment of hitting the ball was determined using a high-speed camera. The electromyographic signals of the measured muscle groups during the three phases were recorded. Then, the signals were rectified and processed by a 50 Hz high-pass filter and a 15 Hz low-pass filter. Finally, the root-mean-square (RMS) value and integral electromyographic (IEMG) value were calculated using the built-in program of the sEMG system. SPSS software [5] was used to record the collected data. The values of the electromyographic indicators of the same running speed group were averaged and represented as $x \pm s$, and an independent t-test was used to compare the differences between different groups.



T_1 T_2 T_3 T_4

Fig. 3 Characteristic moments of the stop-jump movement

Test results
Due to space limitations, this article only presents the changes in RMS of electromyographic signals during the stop-jump process for athletes in the low-speed group, as shown in Fig. 4. As the time required for athletes to complete multiple stop-jumps may vary, a percentage-based expression was used for measuring time, with 100% representing the duration of one complete stop-jump movement.

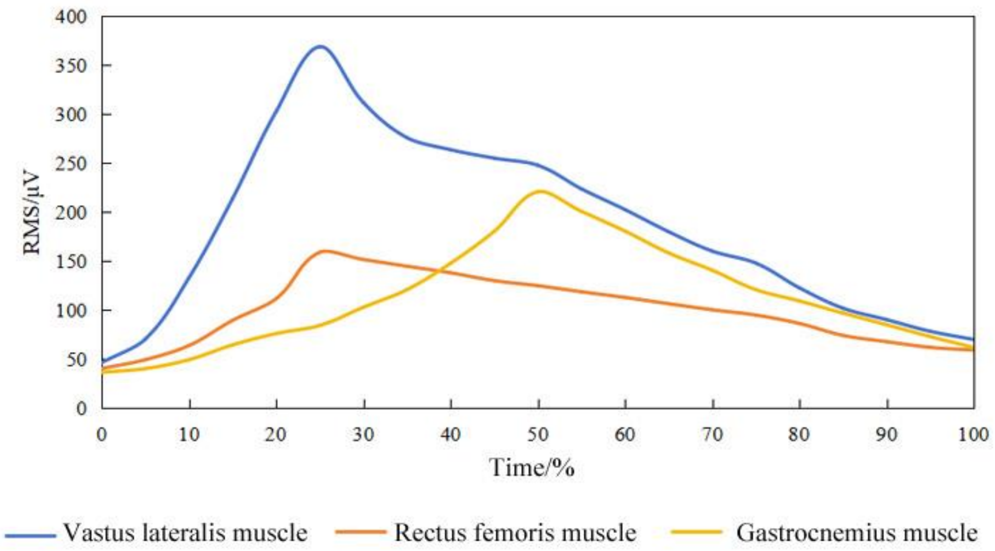


Fig. 4 Changes in the RMS value of the electromyographic signal in the low-speed group during the stop-jump

The characteristic moments of the four stop-jump actions, T_1 to T_4, were respectively located at 0%, 25%, 50%, and 75% of the duration of the stop-jump action. The phase from 0% to 25% was the stop phase, from 25% to 50% was the jump phase, from 50% to 75% was the flight phase, and from 75% to 100% was the landing phase after hitting. From Fig. 4, it can be observed that the electromyographic signals of each muscle group showed a trend of initially increasing followed by decreasing RMS values. Among them, the vastus lateralis and rectus femoris muscles reached their maximum RMS earlier than the gastrocnemius muscle.

Table 1 presents the electromyographic signals during the stop phase of the player's stop-jump at various running speeds.

Table 1. Electromyographic signals in the stop phase at different running speeds

Muscle group	**Electromyographic index**	**Low speed**	**Medium speed**	**High speed**	***p*-value**
Vastus lateralis muscle	RMS, μV	368.6 ± 114.1	468.9 ± 102.5	629.6 ± 164.2	0.027
	IEMG, μVs	13.3 ± 4.4	16.5 ± 3.6	17.6 ± 3.8	0.013
Rectus femoris muscle	RMS, μV	158.5 ± 98.3	249.0 ± 17.8	294.8 ± 99.2	0.023
	IEMG, μVs	5.6 ± 3.4	6.9 ± 1.1	7.1 ± 2.8	0.011
Gastrocnemius muscle	RMS, μV	83.7 ± 26.3	80.3 ± 22.5	78.7 ± 36.6	0.013
	IEMG, μVs	2.8 ± 1.1	2.4 ± 1.4	1.9 ± 0.3	0.011

Table 1 reveals that, with the increase in running speed, there was a noticeable and significant increase in the electromyographic indicators of the vastus lateralis muscle and rectus femoris muscle, and the indicators of the gastrocnemius muscle decreased.

Table 2 displays the electromyographic signals during the initial phase of the player's stop-jump at different running speeds.

Table 2. Electromyographic signals during the jump phase at different assist speeds

Muscle group	Electromyographic index	Low speed	Medium speed	High speed	*p*-value
Vastus lateralis muscle	RMS, μV	247.4 ± 74.7	367.8 ± 181.7	462.5 ± 186.9	0.017
	IEMG, μVs	5.4 ± 1.4	6.2 ± 1.1	6.8 ± 1.3	0.016
Rectus femoris muscle	RMS, μV	124.3 ± 68.9	192.5 ± 62.8	217.5 ± 95.6	0.021
	IEMG, μVs	2.2 ± 0.6	2.4 ± 0.3	2.6 ± 0.5	0.010
Gastrocnemius muscle	RMS, μV	220.3 ± 38.5	199.4 ± 70.7	181.4 ± 71.8	0.011
	IEMG, μVs	3.2 ± 1.3	4.5 ± 1.0	5.1 ± 1.1	0.012

It can be seen from Table 2 that as the running speed increased, there was a notable and significant elevation in the electromyographic indicators for the m. vastus lateralis and m. rectus femoris, while the gastrocnemius muscle showed a decreasing RMS value and an increasing IEMG value.

Table 3 illustrates the electromyographic signals during the flight phase of the player's stop-jump at different running speeds.

Table 3. Electromyographic signals in the flight phase at different running speeds

Muscle group	Electromyographic index	Low speed	Medium speed	High speed	*p*-value
Vastus lateralis muscle	RMS, μV	147.4 ± 72.7	267.8 ± 151.7	362.5 ± 156.9	0.018
	IEMG, μVs	4.4 ± 1.2	5.2 ± 1.2	5.8 ± 1.1	0.017
Rectus femoris muscle	RMS, μV	94.3 ± 67.4	162.5 ± 61.3	197.5 ± 94.1	0.020
	IEMG, μVs	1.2 ± 0.6	1.4 ± 0.3	1.6 ± 0.5	0.010
Gastrocnemius muscle	RMS, μV	120.3 ± 38.4	99.4 ± 70.2	81.4 ± 71.2	0.014
	IEMG, μVs	2.2 ± 1.1	3.5 ± 1.1	4.1 ± 1.2	0.013

Table 3 shows that as the running speed increased, there was a significant increase in the electromyographic indices for the vastus lateralis and rectus femoris muscles, while the gastrocnemius muscle showed a decreasing RMS value and an increasing IEMG value.

Discussion

Volleyball, characterized by intense ball confrontations, demands high skill levels and rapid reactions from players. The primary objective during these confrontations is to skillfully propel the ball into the opponent's court while adhering to the rules. The net positioned at the centre of the volleyball court stands at 2.43 m and 2.24 m for men's and women's volleyball, respectively, surpassing the average height of most players. Consequently, executing a flat hit from the ground when facing the net is essentially impractical. Although flat hitting is feasible from the baseline, the extended flight time of the volleyball allows opponents more reaction time. Therefore, players often resort to jumping to strike the ball, requiring swift coordination and movement to position themselves optimally. The stop-jump emerges as a frequently employed skill in volleyball. The stop-jump requires players to quickly buffer and reduce their own translational speed after reaching the designated position, and then jump. This process puts a significant burden on the lower limbs. This article analyzed the movement characteristics of lower limb muscle groups during stop-jumps using electromyographic signals, providing effective references for better training in stop-jumps. sEMG technology is a simple, non-invasive method for measuring muscle activity. Lin et al. [10] utilized a three-dimensional motion analysis system, force-measuring plate, and sEMG to investigate the effects of rectus abdominis fatigue on jump performance and landing load in volleyball players during spike jumps and countermovement jumps. The results indicated that rectus abdominis fatigue decreased jump height and led to changes in landing strategy. Pacheco et al. [13] examined the electromyographic response time of the peroneus muscle in injured and healthy ankles during sudden inversion. The results indicated that the electromyographic response time of the peroneus muscle to the sudden angular displacement of the ankle joint was not affected by ankle sprains. This study also utilized sEMG signals to analyze lower limb muscle activity during volleyball players' stop-jump movements. Compared to the previous studies mentioned, this study focuses on the running speed before a stop in the stop-jump movement, investigating how the running speed affects lower limb muscles during a stop-jump.

The present study conducted a case analysis on 30 players from the volleyball team at Chongqing Normal University. These players were randomly divided into three groups, namely the low-speed running group, medium-speed running group, and high-speed running group. sEMG sensors were used to collect the electromyographic signals of these three groups during stop-jumps. The stop-jump can be divided into three stages: stop, jump, and flight. Regardless of which stage it is in, the higher the running speed, the higher the electromyographic indicator values of the vastus lateralis and rectus femoris muscles. The reason behind this is that with faster running speed during a stop-jump, more force is required for buffering to come to a sudden halt. Similarly, more force is needed to change direction during this movement. This force is provided by the reactive force exerted by muscles against the ground. The greater the muscle output force, the greater the reactive force from the ground. By comparing the electromyographic indicators at different stages, it can be observed that as the stages progressed, the values of these indicators gradually decreased. This is because, during the jump process, individuals gradually leave the ground and consequently experience a reduction in ground reaction forces. As a result, the muscular effort required to counteract these forces naturally diminishes. During the flight phase, muscle groups exert more effort to maintain balance and prepare for landing impact.

Conclusion

This paper provides a concise introduction to volleyball and the stop-jump. Subsequently, it presents a case study involving 30 players from the volleyball varsity team at Chongqing Normal University. The players were categorized into three groups: low-speed running, medium-speed running, and high-speed running. The electromyographic signals during the stop-jump were tested and analyzed. The results are outlined as follows. During the stop phase, there was a notable increase in the electromyographic indices of muscle groups with the augmentation of running speed. In the jumping phase, there was a notable increase in the electromyographic indices of the vastus lateralis and rectus femoris muscles as the running speed increased, and the gastrocnemius muscle demonstrated a decreasing RMS value and an increasing IEMG value. During the flight phase, there was a substantial increase in the electromyographic indices of the vastus lateralis and rectus femoris muscles with the increase in running speed, and the gastrocnemius muscle demonstrated a decreasing RMS value and an increasing IEMG value.

References

1. Bean C., T. Forneris, J. Brunet (2016). Investigating Discrepancies in Program Quality Related to Youth Volleyball Athletes' Needs Support, Psychology of Sport and Exercise, 26, 154-163.
2. Bouhedja T., M. L. Hamida, H. Djemai (2021). Influence of Speed on Vertical Jump When Performing Volleyball Smash, Science & Sports, 36(3), E121-E129.
3. Charlton P. C., C. Kenneally-Dabrowski, J. Sheppard, W. Spratford (2017). A Simple Method for Quantifying Jump Loads in Volleyball Athletes, Journal of Science and Medicine in Sport, 20(3), 241-245.
4. De Vries A. J., H. van der Worp, R. L. Diercks, I. van den Akker-Scheek, et al. (2015). Risk Factors for Patellar Tendinopathy in Volleyball and Basketball Players: A Survey-based Prospective Cohort Study, Scandinavian Journal of Medicine and Science in Sports, 25(5), 678-684.
5. Giannousi M., E. Kioumourtzoglou (2017). Factors Influencing Physical Education Teachers' Satisfaction in E-learning Volleyball Courses, Sport Science, 10(1), 122-127.
6. Kirkaya I., D. Simsek, H. Ertan (2015). The Effects of Vibration Frequency Variation on Volleyball Players' Drop Jump Ability and Postural Control Performance, Turkish Journal of Sport and Exercise, 17(2), 14-21.
7. Kumar G., A. Shukla, A. Chhoker, R. K. Thapa (2021). Identification of Factors Determining Winning in Men's and Women's Beach Volleyball: A Logistical Regression Approach, Physical Education Theory and Methodology, 21(1), 26-35.
8. Kuniszyk-Jóźkowiak W., J. Jaszczuk, A. Czaplicki (2018). Changes in Electromyographic Signals and Skin Temperature during Standardised Effort in Volleyball Players, Acta of Bioengineering and Biomechanics, 20(3), 115-122.
9. Li Z., J. Wang, Y. Yang (2021). Motion Features of Legs in Volleyball Block Jump Based on Biomechanical Analysis, Molecular & Cellular Biomechanics, 18(2), 87-97.
10. Lin H. T., Y. C. Huang, Y. Y. Li, J. H. Chang (2021). The Effect of Rectus Abdominis Fatigue on Lower Limb Jumping Performance and Landing Load for Volleyball Players, Applied Sciences, 11(15), 6697.
11. Martinez D. B. (2017). Consideration for Power and Capacity in Volleyball Vertical Jump Performance, Strength & Conditioning Journal, 39(4), 36-48.
12. Okano K., H. Yamanaka, S. Kuki, S. Tanigawa (2017). Identifying the Characteristics of Top-level Male Volleyball Players' Jump Performance by Examining Their Stretch-shortening Cycle Exercise, Japan Journal of Physical Education, Health and Sport Sciences, 62(1), 105-114.
13. Pacheco A. M., M. A. Vaz, I. Pacheco (2005). Evaluation of the Time for the Electromyographic Response in Volleyball Athletes and Non-athletes Who Had Ankle Sprain, Brazilian Journal of Sports Medicine, 11(6), 325-330. (in Portugal)
14. Peebles A. T., K. R. Ford, J. B. Taylor, J. M. Hart, et al. (2019). Using Force Sensing Insoles to Predict Kinetic Knee Symmetry during a Stop Jump, Journal of Biomechanics, 95, 109293.

15. Stamm R., M. Stamm, D. Torilo, K. Thomson, et al. (2016). Comparative Analysis of the Elements of Attack and Defence in Men's and Women's Games in the Estonian Volleyball Highest League, Papers in Anthropology, 25(1), 37-54.
16. Subramanian A., P. Venkatesh (2019). Counter Movement Vertical Jump Ability of Volleyball Players, Adalya Journal, 8(8), 210-213.
17. Tanigawa S., H. Yamanaka, K. Okano, N. Akiyama, et al. (2015). Effect of Age on Peak Jump Performance in Volleyball Players, Medicine & Science in Sports & Exercise, 47(5S), 120.
18. Yildiz M., Z. Akyildiz, F. M. Clemente, D. Yildiz (2023). Using an Overhead Target Increases Volleyball-specific Vertical Jump Performance, Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, 237(3), 134-141.

Assoc. Prof. Hua Zheng, M.Sc.
E-mail: zhuazhengh@outlook.com

Hua Zheng, born in 1980, is an Associate Professor in the College of Physical Education and Health Science at Chongqing Normal University, Chongqing, China. He received his M.Sc. Degree and majored in Physical Education and Sports Training at Chengdu Sport University in 2006. His research interests are focused on volleyball teaching and training.

Assoc. Prof. Zengliang Cai
E-mail: caizlc@hotmail.com

Zengliang Cai, born in 1981, is an Associate Professor in the Department of Physical Education at Shanghai University of Traditional Chinese Medicine, Shanghai, China. He received his M.Sc. Degree and majored in Physical Education and Sports Training at Shanghai University of Sport in 2008. His research interests are focused on exercise promoting health.

Changqing Li
E-mail: cqli3278@163.com

Changqing Li is a lecturer in the College of Physical Education and Health Science at Chongqing Normal University, Chongqing, China. She received her Ed.D. Degree and majored in Exercise Science at Beijing Sport University in 2016. Her research interests are focused on physical activity and health promotion.