Motion Force Analysis of Group B Difficulty Movements in College Students' Aerobics Based on Surface Electromyography Characteristics

Change Bu, Yangyang Liu*

Sports and Military Department,
China Jiliang University
Hangzhou 310018, Zhejiang, China
E-mails: brbu70@163.com,
yangkuang23923786@163.com

**Corresponding author*

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Abstract: *This paper aims to understand the motion force characteristics of college students when performing group B difficulty movements in aerobics through surface electromyography and 3D camera technology. Subjects were five male aerobics national first-grade. The surface electromyography characteristics were collected by Noraxon electromyography system and kinematic characteristics were collected by a motion capture system. Subjects were required to perform the B588 movement (1/2 turn pike jump 1/2 twist to push up) three times, and the best one was analysed. The average value was taken to analyse the athletes' motion force characteristics. Results showed that in the take-off phase, the lower limb muscles primarily underwent electrical discharge. The left rectus femoris muscle exhibited the highest discharge during the cushioning and extension phases, measuring 256.17 μV and 185.77 μV, respectively, with full extension of the hip and knee joints. During the flight phase, both lower limb and abdominal muscles exerted noticeable force while maintaining extended knee and ankle joints, although there was a slight difference in angle between left and right ankles. In the landing phase, all muscles exerted significant force and the elbow joints were primarily responsible for joint cushioning. Completing the B588 movement requires athletes to have higher levels of lower limb explosive force, body balance force, and joint control force. During the training process, athletes should focus on strengthening muscle strength and improving ankle joint stability.*

Keywords: *Surface electromyography, Aerobics, B588 movement, Difficult movements, Kinematics.*

Introduction

Aerobics is an exercise with a high artistic degree and high difficulty [15] which has a positive effect on the body's physical and mental health [8]. With the development of competitive aerobics [12], the difficulty and complexity of technical movements are increasing. Difficult movements in group B of aerobics involve challenging air movements that require explosive power from the lower limbs as well as strength from the abdomen and back. It has high requirements for the motion force of the muscles and joints of the body, and it is more difficult to obtain high scores, which brings great difficulty to the athletes' movement learning and the coaches' movement instruction. It is crucial for competitive aerobics athletes to better master the difficult movements in group B. Therefore, further analysis of the key points of force exertion in these movements is needed to enhance their mastery. In order to effectively improve the performance of the game, technical means can be used to help athletes better master the force characteristics of the movements. High-speed camera, surface electromyography (sEMG), and other technologies have been well applied in the field of sports [10].

The analysis of the throwing motion using an infrared motion capture system found that at the moment of stepping foot contact, an increase in pelvic opening angle was significantly correlated with an increase in trunk flexion to the non-throwing arm side and a decrease in hip flexion angle on the throwing arm side [5]. Study of the human undulatory swimming technique founds that using a motion capture system, the athletes presented external rotation of the lower limbs at the end of downward kicking which obtained thrust by generating vortexes around the feet [7]. Analysis of the kinematics and sEMG data of sanda athletes during the whipping movement proved the importance of the hip joint during this movement [11]. The ankle muscle characteristics of mountain bikers when performing the “rear wheel jump” showed that the muscles controlling the ankle joint were similar to those required for the jump, so this muscle group could be trained through similar exercises [1]. The restricted Boltzmann machine model based on an infrared high-speed motion capture system analyses difficult movements and constructed motion graphs to control movement trajectories, adjust movement patterns, and help trainers fully understand difficult movements [6]. Analysing female aerobics athletes is found that chest circumference and sit-and-reach had the greatest impact on athletes’ performance, providing some reference for improving the performance of aerobics athletes [14]. Another study [2] used Vicon system and Kistler force plates to record kinematic and kinetic parameters for analysis of 10 female aerobics instructors, and found that the knee joint is the most susceptible to injury and overtraining. In competitive aerobics, difficult movements in group B are the core of the difficult movements. Among them, B588 is a high-scoring, difficult movement that includes jumping, rotating, and push-up techniques. Movements with higher difficulty levels are more difficult to obtain scores. It requires high quality execution. Studying the B588 movement is of great significance in strengthening athletes’ mastery of difficult movements and helping coaches standardize training methods. This paper analysed the motion force characteristics of B588 in the group B difficulty movements of college students’ aerobatics based on combining the characteristics of sEMG, in order to provide some scientific and reasonable theoretical bases for the training of this movement. This study helps coaches to clarify the key and difficult points in training and also provides a reference for the better application of sEMG research in aerobatics.

Materials and methods

Subjects

Five male aerobics athletes from China Jiliang University were selected as subjects. They performed the B588 movement in the group B difficulty movements of aerobatics, i.e., 1/2 turn pike jump and 1/2 twist to push up. The general information of the subjects is presented in Table 1.

Table 1. Subjects general information

Athlete No	Age, (year)	Height, (m)	Weight, (kg)	Exercise practice, (year)	Sport grade
1	21	1.81	84	5	China national first grade
2	22	1.79	81	7	China national first grade
3	21	1.79	82	6	China national first grade
4	23	1.78	78	9	China national first grade
5	22	1.76	76	8	China national first grade

Studied movement

Group B difficulty movements contain a large number of air movements. They need to adjust shapes and body postures in the air, which has high requirements for the height of the athlete's air lifting, landing stability, etc., and needs sufficient strength to support. Group B difficulty movements include three categories according to the "International gymnastics federation 2022-2024 competitive aerobatics scoring rules" (see Table 2).

Table 2. Group B difficulty movements

Category 4: power jump	**Category 5: posture jump**	**Category 6: sagittal split jump/leap**
Air turn	Tuck jump	Scissors leap
Free fall	Cossack jump	Switch leap
Gainer	Pike jump	Sagittal split jump
Spin	Straddle jump/frontal split jump	–
Horizontal circle	–	–

The movement studied in this paper is B588 in category 5 (posture jump) are 1/2 turn pike jump and 1/2 twist to push up (Fig. 1). The actual images of the experimental process are presented in Fig. 2. The movement is described as follows:

1) Take off vertically and turn the body 180° to complete the pike jump;
2) During the flight phase, the body turns 180°, and the body leans forward to land;
3) Land in a prone position with an end orientation the same as the beginning.

According to the B588 movement characteristics, it can be divided into three stages:

1) Take-off: the process of taking off vertically and pushing off the ground;
2) Flight: the process of performing a 1/2 turn pike jump and a 1/2 twist in the air;
3) Landing: the process of landing by lower limbs and supported by arms.

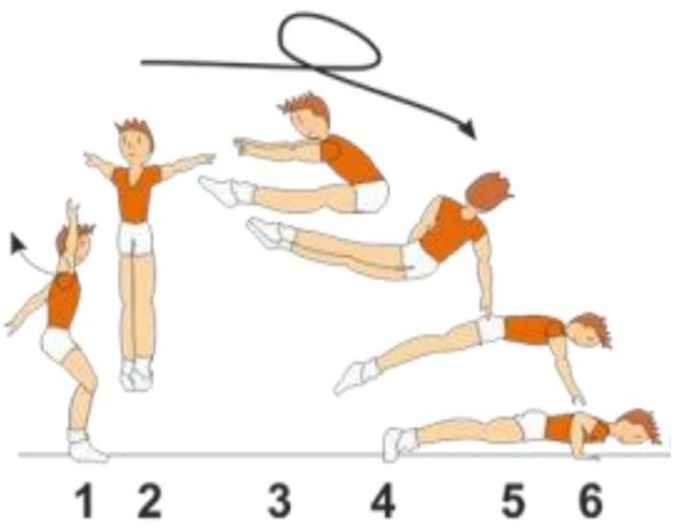

Fig. 1 Scheme of B588 movement

Fig. 2 Images of the B588 movement

In the analysis of the subsequent movement force, the above three stages are further subdivided, as shown in Fig. 3.

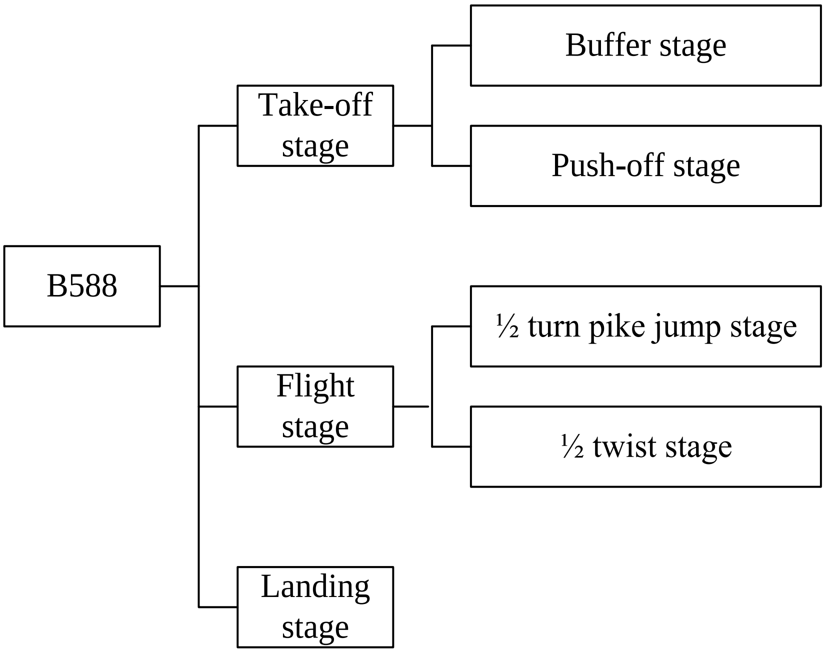

Fig. 3 Stage division of the B588 movement

Research methods

Equipment

1) sEMG characteristics: Noraxon 16-channel sEMG system from USA [3].
2) Kinematic features: 3D motion capture system (Motion, USA), including eight Raptor-4 digital capture lenses and 29 marker spheres with a diameter of 14 mm, with a sampling frequency of 200 Hz;
3) Others: medical tape, medical alcohol, electrode sheet, etc.

Testing process

Preparation before the experiment:

1) The basic information of the athletes was recorded.
2) The athletes were required to wear uniform clothes and complete the preparation activities under the leadership of the experimenter.
3) The experimenter debugged the equipment and checked the normal operation of the equipment through the pre-experiment.

The test process is as follows:

1) The electrode sheets and marker spheres were pasted on six muscles on the left side and six muscles on the right side by the experimenter after the hair on the test site was removed and wiped with medical alcohol. Fig. 4 shows the position of the six muscles on the right side. The marker placement scheme referred to the Helen Hayes 29-point model [9] included in the Cortex software is shown in Table 3.
2) The equipment was connected to the computer, the Motion system, and the electromechanical equipment, and the data were received simultaneously. Each athlete performed three times B588 movements, and the best performance was taken for analysis.

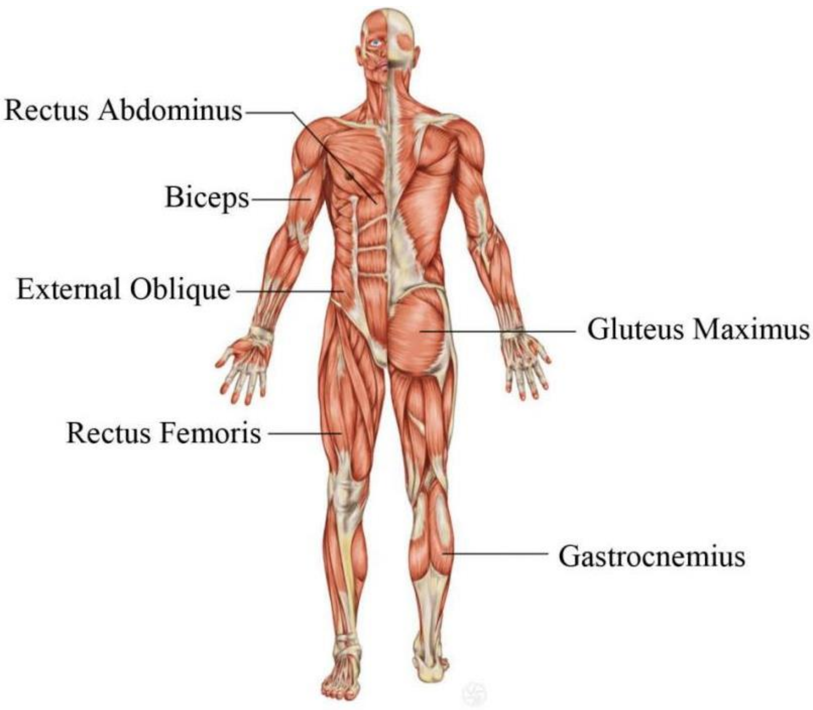

Fig. 4 Right electrode sheet sticking position

Table 3. Sticking point scheme

No	Name	Location
1	top.head	top of the head
2	front.head	the upper edge of the brow in front of the head
3	rear.head	the superior margin of the occipital bone at the back of the head
4	r.shoulder	right shoulder peak
5	r.offset	right back
6	r.elbow	right elbow joint
7	r.wrist	left wrist joint
8	l.shoulder	left shoulder peak
9	l.eblow	left elbow joint
10	l.wrist	left wrist joint
11	r.asis	right hip joint
12	l.asisi	left hip
13	v.sacral	upper margin of sacrum
14	r.think	front of right thigh
15	r.knee	right knee joint
16	r.shank	front of right shank
17	r.ankle	right ankle joint
18	r.heel	right heel
19	r.toe	right toe tip
20	l.think	the front of the left thigh
21	l.knee	left knee joint
22	l.shank	front of left shank
23	l.ankle	left ankle joint
24	l.heel	left heel
25	l.toe	left toe tip
26	r.knee.medial	medial right knee
27	r.ankle.medial	medial right ankle
28	l.knee.medial	left knee medial
29	r.knee.medial	medial left ankle

Data processing and analysis

EMG data were processed in Nexus 2.2.1 and exported in .csv format, and then muscle discharge, muscle contribution rate, and other indicators were calculated in MATLAB R2009b software. The kinematics data were processed in Cortex software, and the joint angle changes and other indicators were calculated. Finally, the data were processed and analysed in Microsoft Excel software, and the final results were averaged.

Results

Analysis of the movement during the buffer phase

The EMG characteristics of athletes in the buffer stage are presented in Table 4. At this stage, the left rectus femoris muscle had the highest average discharge 256.17 μV, followed by the left gastrocnemius muscle 216.55 μV, and the top five muscles were the left rectus femoris muscle, left gastrocnemius muscle, right rectus femoris muscle, right gluteus maximus muscle, and right gastrocnemius muscle. The muscles with the highest contribution rate were left rectus femoris muscle and left gastrocnemius muscle accounting 14.34% and 11.67%, respectively.

The contribution rates of arm and abdominal muscles were lower than those of the lower limbs. At this stage, the athlete moved the centre of gravity from right to left, so the left side of the lower limb generated more force, and the force of the lower limb was greater than that of the arm and the abdomen. The characteristics of the lower limb joints of the athletes at this stage are displayed in Table 5.

Table 4. EMG characteristics during the buffer phase

	Average muscle discharge value, [μV]		**Average muscle contribution rate, [%]**	
	Left	**Right**	**Left**	**Right**
Biceps brachii	62.34	26.33	3.12	1.76
Rectus abdominis	36.12	38.27	2.77	2.56
External oblique	36.44	47.56	4.21	4.61
Gluteus maximus	91.23	130.07	5.22	8.63
Rectus femoris	256.17	138.62	14.34	8.07
Gastrocnemius	216.55	101.24	11.67	9.22

Table 5. Lower extremity joint characteristics during the buffer phase

	Maximum buffer angle/angle	**Buffer amplitude/angle**
Hip joint	171.23	6.12
Knee joint	141.26	35.64
Ankle joint	92.37	43.27

Analysis of force generation during the push-off phase

The EMG characteristics of athletes in the push-off stage are shown in Table 6. During this stage, according to Table 6, there was a noticeable force exertion in the lower limbs, with greater activation of the left and right rectus femoris muscles at 185.77 μV and 181.97 μV, respectively. The gastrocnemius and gluteus maximus muscles also exhibited significant force generation. Comparatively, the left side demonstrated greater force exertion than the right side, while abdominal muscles generated more force than arm muscles. As to the contribution rate of muscles, the highest was the left rectus femoris at 14.21%, followed by the right rectus femoris at 12.36%, respectively. The biceps brachii muscle had the smallest contribution rate, with 2.12% and 1.81% for left and right side, respectively. During this stage, the athletes exerted force on their lower limbs to generate enough explosive power, supporting subsequent leaps and rotations in mid-air.

When pushing off, the lower limb lifted off the ground, and the hip and knee angles at this moment are shown in Fig. 5. It can be found in Fig. 5, that at this stage, the left hip angle of the athletes was slightly smaller than the right hip, and the right knee angle was slightly smaller than the left knee. The angle of the hip joint of the athletes was above 170°, close to 180°, indicating that the hip was fully extended at the moment. Since the athletes were turning to the left, the angle of the right hip joint was larger to ensure the flight height after the jump.

The angle difference between the two knee joints was small, indicating that the power of the left and right legs was balanced.

Table 6. EMG characteristics of the pedal extension phase

	Average muscle discharge value, [μV]		**Average muscle contribution rate, [%]**	
	Left	**Right**	**Left**	**Right**
Biceps brachii	26.76	18.97	2.12	1.81
Rectus abdominis	50.47	56.78	4.67	4.77
External oblique	37.46	45.45	4.25	5.71
Gluteus maximus	93.16	80.12	7.32	6.32
Rectus femoris	185.77	181.97	14.21	12.36
Gastrocnemius	121.33	81.44	8.72	6.37

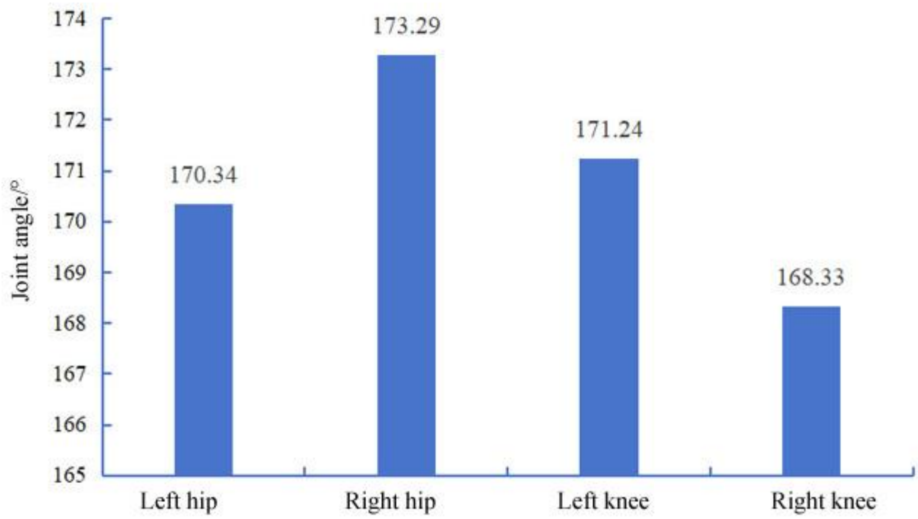

Fig. 5 Lower limb joint characteristics during push-off phase

Analysis of force generation during 1/2 turn pike jump phase

The EMG characteristics in this stage are presented in Table 7. The most significant force exerted was by the right rectus femoris, reaching 245.61 μV. Following by the right gastrocnemius muscle at 215.37 μV, while the lowest force was observed in the biceps brachii muscle. When comparing left and right sides, except for the rectus abdominis, all other muscles showed greater force generation on the right side. Notably, there were substantial differences between left and right lower limbs. From the perspective of muscle contribution rate, the contribution rate of lower limb muscles was greater than that of arm and abdominal muscles. The contribution rate of the right gastrocnemius muscle was the highest, which was 13.87%, followed by the right rectus femoris muscle, which was 13.58%. At this stage, the body was in the ascending stage, and the movement required the knee joint and toe to be straight, so it required a higher force of the lower limb muscles. At the same time, it also required the body to maintain a good balance force, so the force generation of the abdominal muscles were also obvious.

Table 7. EMG characteristics of the 1/2 turn pike jump phase

	Average muscle discharge value, [μV]		Average muscle contribution rate, [%]	
	Left	Right	Left	Right
Biceps brachii	27.64	29.46	1.49	1.88
Rectus abdominis	97.62	46.23	2.97	2.56
External oblique	33.26	50.11	2.61	4.45
Gluteus maximus	115.78	144.26	5.94	8.12
Rectus femoris	166.32	245.61	9.49	13.58
Gastrocnemius	133.64	215.37	12.64	13.87

The lower limb joint angle of the athletes at this stage is presented in Fig. 6. It shows that the knee joint angle of the athletes was well maintained with left knee reaching 173.64° and right knee reaching 170.21°, respectively, basically close to the straight knee state. The left joint ankle was 92.26°, and the right ankle was 107.33°, respectively, indicating that the athlete's ankle joints were not stretched straight enough, and the difference between left and right ankle joints was slightly large.

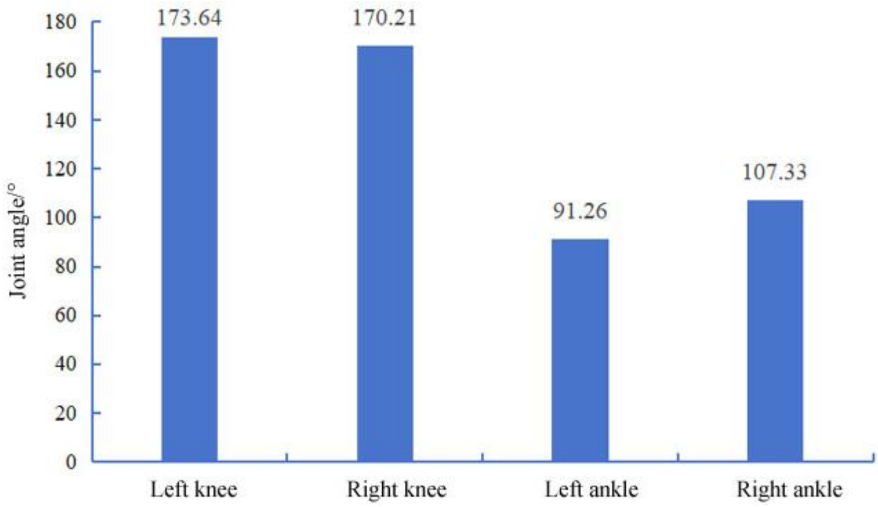

Fig. 6 Lower limb joint characteristics in the stage of 1/2 turn pike jump

Analysis of force generation in the 1/2 twist phase

The EMG characteristics of athletes during 1/2 twist are displayed in Table 8. According to it, during this stage, the right rectus femoris muscle had the highest electrical discharge at 281.77 μV, followed by the gluteus maximus muscle of the right side at 207.12 μV. The biceps brachii muscle of the left arm had the lowest discharge at 47.68 μV. The muscles on the right lower limb exerted greater force than those on the left side, while there was less disparity in force between abdominal muscles on both sides. Compared to the previous stage, there was also an increase in discharge from the biceps brachii muscle. From the perspective of muscle contribution rate, the lower limbs still played a dominant role with the highest being the right rectus femoris muscle at 16.07%, followed by the right gastrocnemius muscle at 11.57%. At this stage, athletes need to maintain their balance and prepare for subsequent ground support.

Table 8. EMG characteristics during 1/2 twist

	Average muscle discharge value, [μV]		**Average muscle contribution rate, [%]**	
	Left	**Right**	**Left**	**Right**
Biceps brachii	47.68	78.14	2.33	2.67
Rectus abdominis	79.12	78.45	3.46	3.39
External oblique	72.31	64.56	5.42	4.81
Gluteus maximus	179.21	207.12	9.18	11.48
Rectus femoris	160.07	281.77	8.21	16.07
Gastrocnemius	115.92	176.84	4.89	11.57

Fig. 7 shows that at this stage, the athlete bent the hip at a certain angle to prepare for the subsequent landing, and the difference between the left and right hip joints was small. In addition, in the process of completing the movement, the athlete needs to stretch the foot to obtain the posture beauty. In comparison, the knee joint had a good extension effect while the ankle joint had a poor extension effect which is similar to the previous stage.

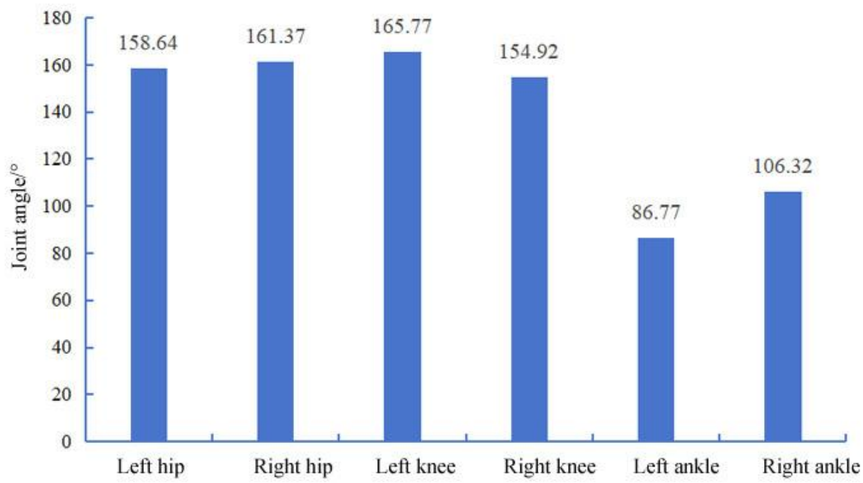

Fig. 7 Lower limb joint characteristics during 1/2 twist

Analysis of movement force in the landing phase

The EMG characteristics of athletes in the landing stage are shown in Table 9. During this stage, the left gastrocnemius muscle exhibited the highest electrical discharge at 185.94 μV, followed by the right quadriceps femoris muscle at 182.27 μV. The left biceps brachii muscle had the lowest electrical discharge at 60.01 μV. Except for gluteus maximus muscle and gastrocnemius muscle, all other muscles exerted greater force on the right side than on the left side. The rectus femoris muscle on the right side contributed most significantly followed by the left gastrocnemius muscle while the contribution rate of the left biceps brachii muscle was minimal at only 2.78%. At this stage, the toes touched the ground with the weight cantered on the front of the foot. The muscles in the lower limbs contracted centrifugally while maintaining balance in the torso. As a result, there was noticeable exertion in the arms, abdomen, and lower limb muscles.

Table 9. EMG characteristics during the landing phase

	Average muscle discharge value, [μV]		Average muscle contribution rate, [%]	
	Left	Right	Left	Right
Biceps brachii	60.01	90.23	2.78	4.32
Rectus abdominis	62.33	68.11	3.33	3.21
External oblique	60.71	78.16	4.01	5.89
Gluteus maximus	173.91	86.23	7.98	5.08
Rectus femoris	134.78	182.27	6.81	9.49
Gastrocnemius	185.94	160.04	9.32	8.37

At this stage, the buffer amplitude of the athlete's joints is shown in Fig. 8. It can be found that the buffer amplitude of upper limb joints was relatively large in this stage, in which the elbow joint was the main one, elbow > shoulder > wrist. The buffer amplitude of the left elbow joint was the largest, reaching 60.77° followed by the right elbow joint, reaching 43.21°, respectively. Among the lower limb joints, the ankle joint was the main one, and the left ankle joint had a buffer amplitude of 38.24°. In this stage, the athlete landed, flexed wrist and elbow, and provided support for the body through the ankle joint.

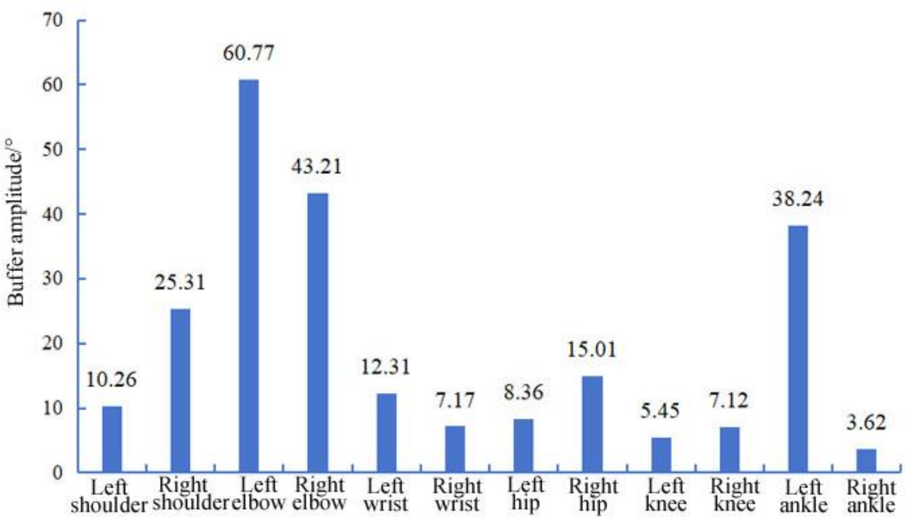

Fig. 8 Characteristics of athletes' joints in the landing stage

Discussion

Aerobics requires athletes to perform complex, continuous movements under fast-paced music and show the physical beauty and movement beauty of the athlete [4, 13]. With the continuous improvement of the difficulty of movements, the requirements for the guidance and training of movements are also getting higher and higher. In this paper, the B588 movement in group B difficulty movements was studied to understand its force characteristics in the process of movement, so as to provide support for training.

In the process of take-off, the movements of the lower limb joints were hip flexion, knee flexion, and ankle extension, and the elastic potential energy was reserved for the later push-off. The analysis of the motion force in the buffer stage demonstrated that the muscle force of the athlete was mainly generated by the lower limb muscles, especially the rectus femoris muscle.

At the same time, the hip and knee joints were fully extended to drive the muscle force and prepare for the push-off. Take-off and push-off were a process in which the feet took off from the ground after the centre of gravity reached the lowest point after cushioning, and the muscles actively contracted. During this process, the athlete performed hip extension, knee extension, and ankle flexion to obtain the ground reaction force and fly into the air. From the analysis of force generation during the push-off phase, it can be observed that the primary muscles involved were lower limb joints, and the force of the left muscles was greater than that of the right side, while the angle of the right hip joint was greater than that of the left side. The muscle contraction force was driven by the rapid flexion of the joint to produce greater explosive force. According to the analysis results of motion force at this stage, athletes should pay attention to the speed and strength exercise of lower limb muscles in the training process to obtain higher take-off explosive force.

In the flight stage, athletes need to quickly perform 1/2 turn pike jump and then 1/2 twist which has high requirements for the control of muscles and joints. According to the analysis of the motion force of the 1/2 turn pike jump stage, the discharge of the lower limbs and abdominal muscles of the athletes was obvious, and the knee and ankle joints were straight but the performance in stretching and straightening the foot was not good. In the training process, attention should be paid to the training of the ankle joint to keep the details perfect. In the 1/2 twist stage, the difference between the left and right abdominal muscles was smaller than that in the previous stage, and the power of the lower limbs was also significant. At the same time, in this stage, athletes need to prepare for the subsequent landing by flexing the hip to reduce the impact of the landing, and they need to maintain the stability of the centre of gravity. However, from the perspective of the lower limb joints, athletes do not have enough control of the ankle joint, which needs to be strengthened in training.

In the landing stage, the discharge of each muscle was obvious, and the muscle group contracted centrifugal contraction to flex the wrist and elbow. The lower limb buffer was mainly provided by the ankle joint, and the knee joint was kept straight to obtain better landing stability. The analysis of motion force in the landing stage showed that the ground reaction force was reduced by the cushioning of the elbow and shoulder joints. Moreover, the wrists were bent, and the feet were hooked to land which played a role of fixation and support to avoid limb injury. In the training process of this movement, athletes should pay attention to the training of the hook and ankle extension when landing, so as to ensure the quality of the movement and reduce the possibility of sports injury as much as possible.

Conclusion

This paper studied the B588 movement in the difficulty movements of group B in aerobics. Through the analysis of five China national first grade athletes, it was found that in the take-off stage, the lower limb muscles primarily generated force, and the athletes flexed their hip and knee while extending the ankle, and then extended their hip and knee while flexing the ankle to obtain sufficient explosive power. In the flight stage, the discharge of lower limb and abdominal muscles was obvious, and the knee and ankle joints were kept straight. In the landing stage, the muscle group underwent centrifugal contraction, the buffer was realized mainly by the elbow and shoulder joints, and the support force was generated through hooking the feet.

This paper analysed the motion force characteristics of the B588 movement which is beneficial to provide some targeted guidance for athletes' training. In future work, more aerobics athletes will be used as samples to further validate the research findings of this paper and provide references for an in-depth study of the B588 movement.

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Change Bu, M.Sc.
E-mail: brbu70@163.com

Chang Bu graduated from Harbin Normal University, China, with M.Sc. Degree in Education. Currently, she works at China Jiliang University. Her research interests include physical education teaching and training. She has published 4 papers and participated in the compilation of 4 books.

Yangyang Liu, M.Sc.
E-mail: yangkuang23923786@163.com

Yangyang Liu graduated from Harbin Normal University, China. He received M.Sc. Degree in Education. Currently, he works at China Jiliang University. His main research interests are physical education teaching and training. He has published 3 papers and participated in the compilation of 2 books.