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Analysis of volleyball players' force generation during jump spike from the perspective of electromyographic characteristics

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Purpose: The aim of this study was to investigate the force characteristics of novice athletes and professional athletes in completing a cross spike at position four from the perspective of electromyographic characteristics. *Methods*: Ten novice and ten professional athletes were selected as subjects. The electromyographic characteristics of the athletes were obtained by the Noraxon Ultium electromyography (EMG) and compared. *Results*: In the first stage, i.e., the takeoff stage, the activation level of the rectus abdominis and external abdominal obliques was significantly higher in the professional group ($p < 0.05$). During the second stage, i.e., the stage of flying to hit the ball, the professional group had a higher integrated electromyography (iEMG) value in the trapezius. Moreover, it showed significantly higher muscle contribution from the rectus abdominis (5.59 ± 1.58%), external abdominal obliques (3.67 ± 1.21%), and trapezius (10.12 ± 2.61%) compared to the novice group ($p < 0.05$). In the third stage, i.e., the stage of landing and buffering, $p < 0.05$ in the comparison of the iEMG values of trapezius and gluteus maximus between the two groups. Moreover, the professional group exhibited higher muscle activation levels in all muscles except for the gastrocnemius, compared to the novice group ($p < 0.05$). *Conclusions*: Professional athletes display superior muscle coordination and more effective muscle force generation in the trunk and lower limbs during the execution of the jump spike action.

Key words: *electromyographic characteristic, volleyball player, jump spike, muscle contribution rate*

1. Introduction

Volleyball is a team sport that requires athletes to possess high physical fitness and quick reflexes [11]. With the continuous development and innovation in technology, competition in volleyball matches has become even more intense [7]. Spike is a major offensive and scoring technique in volleyball [4]. When the ball reaches our court, the main attacker strives to score by executing a strong and powerful spike and then serve the ball to attack. The spike strength is crucial in determining the outcome of the game [15]. To better understand the technical characteristics and improve competition levels, sports training has incorporated various technologies such as high-speed cameras and surface electromyography (EMG) [14]. Torres et al. [16] compared muscle activation between male and female soccer players during squatting and lunge exercises, revealing significant differences. Hales et al. [5] investigated muscle activity during short sprints before and after a fatigue intervention, and found that the peak muscle activity of the biceps femoris exhibited significant differences after the fatigue intervention, with greater strength attenuation. Scarneo-Miller et al. [13] compared the performance of athletes who had received anterior cruciate ligament reconstruction (ACLR) with that of healthy controls in jump-cut tasks and single-leg squats (SLS). The study revealed that the ACLR group exhibited less sagittal plane movement

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during SLS and jump-cut tasks ($p < 0.05$). Donnan et al. [2] compared soccer players with and without a history of hamstring strain injury (HSI) and identified changes in sagittal plane hip joint and lumbar spine position with increasing fatigue in athletes with a history of HSI. Xiang et al. [18] investigated the influence of foot posture on lower limb stability during running by comparing arch pressure and acceleration at distances of 1, 4, 7 and 10 km. They found that excessive foot pronation during long-distance running increased peak impact acceleration at the distal tibia but did not affect running stability. Holub et al. [6] conducted a study on 17 male and female swimmers to analyze the relationship between jump height, lower limb strength and swimming speed. They discovered a strong correlation between performance variables of swimmers on land and in water. Currently, research on volleyball technical movements mainly focuses on kinematics, dynamics and sports injuries [17], with relatively little attention given to the study of electromyographic characteristics. Therefore, this article primarily analyzed the electromyographic characteristics of muscle force exerted by volleyball players at different skill levels during jump spikes to comprehend the muscle force characteristics exhibited by elite athletes. This paper aims to provide theoretical support for practicing jump spike movements and offer a scientific and rational basis for coaching guidance, thereby helping athletes improve their technical level in executing the jump spike movement through more targeted practice. Furthermore, this method can also be applied to analyze other movements performed by volleyball athletes, thereby promoting further improvement in their competitive level.

2. Materials and methods

2.1. Research target

Ten professional volleyball players and 10 novice volleyball players were selected as study subjects. They were proficient in the jump spike movement of volleyball, had no history of limb injury or surgery in the past six months, were in good health and did not engage in strenuous exercise 24 hours before the experiment. All of them understood the purpose and procedure of the experiment and signed the informed consent form. The basic information of the subjects is presented in Table 1.

Table 1. Basic information of the subjects

	Novice group (n = 10)	Professional group (n = 10)
Age [year]	20.12 ± 1.33	22.42 ± 2.16
Height [m]	1.88 ± 0.09	1.87 ± 0.12
Weight [kg]	80.77 ± 3.94	81.33 ± 4.06
Training time [year]	2.33 ± 0.56	7.12 ± 1.14
Dominant side	right	Right
Sports level	none	first level
Position	main attack	main attack

2.2. Movement for study

The action being studied is a cross spike at position 4. The subject needs to judge the direction of the pass from the setter at position 3, adjust their body to

Fig. 1. Cross spike after jump at position 4

face the incoming direction and run to receive the ball. After approach, the subject jumps by forcefully pushing off with both legs and swings his/her arms upward. When in the air, it is necessary to maintain an upright body posture with a forward lean of the center of gravity. The subject uses arm and wrist strength to swing and hit the ball, aiming to spike it towards position 5 on the court. After spiking, the subject quickly lands with slightly bent legs while maintaining balance. The specific demonstration of this movement is shown in Fig. 1. In Figure 2, the volleyball court and positions are shown.

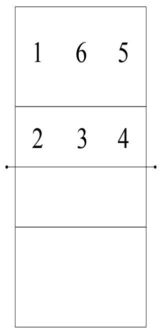

Fig. 2. Experimental site

2.3. Test methods

After selecting the subjects, the researchers collected and recorded the subjects' basic information, and then guided them to perform a 20 min warm-up activity and a practice of cross spike at position 4.

The equipment used for the experiments was a Noraxon Ultium EMG (USA) [3]. It was connected to a laptop to input the relevant data of the athletes into software. It was tuned to ensure that the tests could be performed properly.

The surface electrode patch was pasted by the researcher. The muscles to be tested are shown in Fig. 3. The researcher scraped off the hair on the surface of the muscle to be tested, wiped the skin with alcohol to avoid the influence of sweat and pasted the electrode patch at muscle belly. The direction of the electrode patch was the same with the direction of the muscle contraction. The distance between the electrode patches was approximately 2 cm and medical adhesive tape was utilized to secure the sensor.

The researcher observed the EMG of the subject in a quiet state and during movement to ensure that the instrument is working properly. The athletes were guided to undergo one to two tests to observe whether the electrode patch placement affects their normal movements. Simultaneously, abnormal fluctuations in the EMG signals and proper functioning of data collection for each muscle were monitored. The experiment started after confirming everything was correct.

The second passer passed the ball upon hearing the command released by the researcher. The subject did the movement of cross spike at position four thrice. Whether the movement is effective or not was determined by the researcher. The best movement was selected for follow-up study. Furthermore, the experimenters should promptly observe any changes in EMG, and if they detect any abnormalities, classify this particular movement as ineffective.

After completing all tests, the researcher removed the electrode patches from the athletes' bodies, properly stored the equipment, and cleaned up the site.

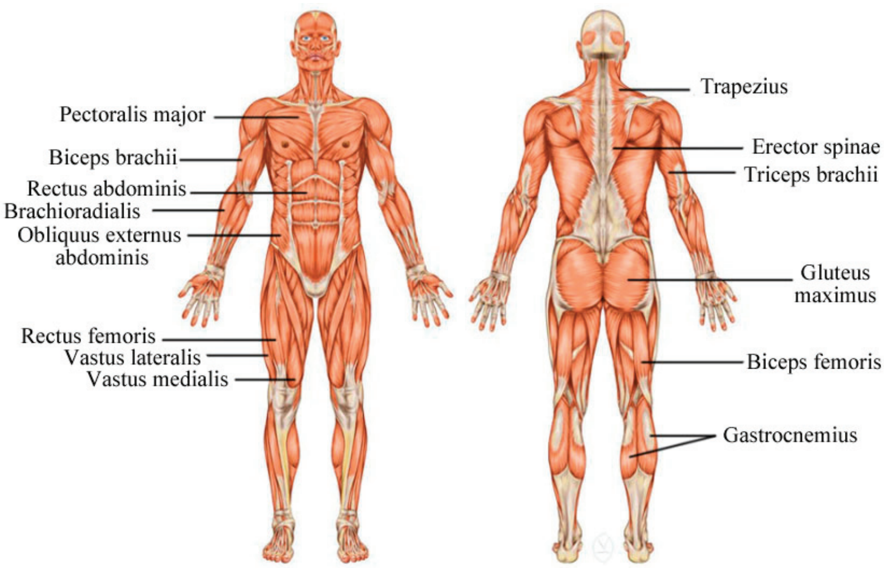

Fig. 3. Position of the electrode patch

2.4. Data processing

The Myomuscle analysis system, built into the EMG device, was used to process data by smoothing, rectification, and filtering, and save them in Excel format. Integrated electromyography (iEMG), muscle contribution rate and activation level were calculated to analyze athletes' force characteristics during movement execution. Data was recorded as mean ± standard deviation. The calculation method is as follows.

(1) IEMG: it refers to the area enclosed by the EMG curve. Its equation is:

$$\text{iEMG} = \int_{N2}^{N1} X(t)d_t ,$$

where $N1$ and $N2$ are the start and end of the integral, $X(t)$ is the EMG curve, and d_t is the sampling time interval.

(2) Muscle contribution rate: it refers to the ratio of the iEMG of the selected channel to the sum of iEMG of all channels.

(3) Muscle activation level: the activation level is determined by the ratio of iEMG to RMSByMax for each channel, using the RMSByMax of each channel as the normalization reference value.

The cross spike at position four was divided into three stages for analysis: stage 1 – takeoff; stage 2 – flying to hit the ball; stage 3 – landing and buffering. Statistical analysis was conducted using SPSS 17.0 with a significance level of 0.05.

3. Results

First, the comparison of the iEMG in stage 1 between the two groups is shown in Table 2.

According to data collected in Table 2, it can be observed that during this stage, the iEMG value of the upper limb muscles in the novice group was slightly higher than that of the professional group. More specifically, for the biceps brachii muscle, its iEMG value was recorded as 4.97 ± 1.33 μVs for novices and 4.03 ± 1.34 μVs for professionals ($p < 0.05$). As to the trunk muscles, the iEMG value of the professional group was slightly higher than that of the novice group. Specifically, the iEMG value of the rectus abdominis muscle was 3.56 ± 1.87 μVs in the novice group and 4.26 ± 1.67 μVs in the professional group ($p < 0.05$). In the comparison of lower limb muscles, a significant difference was observed in the biceps femoris muscle, with a value of 6.83 ± 1.85 μVs for the novice group and 9.36 ± 0.41 μVs for the professional group. Comparatively speaking, in this stage, the novice group exhibited a higher iEMG value, and the main muscles responsible for generating force were the trapezius, erector spinae, rectus femoris, and vastus lateralis. The professional group generated force mainly through the same muscles as the novice group, the vastus medialis muscle, and the biceps femoris muscle. This finding suggested that during stage 1, there was less upper limb muscle activity in professionals as they primarily rely on trunk and lower limb muscles to exert force.

Table 2. The iEMG of two groups during takeoff in stage 1

		Novice group (n = 10)	Professional group (n = 10)
Upper limb	Biceps brachii	6.72 ± 1.49	6.12 ± 1.58
	Briceps brachii	4.97 ± 1.33	4.03 ± 1.34*
	Brachioradialis	4.19 ± 0.87	4.05 ± 0.87
Trunk	Bectoralis major	5.36 ± 1.27	5.33 ± 1.36
	Bectus abdominis	3.56 ± 1.87	4.26 ± 1.67*
	Bbliquus externus abdominis	2.88 ± 0.12	3.81 ± 0.12
	Brapezius	9.12 ± 1.07	9.36 ± 3.21
	Brector spinae	8.87 ± 2.86	8.68 ± 0.44
Lower limb	Bluteus maximus	6.12 ± 1.46	6.16 ± 0.45
	Bectus femoris	11.07 ± 4.28	11.21 ± 3.26
	Bastus medialis	7.74 ± 2.87	8.33 ± 1.21
	Bastus lateralis	8.16 ± 2.29	8.69 ± 2.61
	Biceps femoris	6.83 ± 1.85	9.36 ± 0.41*
	Bastrocnemius	4.35 ± 0.68	4.12 ± 1.07

* $p < 0.05$ compared to the novice group.

At stage 1, the muscle contribution of the two groups was compared, as presented in Table 3.

According data collected to Table 3, the main muscle doing work in the upper limb at this stage was the biceps brachii muscle, and in terms of the contribution rate of this muscle, the two groups were 6.89 ± 1.67% and 6.56 ± 2.12%, respectively. Then, the contribution rate of the trunk and lower limb muscles of the professional group was slightly higher than that of the novice group. In the comparison of the trapezius muscle, it was 8.03 ± 1.18% in the novice group and 9.61 ± 2.12% in the professional group ($p < 0.05$). In the comparison of the biceps femoris muscle, it was 6.61 ± 2.13% in the novice group and 8.56 ± 1.47% in the professional group ($p < 0.05$). The results indicated that at this stage, the novice group had insufficient muscle activity in the trunk and lower limbs, and their body balance was not as good as that of the professional group.

Table 3. Comparison of muscle contribution rate between the two groups in stage 1 (in %)

		Novice group (n = 10)	Professional group (n = 10)
Upper limb	Biceps brachii	6.89 ± 1.67	6.56 ± 2.12
	Triceps brachii	5.12 ± 1.13	4.58 ± 1.26
	Brachioradialis	4.09 ± 1.07	5.41 ± 2.48
Trunk	Pectoralis major	5.14 ± 1.49	5.52 ± 3.12
	Rectus abdominis	4.18 ± 1.53	4.46 ± 1.62
	Obliquus externus abdominis	2.88 ± 1.12	3.51 ± 0.89
	Trapezius	8.03 ± 1.18	9.61 ± 2.12*
	Erector spinae	8.26 ± 1.58	8.89 ± 2.12
Lower limb	Gluteus maximus	5.86 ± 1.47	6.07 ± 2.36
	Rectus femoris	9.66 ± 1.89	9.77 ± 1.33
	Vastus medialis	8.01 ± 2.88	8.28 ± 1.56
	Vastus lateralis	9.12 ± 2.78	9.33 ± 1.78
	Biceps femoris	6.61 ± 2.13	8.56 ± 1.47*
	Gastrocnemius	4.89 ± 0.68	5.17 ± 1.33

* $p < 0.05$ compared to the novice group.

In stage 1, the comparison of muscle activation levels between the two groups is shown in Table 4.

Table 4. Comparison of muscle activation level between the two groups during stage 1 (in %)

		Novice group (n = 10)	Professional group (n = 10)
Upper limb	Biceps brachii	43.26 ± 1.64	36.56 ± 2.45
	Triceps brachii	44.33 ± 2.56	41.33 ± 2.34
	Brachioradialis	49.87 ± 3.26	37.12 ± 2.66
Trunk	Pectoralis major	49.66 ± 3.27	47.64 ± 3.12
	Rectus abdominis	38.07 ± 2.68	45.07 ± 3.01*
	Obliquus externus abdominis	44.12 ± 2.33	48.64 ± 1.56*
	Trapezius	48.99 ± 2.12	46.33 ± 3.37
	Erector spinae	53.67 ± 2.12	47.64 ± 2.12
Lower limb	Gluteus maximus	48.68 ± 1.61	48.64 ± 2.23
	Rectus femoris	52.12 ± 2.07	48.12 ± 2.33
	Vastus medialis	48.64 ± 1.33	44.56 ± 2.97
	Vastus lateralis	42.36 ± 2.11	47.33 ± 1.34
	Biceps femoris	50.45 ± 1.64	45.64 ± 2.36
	Gastrocnemius	38.77 ± 1.56	39.12 ± 2.51

* $p < 0.05$ compared to the novice group.

According to data collected in Table 4, the muscle activation level in the novice group was around 35–55%, with relatively high activation observed in the erector spinae, rectus femoris, and biceps femoris. On the other hand, the muscle activation level in the professional group was around 35–50%, with relatively high activation observed in the obliquus externus abdominis, gluteus maximus and rectus femoris. In comparison, there were significant differences between the two groups in the activation of the rectus abdominis and obliquus externus abdominis. The degree of activation of the rectus abdominis in the professional group was 45.07 ± 3.01% and that of the obliquus externus abdominis was 48.64 ± 1.56%, which was significantly higher compared to the novice group ($p < 0.05$). These results demonstrated that there was a remarkable difference in the activation of lumbar and abdominal muscles between the two groups at this stage.

The comparison of the iEMG between the two groups in stage 2 is presented in Table 5.

Table 5. Comparison of the iEMG between the two groups during stage 2 (in μVs)

		Novice group (n = 10)	Professional group (n = 10)
Biceps brachii	Biceps brachii	9.84 ± 1.26	9.25 ± 2.56
	Triceps brachii	5.79 ± 1.21	5.12 ± 1.15
	Brachioradialis	6.62 ± 0.49	6.54 ± 2.01
Triceps brachii	Pectoralis major	6.55 ± 1.63	6.92 ± 2.56
	Rectus abdominis	4.46 ± 0.14	5.21 ± 0.12
	Obliquus externus abdominis	3.22 ± 1.15	3.87 ± 1.45
	Trapezius	8.49 ± 2.55	10.26 ± 2.57*
	Erector spinae	5.82 ± 0.25	5.12 ± 2.97
Brachioradialis	Gluteus maximus	7.21 ± 1.62	6.89 ± 3.56
	Rectus femoris	8.75 ± 1.13	7.56 ± 2.35
	Vastus medialis	5.93 ± 1.88	7.39 ± 2.12
	Vastus lateralis	5.74 ± 2.52	5.77 ± 1.45
	Biceps femoris	7.61 ± 2.26	8.65 ± 2.15
	Gastrocnemius	2.94 ± 0.98	3.46 ± 0.21

* $p < 0.05$ compared to the novice group.

According to data collected in Table 5, the muscles that exhibited more pronounced activity in the novice group were the biceps brachii, rectus femoris, and trapezius; in the professional group, the trapezius, biceps brachii, and gastrocnemius muscles demonstrated more noticeable activity. It is evident that the iEMG value of the trapezius muscle was 8.49 ± 2.55 μVs for novices and 10.26 ± 2.57 μVs for professionals respectively ($p < 0.05$). This result indicated that at this stage professionals exerted greater force with their trapezius muscle.

The muscle contribution rate of the two groups in stage 2 was compared, and the results are shown in Table 6.

Table 6. Comparison of muscle contribution rate between the two groups during stage 2 (in %)

		Novice group ($n = 10$)	Professional group ($n = 10$)
Upper limb	Biceps brachii	9.74 ± 1.52	9.79 ± 1.87
	Triceps brachii	5.81 ± 1.12	5.89 ± 1.36
	Brachioradialis	6.59 ± 1.63	6.38 ± 1.87
Trunk	Pectoralis major	6.55 ± 1.63	6.62 ± 1.05
	Rectus abdominis	4.46 ± 0.14	5.59 ± 1.58*
	Obliquus externus abdominis	3.21 ± 1.12	3.67 ± 1.21*
	Trapezius	8.49 ± 2.55	10.12 ± 2.61*
	Erector spinae	5.64 ± 0.23	5.26 ± 1.78
Lower limb	Gluteus maximus	7.21 ± 1.55	6.48 ± 2.87
	Rectus femoris	8.76 ± 1.12	8.12 ± 2.64
	Vastus medialis	5.89 ± 1.88	7.49 ± 2.14
	Vastus lateralis	5.71 ± 2.25	6.12 ± 1.87
	Biceps femoris	7.55 ± 2.23	7.64 ± 2.08
	Gastrocnemius	2.87 ± 1.01	3.78 ± 1.44

* $p < 0.05$ compared to the novice group.

According to data collected in Table 6, at this stage, the main muscles doing work in the novice group were biceps brachii, trapezius and rectus abdominis and the main muscles doing work in the professional group were biceps brachii, trapezius and rectus femoris. In comparison, the difference in the contribution rate of the different muscles of the lower limbs was great in the novice group, the contribution rate of the trunk muscles was smaller than that of the professional group, and the contribution rate of the rectus abdominis and obliquus externus abdominis was 4.46 ± 0.14% and 3.21 ± 1.12%, respectively. In addition, the contribution rate of the trapezius in the professional group was 10.12 ± 2.61%, significantly greater than that of the novice group. These results suggested that at this stage, the professional group had greater force exerted by the lumbar and abdominal muscles and a higher contribution from the trapezius.

The muscle activation level in stage 2 was compared between the two groups, as shown in Table 7.

According to data collected in Table 7, at this stage, the degree of muscle activation in the novice group was around 30–40%, with relatively high activation observed in the obliquus externus abdominis, trapezius, gluteus maximus, and biceps femoris. The degree of muscle activation in the professional group was around 30–47%, with relatively high activation seen in the obliquus externus abdominis, rectus abdominis, and biceps femoris. The two groups showed a significant difference in the activation level of the rectus abdominis muscle, which was 34.54 ± 1.68% in the novice group and 37.12 ± 3.18% in the professional group.

Table 7. Comparison of muscle activation level between the two groups during stage 2 (in %)

		Novice group ($n = 10$)	Professional group ($n = 10$)
Upper limb	Biceps brachii	37.64 ± 1.27	36.43 ± 2.87
	Triceps brachii	33.24 ± 2.46	33.64 ± 1.67
	Brachioradialis	30.47 ± 3.21	37.77 ± 3.64
Trunk	Pectoralis major	37.71 ± 1.37	39.21 ± 2.79
	Rectus abdominis	34.54 ± 1.68	37.12 ± 3.18*
	Obliquus externus abdominis	40.77 ± 3.32	41.27 ± 3.89
	Trapezius	40.68 ± 2.47	39.88 ± 2.36
	Erector spinae	37.86 ± 1.03	36.61 ± 1.68
Lower limb	Gluteus maximus	42.88 ± 2.67	39.66 ± 1.07
	Rectus femoris	39.87 ± 2.11	40.67 ± 1.97
	Vastus medialis	36.12 ± 1.37	38.64 ± 2.67
	Vastus lateralis	32.89 ± 1.67	37.21 ± 3.66
	Biceps femoris	40.68 ± 2.13	41.56 ± 1.61
	Gastrocnemius	33.12 ± 2.27	34.07 ± 1.05

* $p < 0.05$ compared to the novice group.

The comparison of the iEMG value between the two groups in stage 3 is presented in Table 8.

Table 8. Comparison of the iEMG between the two groups in stage 3 (in μVs)

		Novice group ($n = 10$)	Professional group ($n = 10$)
Upper limb	Biceps brachii	5.53 ± 2.36	9.23 ± 0.24
	Triceps brachii	1.74 ± 0.85	4.75 ± 1.25
	Brachioradialis	4.15 ± 0.17	5.37 ± 3.01
Trunk	Pectoralis major	5.71 ± 1.13	6.49 ± 1.55
	Rectus abdominis	5.76 ± 1.51	4.76 ± 1.77
	Obliquus externus abdominis	4.31 ± 2.51	3.77 ± 0.76
	Trapezius	7.05 ± 1.18	9.92 ± 1.46*
	Erector spinae	9.56 ± 0.98	7.94 ± 1.52
Lower limb	Gluteus maximus	10.53 ± 3.09	5.43 ± 2.45*
	Rectus femoris	10.08 ± 2.35	9.91 ± 0.76
	Vastus medialis	6.35 ± 2.75	7.89 ± 1.87
	Vastus lateralis	5.78 ± 2.77	4.72 ± 0.64
	Biceps femoris	8.45 ± 2.55	9.14 ± 1.88
	Gastrocnemius	5.67 ± 0.26	4.21 ± 1.89

* $p < 0.05$ compared to the novice group.

From the data collected in Table 8, it can be observed that the novice group exhibited significant activation of the gluteus maximus and rectus femoris muscles during this stage, with iEMG values exceeding 10 μVs. The professional group primarily relied on the biceps brachii, trapezius, and rectus femoris muscles for exertion. In comparison, the professional group showed an iEMG value of 9.92 ± 1.46 μVs for the trapezius muscle, which was significantly different from that of the novice group ($p < 0.05$). The gluteus maximus muscle value of 5.43 ± 2.45 μVs in the professional group compared to that in the novice group ($p < 0.05$). In this stage, the professional group reduced the buffering during landing through the work done by the rectus femoris and and relying less frequently on the gluteus maximus compared to the novice group.

The muscle contribution rate of the two groups in stage 3 was compared, as displayed in Table 9.

around 10–20%, in which the triceps brachii, obliquus externus abdominis and gastrocnemius were activated to a high level; the muscle activation level of the professional group was around 20–30%, and the activation level of the brachioradialis, pectoralis major, trapezius and biceps femoris were activated to a high level. It can be found that the overall muscle activation level of the professional group was significantly higher than that of the novice group, and the difference was significant except for the gastrocnemius muscles ($p < 0.05$). The muscle activation level of the professional group was always above 20%, suggesting good overall muscle coordination.

Table 9. Comparison of muscle activation rate between the two groups during stage 2 (in %)

		Novice group (n = 10)	Professional group (n = 10)
Upper limb	Biceps brachii	5.33 ± 1.46	7.21 ± 1.23
	Triceps brachii	3.55 ± 0.78	6.63 ± 1.37
	Brachioradialis	5.62 ± 1.57	5.21 ± 0.77
Trunk	Pectoralis major	5.54 ± 1.39	6.49 ± 0.27
	Rectus abdominis	3.91 ± 0.78	4.56 ± 0.28
	Obliquus externus abdominis	3.98 ± 0.26	3.87 ± 1.22
	Trapezius	6.77 ± 1.21	8.97 ± 1.55
	Erector spinae	9.23 ± 3.55	7.34 ± 3.33
Lower limb	Gluteus maximus	9.95 ± 3.57	6.05 ± 1.88*
	Rectus femoris	10.81 ± 1.55	9.12 ± 1.78
	Vastus medialis	6.21 ± 1.27	6.97 ± 2.01
	Vastus lateralis	6.14 ± 1.49	4.78 ± 0.27
	Biceps femoris	8.77 ± 2.43	9.06 ± 1.68
	Gastrocnemius	5.23 ± 1.57	6.41 ± 0.35

* $p < 0.05$ compared to the novice group.

Table 10. Comparison of the muscle activation level between the two groups during stage 3 (in %)

		Novice group (n = 10)	Professional group (n = 10)
Upper limb	Biceps brachii	16.77 ± 2.12	24.77 ± 1.88*
	Triceps brachii	18.33 ± 2.46	22.56 ± 4.12*
	Brachioradialis	17.02 ± 3.44	25.77 ± 1.12*
Trunk	Pectoralis major	15.27 ± 2.15	26.12 ± 1.68*
	Rectus abdominis	14.36 ± 1.38	24.26 ± 1.87*
	Obliquus externus abdominis	17.49 ± 4.51	24.21 ± 2.45*
	Trapezius	15.79 ± 4.86	25.77 ± 2.68*
	Erector spinae	16.88 ± 1.46	23.22 ± 2.77*
Lower limb	Gluteus maximus	12.21 ± 3.46	22.33 ± 2.12*
	Rectus femoris	14.56 ± 1.38	23.88 ± 2.24*
	Vastus medialis	16.33 ± 1.26	25.51 ± 1.89*
	Vastus lateralis	13.21 ± 2.07	23.22 ± 2.11*
	Biceps femoris	14.37 ± 2.64	28.97 ± 1.15*
	Gastrocnemius	20.23 ± 2.98	24.33 ± 1.74

* $p < 0.05$ compared to the novice group.

From data collected in Table 9, during this stage, it can be seen that the main muscles for force generation in the novice group were gluteus maximus, rectus femoris, and erector spinae, while the main muscles for force generation in the professional group were trapezius, rectus femoris, and biceps femoris. In comparison, the contribution rate of the gluteus maximus in the novice group was 11.95 ± 3.57%, which was significantly higher than the professional group (6.05 ± 1.88%, $p < 0.05$). In addition, both groups demonstrated a large contribution rate of the rectus femoris muscle, which was 10.81 ± 1.55% and 9.12 ± 1.78%, respectively, suggesting that the rectus femoris muscle played a great role in this stage.

The comparison of the muscle activation level in stage 3 between the two groups is displayed in Table 10.

According to data collected Table 10, at this stage, the muscle activation level of the novice group was

4. Discussion

There are many high-intensity jumping activities in volleyball [12], such as jump spike. Jump spike in volleyball is a complex attacking movement, and research has shown that spike speed is related to factors such as the athlete's arm speed and jumping height [10], as well as muscle fatigue [8]. A study by Aka et al. [1] suggested that the serving and spiking speeds of volleyball players are related to upper limb strength, but only wrist or shoulder strength cannot increase serving and spiking speed. Therefore, this article compared the force differences in completing a cross spike at position 4 among volleyball players at different levels from the perspective of electromyographic characteristics.

iEMG can reflect the intensity of muscle activity over a period of time. The muscle contribution rate can reflect the overall muscle work during the completion of an action [19], while the muscle activation level can evaluate the activation status of a specific muscle during the completion of an action [9]. From the comparison in stage 1, it was found that novice group had greater activity and slightly higher iEMG values in upper limb muscles, but lower trunk and lower limb muscle contribution rates compared to the professional group. This resulted in insufficient force generation from trunk and lower limbs during takeoff in the novice group, making them more prone to instability. Additionally, the professional group exhibited significantly higher activation levels in their rectus abdominis and obliquus externus abdominis compared to the novice group, indicating insufficient force exertion in the waist and abdominal muscles of beginners. Stage 1 is a preparatory stage that requires sufficient strength accumulation for achieving better results in subsequent shots. Compared to the novice group, the professional group demonstrated better muscle coordination and more average activation level, primarily focusing on generating lower limb force to achieve higher shot heights.

In stage 2, athletes executed a quick hitting motion after achieving sufficient jumping height. Significant force was exerted by the upper body muscles, and overall power was transmitted through a whip-like motion. The rapid generation of force from major muscle groups such as the rectus abdominis and obliquus externus abdominis drove the upper body muscles to complete power transmission. Comparative results showed that novice participants exhibited insufficient core muscle force generation and weak coordination between different muscle groups in this stage, resulting in inadequate power transmission.

In stage 3, after completing the hitting action, athletes quickly landed. During this stage, the lower limb muscles of both groups had high iEMG values and contributed significantly to maintain body balance during descent and prepare for the next movement. In comparison, the contribution rate of the rectus femoris muscle was high in both groups, as it aims to provide some cushioning to the knee joint during landing to avoid the knee flexing too fast and causing injury. From the comparison of muscle activation levels, it can be seen that in the landing and cushioning phase, the professional group had higher activation levels for all muscles compared to the novice group. Among them, the role of the biceps femoris was particularly evident as it provided power for active cushioning while trunk muscles played a secondary role. The novice group mainly relied on lower limb muscle force, resulting in poor stability and continuity of movement, inadequate landing posture and increased risk of injury.

Based on the force generation characteristics of the novice and professional groups, in future training, the novice group should focus on strengthening training for the trunk and lower limb muscles to improve body stability. In addition, they should not only focus on control effects but also pay attention to the continuity of movements and enhance muscle coordination to improve their level of jump spike.

5. Conclusions

In this paper, the force generation characteristics of volleyball jump spike were analyzed mainly from the perspective of electromyographic characteristics. The following results were obtained after comparing the novice group with the professional group.

In stage 1, during the athletes' takeoff, the iEMG values of the upper limb muscles in the professional group were slightly lower than those in the novice group. The trunk and lower limb muscles contributed slightly more in the professional group than in the novice group, and the activation level of the rectus abdominis and obliquus externus abdomini was significantly higher than in the novice group ($p < 0.05$).

In stage 2, i.e., the stage of flying to hit the ball, the main focus was on upper body muscle power. The lumbar and abdominal muscles of the professional group generated forces more sufficiently, and the iEMG value of the trapezius was significantly higher. The contribution rate of the rectus abdominis, obliquus externus abdomini and trapezius of the professional group was significantly higher than that of the novice group, and the activation level of the rectus abdominis muscle was also significantly higher than that of the novice group ($p < 0.05$).

In stage 3, i..e, the stage of landing and buffering, the activation level of all muscles in the professional group was higher than that of the novice group, and the difference was significant except for the gastrocnemius muscle ($p < 0.05$).

The results demonstrated the difference in force generation between the novice group and the professional group of athletes during jump spike, which provides a reference for the development of the training program for the novice group. In the future training, the novice group needs to strengthen the practice of the trunk and lower limb muscles, so as to improve the completion effect of the movement. However, the study also has some limitations, such as a small sample size and the lack of consideration for differences between male and female athletes. In future work, factors such as gender and age can be incorporated to gain a better understanding of the characteristics of the jump spike movement in volleyball.

References

[1] AKA H., AKARÇEŞME C., AKTUĞ Z.B., ZORLULAR A., GÜZEL N.A., SÖKMEN T., *The relationship of wrist and shoulder joint isokinetic strength and service and spike velocity in elite female volleyball players*, Turk. J. Sport. Exerc., 2019, 21 (1), 182–187, DOI: 10.15314/TSED.513422.

[2] DONNAN L., PIZZARI T., O'DWYER N., EDWARDS S., *Fatigue induced postural changes in australian rules football players with and without a history of hamstring injury*, ISBS Proc. Arch., 2018, 36 (1), 79–79.

[3] GARIKAYI T., HEEVER D.V.D., MATOPE S., *Analysis of surface electromyography signal features on osteomyoplastic transtibial amputees for pattern recognition control architectures*, Biomed. Signal Proces., 2018, 40 (feb.), 10–22, DOI: 10.1016/j.bspc.2017.09.007.

[4] GIATSIS G., TILP M., HATZIMANOUIL D., DIECKMANN C., STERGIOU N., *Beach volleyball spike arm swing techniques of Olympics and world championships winners (1996–2019) reveal gender differences*, Int. J. Sports Sci. Coa., 2022, 17 (2), 391–399, DOI: 10.1177/17479541211024151.

[5] HALES M., JOHNSON J.D., *The Influence of Time-dependent Surface Properties on Sprint Running Performance between Male and Female Athletes*, Int. J. Kinesiol. Sport. Sci., 2020, 8 (4), 42–50, DOI: 10.7575/aiac.ijkss.v.8n.4p.42.

[6] HOLUB M., GLYK W., BARON J., STANULA A., *Correlations of jump height and lower limb power during jump tests with biomechanical parameters of dolphin kick in swimming*, Acta Bioeng. Biomech., 2022, 24 (3), 33–39, DOI: 10.37190/ABB-02100-2022-01.

[7] JIAO G., *Volleyball track acquisition and intelligent analysis technology*, J. Intell. Fuzzy Syst., 2021 (5), 1–10, DOI: 10.3233/JIFS-189842.

[8] LIN H.T., HUANG Y.C., LI Y.Y., CHANG J.H., *The Effect of Rectus Abdominis Fatigue on Lower Limb Jumping Performance and Landing Load for Volleyball Players*, Appl. Sci., 2021, 11 (15), 1–12, DOI: 10.3390/app11156697.

[9] LUCARELI P.R.G., BARCALA L., ARTILHEIRO M.C., SPECIALI D.S., CORRÊA J.C.F., JUNIOR S.A.G., POLITTI F., *The immediate effect of different loads does not alter muscle co-activation of the upper limb in young adults with dyskinetic cerebral palsy*, Gait Posture, 2021, 90 (6), 161–166, DOI: 10.1016/j.gaitpost.2021.08.018.

[10] OLIVEIRA L.D.S., MOURA T., RODACKI A., TILP M., OKAZAKI V., *A systematic review of volleyball spike kinematics: Implications for practice and research*, Int. J. Sports Sci. Coa., 2020, 15 (2), 239–255, DOI: 10.1177/1747954119899881.

[11] OLO K., GRGANTOV Z., KUVAI G., *Reliability and usefulness of the reaction speed test in young female volleyball players*, Phys. Activity Rev., 2022, 10 (1), 77–84, DOI: 10.16926/par.2022.10.09.

[12] REBELO A., PEREIRA J., MARTINHO D., AMORIM G., LIMA R., SANTOS J.V., *Training Load, Neuromuscular Fatigue, and Well-Being of Elite Male Volleyball Athletes During an In-Season Mesocycle*, Int. J. Sport Physiol., 2023, 18 (4), 354–362, DOI: 10.1123/ijspp.2022-0279.

[13] SCARNEO-MILLER S.E., SORGE J.E., BELTZ E.M., MARTINEZ J.C., ROOT H., BURLAND J.P., TROJIAN T.H., DISTEFANO L.J., *The relationship between single-limb squat and jump-cut kinematics*. Sport. Biomech., 2019, 21 (5), 1–12, DOI: 10.1080/14763141.2019.1674913.

[14] SOKOŁOWSKI K., STRZAŁA M., ŻEGLEŃ M., *Study of talented young male swimmers – Scientific approach to the kinematic and physiological predictors of 400-m front crawl race*, Acta Bioeng. Biomech. 2022, 24 (1), 29–38, DOI: 10.37190/ABB-01964-2021-02.

[15] TAI W. H., PENG H. T., SONG C. Y., LIN J.Z., YU H.B., WANG L.I., *Dynamic Characteristics of Approach Spike Jump Tasks in Male Volleyball Players*, Appl. Sci., 2021, 11 (6), 1–8, DOI: 10.3390/app11062710.

[16] TORRES G., ARMADA-CORTÉS E., RUEDA J., FERRER A.S.J., NAVARRO E., *Comparison of Hamstrings and Quadriceps Muscle Activation in Male and Female Professional Soccer Players*, Appl. Sci., 2021, 11 (2), 1–13, DOI: 10.3390/app11020738.

[17] VERHAGEN E., VRIEND I., GOUTTEBARGE V., KEMLER E., DE WIT J., ZOMERDIJK D., NAUTA J., *Effectiveness of a warm-up programme to reduce injuries in youth volleyball players: a quasi-experiment*, Brit. J. Sport Med., 2023, 57 (8), 464–470.

[18] XIANG L., GU Y., WANG A., MEI Q., YU P., SHIM V., FERNANDEZ J., *Effects of foot pronation during distance running on the lower limb impact acceleration and dynamic stability*, Acta Bioeng. Biomech., 2022, 24 (4), 21–30, DOI: 10.37190/ABB-02165-2022-02.

[19] YU J., ZHANG Y., XIA C., *Study of gait pattern recognition based on fusion of mechanomyography and attitude angle signal*, J. Mech. Med. Biol., 2020, 20 (2), 1069–1072, DOI: 10.1142/S0219519419500854.