RESEARCH ARTICLE

Study on lower limb mechanics of Chinese Martial Art (Wushu) athletes during whip kicks based on surface electromyography characteristics

Yanmin Li*

Department of Public Teaching, Xizang Agricultural and Animal Husbandry University, Linzhi, Xizang Autonomous Region, China.

Received: December 26, 2024; **accepted:** August 5, 2025.

Among the numerous techniques in Wushu, the whip kick technique with its rapid offensive and powerful force has become an indispensable offensive move for high-level athletes in competitions. The whip kick not only requires athletes to have excellent physical fitness and coordination but also has extremely high requirements for the mechanical characteristics of their lower limbs. Therefore, in-depth research on the mechanical characteristics of the lower limbs of Chinese Wushu athletes when performing the whip kick is of great significance for improving the technical level of athletes, preventing sports injuries, and promoting the scientific development of Wushu. In this study, ten Sanda athletes from Xizang Agricultural and Animal Husbandry University (Linzhi, Xizang, China) were divided into a high-experience group and a low-experience group. High-speed cameras and surface electromyography (sEMG) sensors were used to simultaneously collect the kinematic parameters and sEMG signals during the whip kick movement for comparison and analysis. The results showed that the reaction speed in the two groups of athletes differed little. The times required for the hip, knee, and ankle joints to reach peak linear velocity were also similar. The athletes in the high-experience group completed the whip kick movement faster, had higher peak linear velocity in hip, knee, and ankle joints, and had more balanced force generation in lower limb muscles than those in the low-experience group. This research provided an effective reference for promoting the scientific development of Wushu in China.

Keywords: Sanda; whip kick; kinematics; surface electromyography.

***Corresponding author:** Yanmin Li, Department of Public Teaching, Xizang Agricultural and Animal Husbandry University, Linzhi 860000, Xizang Autonomous Region, China. Email: lym_li@outlook.com.

Introduction

Sanda's technical movements include utilizing kicks against opponents at a distance, striking with hands against close-range opponents, and employing wrestling techniques for opponents nearby. During a Sanda confrontation, athletes are usually in a confrontational state, and close combat usually ends quickly [2]. To gain more advantages in close fights, athletes usually gain advantages through corresponding technical movements. A whip kick is a commonly used technical movement in the confrontation process [3]. Compared with two-handed boxing, the whip kick movement is faster, more flexible, more powerful, and has a wider range of attacks. When the athletes perform this movement, they need to raise the legs to a certain extent quickly and then promptly lower them while utilizing the strength of their leg muscles to create a whipping effect. This process mainly involves the joints of hip, knee, and ankle. No matter whether the whip kick hits the target or not, the rapid movement of the lower limbs will exert a burden on the muscles and joints. The athlete will be harmed once the burden exceeds the bearing capacity [4].

Lim *et al*. studied the influence of Taekwondo shoes on the risk factors of anterior cruciate ligament (ACL) injury during whip kicks and found that wearing taekwondo shoes could help prevent ACL injury [5]. Comfort *et al*. compared the joint dynamics and kinematics in three commonly used rehabilitation exercises and found that the weight-bearing exercises of the knee and ankle joints should start with the reverse lunge, followed by the forward lunge, and then the one-leg squat during rehabilitation training [6]. Further, Harry *et al*. studied the biomechanical differences between internal and external foci of attention in men and women during vertical jumps, and no significant differences were found [7]. Those previous studies have all analyzed the biomechanical characteristics during Wushu movements. Some studies mainly analyzed the damage to the lower limb joints caused by the whip kick movement, while other studies analyzed the influence of exercise activities on the lower limb joints. In addition, some scientists examined the influence of gender factors on the lower limb biomechanics. Therefore, to improve the whip kick technical level of athletes, prevent athletes from being injured during training or using whip kicks, and promote the scientific development of Wushu in China, it is necessary to conduct in-depth research on the biomechanical characteristics of the lower limbs during whip kicks.

This research investigated ten Sanda athletes from Xizang Agricultural and Animal Husbandry University using high-speed cameras and surface electromyography (sEMG) sensors to simultaneously collect the kinematic parameters and sEMG signals during their whip kick movements. The results of this study would provide an effective reference for promoting the scientific development of Wushu in China.

Materials and methods

Subjects

Ten male athletes were recruited from Xizang Agricultural and Animal Husbandry University (Linzhi, Tibet Autonomous Region, China) with the average age, height, and weight were 19 ± 0.2 years old, 170 ± 1.1 cm, and 65 ± 0.3 kg, respectively. All participants had no family medical history and had not been injured in the past three months. Among them, five athletes with one-year training experience were classified as the low-experience group, while the other five athletes with three-year training experience were classified as the high-experience group. During the test process, the athletes were conscious and had no communication barriers. The procedures of this research were approved by the Ethics Committee of Xizang Agricultural and Animal Husbandry University (Linzhi, Tibet Autonomous Region, China). All participants were given and signed the informed consent form.

Experimental procedures

Before the kinematics and sEMG analysis of the athlete's whip kick, the characteristic moments of this movement were defined to facilitate the comparison of collected data [8]. There were five characteristic moments in four stages in the division of the whip kick movement, which included preparation moment (T1), bending the knee and swinging the kick moment (T2), lifting the hip and buckling the knee moment (T3), kicking moment (T4), and ending moment (T5). Among them, T1 was that the athlete stepped forward with the left foot and shifted the center of gravity forward. At T2 moment, the athlete bent the right knee and raised right leg. In the T3 moment, the athlete swung the right leg forward and meanwhile lifted the hip, while, in the T4 moment, the athlete kicked the target through the right foot before the T5 moment that the athlete retracted right leg after kicking. The five moments were additionally divided into 4 stages, which included T1 - T2, T2 – T3, T3 – T4, and T4 – T5 stages. During the tests, a target sandbag was suspended in the center of the test site with two

Arqus A5 infrared high-speed cameras (Qualisys, Göteborg, Sweden) being set up at 6 m away from the target sandbag [9]. The athlete stood between the camera and the target sandbag, and the distance between the athlete and the target sandbag was short enough for the athlete to kick the sandbag. Before the test started, the relevant information about the athletes in both groups was recorded. The Cometa Picolite sensors of the wireless sEMG device (INFO.instruments Technology Co., Ltd, Shanghai, China) were attached to the skin of athlete using medical tape on the right tibialis anterior muscle, medial gastrocnemius muscle, rectus femoris muscle, triceps femoris muscle, erector spine muscle, and rectus abdominis muscle according to the technical characteristics of the whip kick movement and human anatomical knowledge [10-12]. The high-speed cameras were set according to the position shown in Figure 1, and the most appropriate focal length was adjusted. During the test, the athlete stood at the designated position in front of the target sandbag and got ready. A signal light was set up in the athlete's visual range and was connected to the high-speed cameras and the sEMG sensors using a synchronizer. By activating the signal light, the high-speed cameras and the sEMG sensors were all on at the same time through the synchronizer, and the athlete quickly made a whip kick movement when seeing the signal light [13]. While using a high-speed camera to film the whip kick movement of the athlete, the sEMG signals on the attacking leg were synchronously collected. The root mean square (RMS) amplitude of the sEMG signal was used to describe the average discharge level of the muscle within a certain period. The higher the level, the higher the activation degree of the tested muscle within that period, and the higher the force exertion level.

Statistical analysis

SPSS software (IBM, Armonk, NY, USA) was employed for statistical analysis in this research. The collected experimental data in different groups were compared for significant difference using student t-test with the *P* value less than 0.05 as the statistically significant difference and *P* less than 0.01 as the very significant difference.

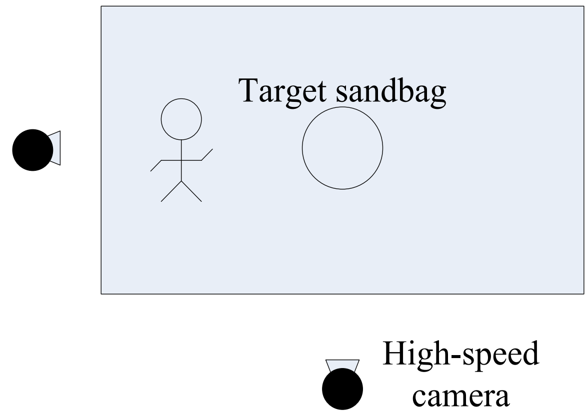

Figure 1. Test site layout.

Results and discussion

Completion time and reaction time of the whip kick

The high-speed cameras were used to shoot the athletes' whip kick after the signal light was on, and the frame rate of the cameras could reflect the reaction time and completion time of the athletes' movement. The results showed that there was a very significant difference in the completion time of the movement between the high-experience group and the low-experience group with the athletes in the high-experience group completing the movement faster than that in the low-experience group ($P < 0.01$) (Table 1). When comparing the reaction time of the movement, the results demonstrated that the athletes in both groups had similar reaction speed to the signal light with no significant difference between two groups ($P > 0.05$).

Joint linear velocity and time characteristics of the whip kick

The frame rate of the athlete's whip kick frames shot by the high-speed cameras reflected the movement time and could be used to calculate the linear speed and time characteristics of the lower limb joint on the kick side of the leg. The results showed that, in terms of the peak linear

Table 1. Completion time and reaction time of the whip kick movement of the two groups of athletes.

	Low experience group	High experience group	*P* value
Completion time of the whip kick movement (s)	0.489 ± 0.028	0.378 ± 0.021	0.005
Reaction time of the whip kick movement (s)	0.312 ± 0.011	0.308 ± 0.010	0.158

Table 2. Linear velocity and time characteristics of the joints of the two groups of athletes during whip kicks.

Joint	Linear velocity and time characteristics	Low experience group	High experience group	*P* value
Hip	Peak linear velocity (m/s)	2.34 ± 0.32	2.86 ± 0.25	0.002
	Time to reach the peak (s)	0.321 ± 0.084	0.243 ± 0.075	0.112
	Proportion of time to reach the peak (%)	65.54 ± 0.74	64.33 ± 0.87	0.126
Knee	Peak linear velocity (m/s)	4.23 ± 0.34	6.36 ± 0.24	0.001
	Time to reach the peak (s)	0.388 ± 0.024	0.298 ± 0.041	0.132
	Proportion of time to reach the peak (%)	79.36 ± 0.54	78.98 ± 0.57	0.134
Ankle	Peak linear velocity (m/s)	8.85 ± 0.36	11.97 ± 0.45	0.001
	Time to reach the peak (s)	0.489 ± 0.028	0.378 ± 0.021	0.132

velocity of the hip, knee, and ankle joints, the athletes in the high-experience group were significantly higher than that in the low-experience group. There was no significant difference between the two groups in terms of the time required for the joint linear speed to reach its peak. The time required for the ankle joint to reach its peak linear speed was the same as the completion time of the whip kick movement. From the perspective of the proportion of time required to reach the peak joint linear speed, the hip joint first reached the peak linear speed followed by the knee joint and finally the ankle joint. When the ankle joint reached the maximum linear speed, it was the moment when the whip leg hit the target (Table 2).

sEMG of the whip kick

The RMS values of the sEMG signals in two athletes groups during different time periods of the whip kick movement demonstrated that, no matter what time period, the athletes in the two groups had different degrees of mobilization of lower extremity muscles. In the T1 - T2 stage, the athletes in the low-experience group mainly mobilized the medial gastrocnemius and biceps femoris, while the athletes in the high-experience group mainly mobilized the biceps femoris and averagely motivated other muscles. In the T2 - T3 stage, the low-experience group mainly mobilized the biceps femoris, and the high-experience group mainly mobilized the medial gastrocnemius, biceps femoris, and rectus abdominis. In the T3 - T4 stage, both groups mainly mobilized the rectus abdominis. In the T4 - T5 stage, the low-experience group mainly mobilized the tibialis anterior muscle and the rectus femoris, while the high-experience group mainly mobilized the tibialis anterior muscle, biceps femoris, and rectus abdominis (Table 3).

Sanda is a type of Chinese martial art (Wushu), and whip kicks are commonly used offensive moves in Sanda, characterized by high speed, flexibility, and strength. When athletes perform the whip kick movement, it mainly involves the coordinated movement of the hip, knee, and ankle joints. The whole movement can be generally described as the athlete lifting the attacking leg and then falling quickly to produce the effect of whipping. As the attacking leg needs to fall in a short period of time, the leg muscles need to generate force, so it will cause a burden on the leg muscles. Moreover, rapid joint angle changes also place a burden on the joint. If the

Table 3. The RMS values of sEMG signals for two groups of athletes during different time periods of whip kicks.

Movement stage	Experience group	Tibialis anterior (μV)	Medial gastrocnemius (μV)	Rectus femoris (μV)	Biceps femoris (μV)	Erector spinae (μV)	Rectus abdominis (μV)
T_1 - T_2	Low	23.4	138.6	6.3	110.2	32.2	9.8
	High	82.1	76.6	43.3	120.1	22.2	33.1
T_2 - T_3	Low	136.4	186.6	67.3	211.2	166.5	45.3
	High	43.5	208.6	137.4	201.3	127.7	190.5
T_3 - T_4	Low	87.4	63.2	119.8	121.4	105.2	196.7
	High	121.4	116.5	105.3	66.4	82.7	240.1
T_4 - T_5	Low	132.4	88.2	113.5	63.6	94.5	77.7
	High	103.2	92.4	92.6	120.3	40.1	120.1

burden is too heavy, it will cause damage to the joints and muscles, affecting the normal play of athletes. By analyzing the kinematic parameters and sEMG signals of the athletes' whip kicks, the movement mechanism and force characteristics of the athletes can be more comprehensively understood. The results of this study found that the reaction time of the athletes in the two groups demonstrated no statistically significant difference, indicating that the conditioned reflex of the athletes in the two groups was similar. However, the time spent in completing the whip kick movement was significantly shorter in the high experience group than the low experience group. When the whip kick movement was carried out, the hip joint first reached the linear speed peak, then the knee joint, and finally the ankle joint because the whip kick was a whipping movement with the leg. First, the hip joint as a big joint generated force to promote the joints and limbs to start faster, and then the knee joint as a middle joint re-laid to further improve the leg movement speed. Finally, the ankle joint as a small joint generated force. As the joint at the end of the whip movement, the force was to control the direction of movement. The sequence in which the joints reached their peak linear velocity was the same as the sequence of force generation. The degree of muscle activity represented by sEMG parameters in different periods of the whip kick movement showed that, no matter at which stage, athletes in the high experience group were able to motivate more muscles, and the active degree of the motivated muscles was relatively balanced, while athletes in the low experience group were not balanced in the motivation of muscles and often only concentrated on using a small part of muscles. Therefore, the muscle force of the athletes in the high experience group was larger and more stable when they performed the whip kick movement. The higher muscle output also increased the joint line speed, and the improvement of the joint linear speed made the time required to complete the whip kick movement shorter.

References

1. Ha AS, Lonsdale C, Ng JYY, Lubans DR. 2017. A school-based rope skipping program for adolescents: Results of a randomized trial. Prev Med. 101:188-194.
2. Lee J, In TS. 2017. The effect of rope-skipping exercise on body composition of young female adults. J Korean Acad Phys Ther Sci. 24(3):64-71.
3. Hassan HS, Hanna SJ, Ameen FM. 2015. Effect of theoretical biomechanics on open jump the platform jumps performance using jumps (vault) in artistic gymnastics. J Hum Sport Exerc. 10(Special Issue 2):742-746.
4. Khuu S, Musalem LL, Beach TAC. 2015. Verbal instructions acutely affect drop vertical jump biomechanics—implications for athletic performance and injury risk assessments. J Strength Cond Res. 29(10):2816-2826.
5. Lim BO, Kim J, Kim SH, Cho JH, Lim S, Lim ST. 2022. The effects of taekwondo shoes on anterior cruciate ligament injury risk factors during jump whip kicks. Sci Sport. 37(1):51-57.
6. Comfort P, Jones PA, Smith LC, Herrington L. 2015. Joint kinetics and kinematics during common lower limb rehabilitation exercises. J Athl Training. 50(10):1011-1018.

7. Harry JR, Lanier R, Nunley B, Blinch J. 2019. Focus of attention effects on lower extremity biomechanics during vertical jump landings. Hum Movement Sci. 68:1-8.
8. Yildiz M, Akyildiz Z, Clemente FM, Yildiz D. 2023. Using an overhead target increases volleyball-specific vertical jump performance. Proc Inst Mech Eng P. 237(3):134-141.
9. Kirkaya I, Simsek D, Ertan H. 2015. The effects of vibration frequency variation on volleyball players' drop jump ability and postural control performance. Turk J Sport Exerc. 17(2):14-21.
10. Stamm R, Stamm M, Torilo D, Thomson K, Jairus A. 2016. Comparative analysis of the elements of attack and defense in men's and women's games in the Estonian volleyball highest league. Papers Anthropol. 25(1):37-54.
11. Bean C, Forneris T, Brunet J. 2016. Investigating discrepancies in program quality related to youth volleyball athletes' needs support. Psychol Sport Exerc. 26:154-163.
12. Logerstedt DS, Ebert JR, Macleod TD, Heiderscheit BC, Gabbett T, Eckenrode BJ. 2022. Effects of and response to mechanical loading on the knee. Sports Med. 52(2):201-235.
13. Mangone M, Bernetti A, Paoloni M, Canonico R, Tognolo L, Attanasi C, *et al*. 2017. Motor imagery and rehabilitation of a professional soccer player after anterior cruciate ligament injury: A case report. Med Sport. 70(1):109-115.