RESEARCH ARTICLE

Surface electromyographic characteristics: a study on muscle force generation during smashing jump serve in adolescent volleyball players

Jing Zhou[1], Yunrui Xu[2,*]

[1]Hebei Sport University, Shijiazhuang, Hebei, China. [2]Jiangsu Normal University, Xuzhou, Jiangsu, China.

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Smashing jump serve is a very key technique in volleyball and is crucial for players to improve their proficiency in effectively performing this skill. This study aimed to examine the muscle force generation characteristics of youth volleyball players during the execution of the smashing jump serve. Six adolescent volleyball players were compared to six adult athletes. Surface electromyography (EMG) data were collected to compare the root mean square (RMS) value, integrated EMG (iEMG) value, and muscle contribution rates of the upper limb, trunk, and lower limb muscles in both groups during the smashing jump serve to understand the characteristics of muscle force generation in adolescents. The results showed that the ball speed of the serve was 78.64 ± 8.74 km/h in the adult group and 72.33 ± 11.26 km/h in the adolescent group (*P* < 0.05). Muscle force was primarily generated by the trunk and lower limbs during the jumping phase. However, the muscle force exerted by each muscle in the adolescent group was lower than that in the adult group. There were significant differences in iEMG values of the trapezius (TU), musculi iliocostalis lumborum (MIL), external oblique (EO), and musculus gastrocnemius (MG), as well as in the muscle activation rates of TU, MIL, and MG (*P* < 0.05). In the hitting phase, the muscle power of the adolescent group remained lower than that of the adult group, and insufficient activation of core muscles was observed as indicated by significant differences in iEMG and muscle contribution rates in the rectus abdominis, EO, rectus femoris, and MG compared to the adult group (*P* < 0.05). The results suggested that adolescent group should pay attention to the force generation of the trunk and lower limb muscles to enhance force transmission during smashing jump serve.

Keywords: surface electromyography; youth volleyball player; integrated electromyography; muscle contribution rate.

[*]**Corresponding author:** Yunrui Xu, Jiangsu Normal University, Xuzhou, Jiangsu 221116, China. Email: yunruixyr@outlook.com.

Introduction

Volleyball is characterized by high-speed and intense confrontations across the net [1]. It is a popular sport in everyday play and a prominent area of research in competitive athletics. The mastery of the serve in volleyball is essential as it is the starting point for both the game and offensive plays [2]. Moreover, it is a significant scoring method. Different from other techniques, the serve is executed solely by the player without requiring the cooperation of teammates. A well-executed serve can greatly influence the outcome of the match. With the increasing competitiveness in volleyball, enhancing the offensive nature of serves has become a trend in enhancing current techniques.

Research on volleyball has become increasingly diverse due to the influence of various advanced technologies [3]. Methods such as high-speed cameras [4] and surface electromyography

(EMG) [5] have been widely applied. Surface EMG technology can partially reflect muscle force generation and has been extensively used in medical research [6], clinical diagnosis [7], and sports science [8]. Hatamzadeh *et al*. obtained surface EMG signals from eight lower limb muscles during a one-legged landing performed by an athlete with an anterior cruciate ligament (ACL) injury for analysis and found that EMG signals could be utilized non-invasively to assess the health status of athletes with ACL injuries and had a good accuracy [9]. Eken *et al*. analyzed the neuromuscular changes that occurred during an eight-day cross-country mountain bike race. The EMG analysis found a decrease in the standardized amplitude of both the biceps femoris and tibialis anterior muscles along with altered coordination among the muscles in athletes experiencing muscle fatigue [10]. In another study conducted by Williamson *et al.*, the muscle activities of athletes during various pull-up variations were compared. The findings revealed a significant increase in the muscle activity of the rectus femoris (RF), gluteus maximus, and rectus abdominis (RA) during kipping and butterfly pull-ups compared to strict pull-ups [11]. Albano *et al*. analyzed the muscle control of the ankle joint during rear wheel hops in mountain biking and discovered that the muscles responsible for controlling the ankle joint during this movement were similar to those required for jumping. Thus, similar exercises could be employed to train this muscle group [12]. Current research on volleyball mainly focuses on techniques such as spiking [13]. Only fewer analyses were conducted on serving.

The smashing jump serve is a vital technique enabling greater ball speed by utilizing a higher hitting point and increased horizontal displacement, making it challenging for opponents to receive the ball. Therefore, correctly mastering the technique of the smashing jump serve holds significant importance in improving athletes' competitiveness. This study analyzed the muscle force generation characteristics of youth volleyball players during the execution of a smashing jump serve by comparing them with higher-level athletes using surface EMG technology. The results of this study would assist youth athletes in refining their serving technique and provide theoretical guidance for volleyball training and instruction.

Materials and methods

Study subjects

Six male, level two sports proficiency, youth volleyball players with the average age of 16.32 ± 1.07 years old, 181.21 ± 1.21 cm height, 53.67 ± 2.06 kg weight, and 5.12 ± 1.64 years training duration were selected from the Youth Sports Training Center in Shijiazhuang, Hebei, China, while another six male, level one sports proficiency, volleyball players from Hebei Sport University (Shijiazhuang, Hebei, China) with the average age of 23.45 ± 1.26 years old, 188.94 ± 1.67 cm height, 76.77 ± 1.84 kg weight, and 8.77 ± 3.69 years training duration were selected for comparison. All participants were proficient in the technique of smashing jump serve and were right-handed. The participants were in good health with no sports injuries or illnesses being reported in the past year. The strenuous exercise was refrained from 24 hours prior to the experiment. All participants were informed about the purpose and procedures of this study. All procedures of this research were approved by the Institutional Review Board of Physical Education Institute in Jiangsu Normal University (Xuzhou, Jiangsu, China).

Electromyography (EMG) data collection

The smashing jump serve involved jumping after an assisted run followed by forcefully striking the ball in mid-air to create rapid rotation at the peak of the jump and sending the ball over to the opponent's court. To facilitate research and analysis, the movement was divided into distinct phases of jumping (executing a quick jump using the lower limbs following the assisted run) and striking (fully extending the body, drawing the arms back to the maximum angle, and hitting the ball with one hand). The experiment was conducted in the gymnasium at Hebei Sport University (Shijiazhuang, Hebei, China). A standard men's volleyball court with a net height of 2.43 meters was utilized. The experiment was conducted when the athletes were at rest and not engaged in training, ensuring they were not fatigued. The experiment was overseen by the same experimenters and coaches. Before the experiment, the athletes dressed uniformly and jogged for 30 minutes as a warm-up and practiced the smashing jump serve movement. EMG data were collected using the Ultium EMG 16 surface EMG system (Noraxon, Scottsdale, Arizona, USA) with a sampling frequency of 2,000 Hz/s [14]. The attachment of electrode slices to the athletes was carried out by the same experimenter following the steps below. Briefly, any sweaty hair in the testing muscle area was removed, and the skin was wiped using an alcohol swab to eliminate sweat. The electrode slice was then positioned on the muscle belly in alignment with the direction of muscle contraction. After attachment, it was secured in place with medical adhesive tape to prevent displacement. The muscle groups on the athlete's dominant side (right side) were selected as the test muscle groups based on the information gathered and collected, which included the upper limb muscle group consisting of biceps brachii (BB) and triceps brachii (TB); the trunk muscle group consisting of trapezius (TU), musculi iliocostalis lumborum (MIL), rectus abdominis (RA), and external obliques (EO); and the lower limb muscle group consisting of rectus femoris (RF) and gastrocnemius (MG). After selecting the test muscles in the system mannequin, the system was debugged, ensuring that each channel was connected correctly. The athlete performed one or two smashing serves to verify that all data could be accurately captured before starting the official data collection. Upon receiving the oral command from the experimental staff, the athletes executed the smashing jump serve movement. Each athlete performed the serve three times. The coaches observed and judged whether each serve was successful or not. At the end of each serve, a 30 second rest period was applied. Once all the athletes had completed the test, the electrode slices were removed from the athletes.

Data analysis

Myomuscle analysis system implemented in the EMG system was used for smoothing, rectification, and filtering of the acquired surface EMG signals. All data were saved in Microsoft Excel (Microsoft, Redmond, WA, USA) to calculate the root mean square (RMS), integral EMG (iEMG) that was the area under all rectifier curves and reflected the total amount of discharge from the active motor units in the muscles within a certain period [15], muscle contribution rate, *etc*. The resulting data were recorded as mean ± standard deviation (SD). SPSS 22.0 software (IBM, Armonk, NY, USA) was employed to analyze differences between the data of the adolescent and adult groups [16]. The P value less than 0.05 was defined as a significant difference between the groups.

Results and discussion

Comparison of the ball speed after serving

The ball speed after serving in the adult group was faster than that in the adolescent group (78.64 ± 8.74 km/h *vs*. 72.33 ± 11.26 km/h) ($P <$ 0.05) (Figure 1), which indicated that the adult group exhibited a higher level of performance in the smashing jump serve. Therefore, the comparison of muscle force characteristics between the two groups could provide valuable guidance to the adolescent group in improving their technique of the smashing jump serve.

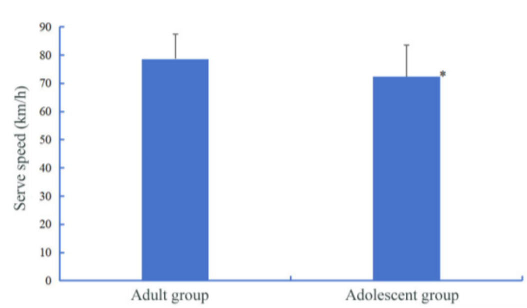

Figure 1. Comparison of ball speed on serve between adolescent and adult groups. *indicated $P < 0.05$.

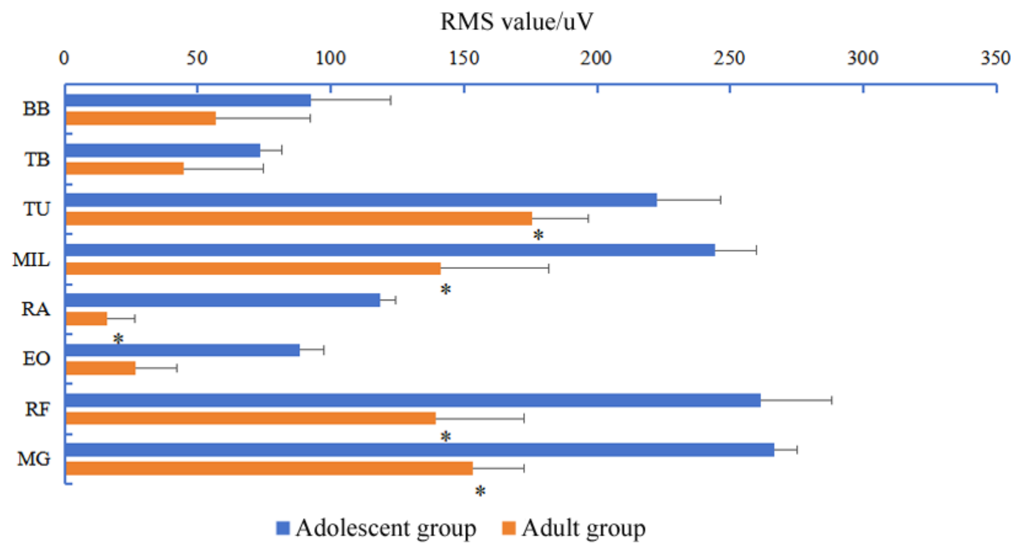

Figure 2. Comparison of RMS values between the two groups during the jumping phase. * indicated $P < 0.05$ compared to the adult group.

Comparison of the RMS value during the jumping phase

The results showed that, during the jumping phase, the RMS values of the upper limb, trunk, and lower limb muscle groups in the adolescent group were lower than those in the adult group. Significant differences were noted when comparing TU, MIL, RA, RF, and MG ($P < 0.05$). Generally, the RMS values of the trunk and lower extremity muscle groups were higher than those of the upper limb during this phase. The result indicated that the trunk and lower limb muscles primarily contributed to muscle force generation during jumping. The maximum RMS value was observed in MG, while the minimum RMS value was observed in TB in the adult group. In contrast, the maximum RMS value was observed in TU, and the minimum RMS value was observed in RA in the adolescent group. Furthermore, the RMS values of MG and RF were higher in the adult group (266.45 ± 40.26 uV *vs*. 261.25 ± 26.89 uV) compared to the adult group (153.47 ± 26.56 uV *vs*. 139.51 ± 33.16 uV) (Figure 2). The maximum RMS value was observed in MG, while the minimum RMS value was observed in TB in the adolescent group. These findings suggested that the lower limb pedaling and stretching of adolescents in the jumping phase was not sufficient, resulting in insufficient energy storage.

Comparison of iEMG during the jumping phase

The iEMG reflected muscle contraction over a specified period. During this stage, the EMG values for the adult group were slightly higher than that of the adolescent group. Significant differences were observed in TU, ES, EO, and MG ($P < 0.05$) (Table 1). More specifically, the activation of the upper limb muscle group was low, while the activation of the trunk and lower limb muscle groups was high in the adult group. The extension of the lower extremities was transmitted to the upper limbs, and the active contraction of the TU muscle elevated the body's center of gravity. In contrast, in the adolescent group, there was insufficient activation of the trunk and lower extremity muscles, which adversely affected the transmission of force.

Table 1. iEMG values of muscles in both groups during the jumping phase (unit: mv·s. * indicated $P < 0.05$ compared to the adult group).

Muscle	Adult group	Adolescent group
BB	0.14 ± 0.08	0.12 ± 0.07
TB	0.13 ± 0.08	0.14 ± 0.08
TU	0.35 ± 0.11	0.27 ± 0.08*
MIL	0.38 ± 0.11	0.19 ± 0.06*
RA	0.15 ± 0.06	0.12 ± 0.08
EO	0.43 ± 0.08	0.26 ± 0.06*
RF	0.16 ± 0.07	0.12 ± 0.07
MG	0.56 ± 0.21	0.28 ± 0.18*

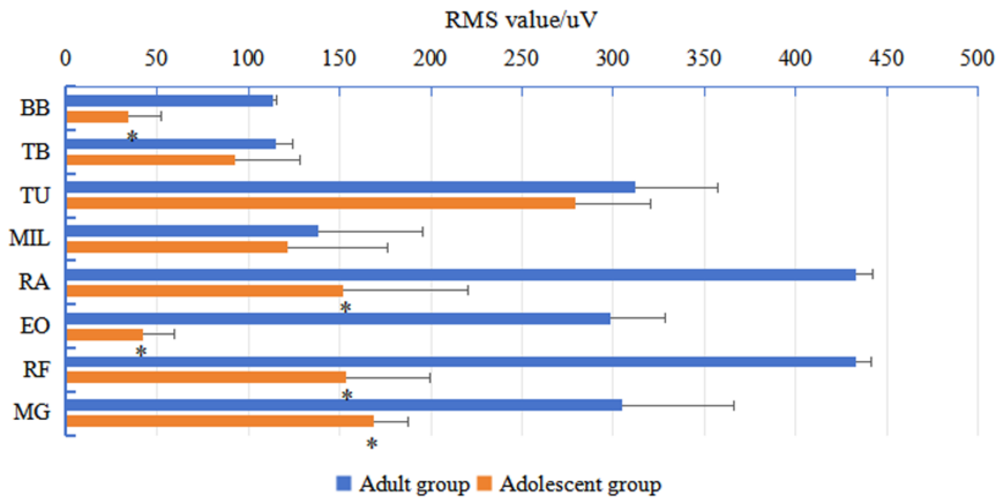

Figure 3. Comparison of RMS values between the two groups during the hitting phase. * indicated $P < 0.05$ compared to the adult group.

Comparison of the muscle contribution rate during the jumping phase

During the jumping phase, the adult group's primary force-generating muscles were MG, EO, and MIL. In contrast, the adolescent group's primary force-generating muscles were MG, EO, and TU. Furthermore, when comparing the contribution rate of each muscle, significant differences were found between the two groups in TU, MIL, and MG ($P < 0.05$) (Table 2). The result indicated that activating the trunk and lower limb muscle groups was crucial during this phase. The adolescent group did not sufficiently activate the core muscle groups.

Table 2. Contribution rate of each muscle in both groups during the jumping phase (unit: %. * indicated $P < 0.05$ compared to the adult group).

Muscle	Adult group	Adolescent group
BB	6.09 ± 0.77	8.00 ± 0.64
TB	5.65 ± 0.56	9.33 ± 0.61
TU	15.22 ± 1.27	18.00 ± 1.34*
MIL	16.52 ± 2.01	12.67 ± 1.21*
RA	6.52 ± 0.55	8.00 ± 0.67
EO	18.70 ± 2.33	17.33 ± 1.27
RF	6.96 ± 0.84	8.00 ± 0.77
MG	24.35 ± 2.54	18.67 ± 2.16*

Comparison of the RMS value during the hitting phase

During the hitting phase, the RMS values of muscle activity in the adolescent group were lower than those in the adult group. Significant differences were observed in BB, RA, EO, RF, and MG ($P < 0.05$). The RMS value of BB in the adult group was 113.26 ± 1.84 μV compared to 34.26 ± 18.25 μV in the adolescent group ($P < 0.05$). Similarly, the RMS values for RA and EO in the adult group were 433.25 ± 8.57 μV and 298.44 ± 30.26 μV, while both RA and EO were considerably lower in the adolescent group at 151.64 ± 68.94 μV and 42.37 ± 16.84 μV, respectively ($P < 0.05$). The RMS values for RF and MG in the adult group were 432.76 ± 8.61 μV and 305.15 ± 61.37 μV, respectively. In contrast, these values were markedly lower in the adolescent group at 153.14 ± 46.28 μV and 168.95 ± 18.73 μV ($P < 0.05$) (Figure 3). These results revealed that, during the hitting phase, the force generation of the upper limb, trunk, and lower limb muscles in the adolescent group was less effective than that in the adult group. The primary muscle engaged in the adolescent group was the TU. There was a backward arm movement during this phase. However, the force generation in the lower limb muscles was inadequate, leading to insufficient force transmission.

Comparison of iEMG during the hitting phase

The muscle discharge characteristics during the hitting phase were similar to those observed during the jumping phase. The main muscles involved in the discharge were RA, RF, and TU in the adult group, while the main muscles were TU, MG, and RF in the adolescent group (Table 3). These results suggested that the trunk and lower limb muscle groups played a significant role during the hitting phase. There were remarkable differences between the two groups in the trunk and lower limb muscle groups. The adolescent group exhibited significantly lower discharge values in RA, EO, RF, and MG than that of the adult group. Therefore, when force was transferred to the upper limb, the iEMG values of BB and TB were also low. Specifically, the iEMG value of the BB was 0.05 ± 0.01 mV·s, which was significantly lower than that of the adult group ($P < 0.05$). The results indicated that the contraction force generation of the lumbar-abdominal muscle group was not prominent during the hitting phase, leading to poor overall muscle coordination and cooperation.

Table 3. iEMG values of each muscle in both groups during the hitting phase (unit: mv·s. * indicated $P < 0.05$ compared to the adult group).

Muscle	Adult group	Adolescent group
BB	0.13 ± 0.01	0.05 ± 0.01*
TB	0.13 ± 0.03	0.09 ± 0.02
TU	0.45 ± 0.15	0.41 ± 0.14
MIL	0.27 ± 0.03	0.26 ± 0.02
RA	0.57 ± 0.18	0.29 ± 0.16*
EO	0.38 ± 0.08	0.06 ± 0.01*
RF	0.57 ± 0.17	0.33 ± 0.11*
MG	0.41 ± 0.09	0.34 ± 0.08*

Comparison of the muscle contribution rate during the hitting phase

The muscles with the highest contribution rates during the hitting phase were RF, RA, and TU in the adult group. In the adolescent group, the muscles with the highest contribution rates were TU, MG, and RF, which aligned with the findings from the EMG analysis. Moreover, the contribution rates of the BB, MIL, RA, EO, and MG muscles differed significantly between the adolescent and adult groups ($P < 0.05$) (Table 4). The results suggested that the adolescent group focused too much on the TU muscles during the hitting phase and neglected the overall coordination of force generation. This imbalance in force generation within the trunk muscle group led to instability in the center of gravity and a lack of smooth power transmission. Thus, the effectiveness of the smashing jump serve in the adolescent group was lower than that in the adult group.

Table 4. Contribution rate of each muscle in both groups during the hitting phase (unit: %. * indicated $P < 0.05$ compared to the adult group).

Muscle	Adult group	Adolescent group
BB	4.47 ± 0.03	2.73 ± 0.03*
TB	4.47 ± 0.02	4.92 ± 0.04
TU	15.46 ± 1.36	22.40 ± 0.86
MIL	9.28 ± 0.87	14.21 ± 1.21*
RA	19.59 ± 2.12	15.85 ± 1.33*
EO	13.06 ± 1.33	3.28 ± 0.05*
RF	19.59 ± 2.01	18.03 ± 1.77
MG	14.09 ± 1.56	18.58 ± 1.34*

Conclusion

This study analyzed the muscle force generation characteristics of the smashing jump serve in youth volleyball players using surface EMG technique. The results showed that, during the jumping phase, the RMS values of the adolescent group's upper extremity, trunk, and lower extremity muscle groups were lower than those of the adult group. There were significant differences in the iEMG values for TU, MIL, EO, and MG, as well as in the muscle contribution rates for TU, MIL, and MG ($P < 0.05$). During the hitting phase, the RMS values of various muscles in the adolescent group were also lower than those in the adult group. In addition, the muscle activation levels in RA, EO, RF, and MG were significantly lower in the adolescent group than in the adult group. Moreover, the muscle contribution rates also differed significantly between the two groups ($P < 0.05$). Compared to the adult group, the adolescent group had inadequate force generation in the trunk and lower extremity muscles, paid excessive attention to the TU, and neglected power transmission. Therefore, during daily training, adolescents should prioritize the development of trunk and lower limb muscles, enhance core strength, and ensure full extension of the lower limbs during the smashing serve to improve power transmission and achieve a higher serve speed. The results revealed the shortcomings in muscle force exertion among adolescent athletes during the smashing jumping serve, which could guide the subsequent daily training of young athletes.

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