*Available online www.jocpr.com*

## Journal of Chemical and Pharmaceutical Research, 2014, 6(6):1854-1861

**Research Article**

**ISSN : 0975-7384**
**CODEN(USA) : JCPRC5**

# Research on the dynamics and biomechanical models of Sanda side kick

**Jian Zhang and Fengmei Gu**

*College of Physical Education, Chuzhou University, Anhui, China*

---

**ABSTRACT**

*As one of China's traditional martial arts sport, Sanda has been arresting the attention of various countries and regions. Through research, this paper obtains the mechanics relationship, dynamics relationship and rotary inertia of athletes doing rear side kick and learns about the potential energy generated by athletes doing side kick. In the side kick model of Sanda athletes established in this paper, athletes can increase the momentum of knee joint through the effective braking effect of hip joint in accordance with the principle that momentum is transferred from proximal to distal. Then the momentum is transferred to the ankle joint via the braking of knee, resulting in the end acceleration. This paper also draws the conclusion that the angular velocity of the left thigh of athletes doing side kick depends on the angular velocity of the hip joint and the velocity of waist, but that of the calf is determined by the angular velocity of the knee joint and left thigh. In addition, the angular velocity of the calf should be greater than that of the thigh, which is more conducive to the acceleration of the knee joint. When doing side kick, athletes should fully fold thigh and calf and reduce the limb's rotary inertia to improve the angular velocity of the knee rapidly. In the meanwhile, muscle groups in side kick can be fully contracted to enable athletes' leg muscle force to achieve the best condition and enhance its contraction speed. China's athletes can conduct targeted training based on the research result of this paper.*

**Key words:** Mechanics and dynamics analysis; rotary inertia; moment equation of rotation tensor

---

## INTRODUCTION

As the crystallization of Chinese martial arts, Sanshou has evolved to modern Sanda through five thousand years of development. It originated from the self-defense methods used to resist beasts and foreign enemies in primitive society. Nowadays, Sanda consists of a variety of martial arts by including Chinese traditional martial arts and referring to foreign martial arts. It absorbs the essence from these martial arts and eliminates its own shortcomings. With the passage of time, the basic exercise form of modern Sanda is abstracted. Modern Sanda is mainly comprised of two forms of attack: linear type and arc type. Compared with Taekwondo, the attack form of Sanda is more various and flexible in that it pays attention to the combination of fists and feet, flexibility and the integration of attack and defense. After many years of war, followed by the foundation of new China and the coming of reform and opening up, China's Sanda rose again from the bottom. It was approved as an official event in 1989 and included in the National Games in 1993.

**Technical characteristics of Sanda:** Modern Sanda has two forms: linear type and arc type. In Sanda, fist position mainly consists of whipped boxing, forward punch, whip fist and lift fist while foot position predominantly includes kicking, heel kick, foot sweep, leg whip, leg swing and hook kick. Characterized with no leaning and fast wrestling, close wrestling is mainly about the destruction of center of gravity and swing circle. The style of play includes clamping wrestling and reacting wrestling and the defense ways of Sanda are comprised of "no touching defense" and "touching defense". In terms of competition rules of Sanda, the traditional contest in martial arts is employed. If one party fails in the contest whose competition system is for the best of three games, it loses. Although Chinese Sanda bears strong antagonism, it differs from Taekwondo and Western Boxing, not to mention Thai Boxing dominated by such ferocious attacks as elbow-strike and knee-strike and Judo. Most Sanda athletes have high morality. According to Sanda rules, Sanda athletes are forbidden to use elbow, knee and anti-joint techniques or attack the neck, crotch and hindbrain of the opponent. Sanda is dominated by hitting near, kicking far and close wrestling. During the Sanda competition process, athletes need to roar loudly to deter the opponent in the manner. And relevant research shows that by way of utterance, 10% of the human body muscle can accelerate 9% of its contraction velocity in the absence of the burden of work. With the burden of work, the acceleration effect is more significant, being about 14%. Therefore, in contests, Sanda athletes would yell at each other. Sanda's foot position predominantly includes kicking, side kicking, foot sweep, leg whip and so on. This paper will focus on the side kick which has good strike effects and precise attacks.

**2. ESTABLISHMENT AND SOLUTION OF THE MODEL**

*2.1 Basic steps of side kick*

Side kick is a linear attack form of Sanda. Its standard action is as follows. Athletes should firstly put on the guard position, shift the center of gravity toward the right leg by taking a skip step of the right foot, buckle the knee of the left leg, tilt the upper body and kick out towards the attack direction swiftly. In the process of side kick, athletes should attack the abdomen, chest and head of the target by straightening the knee joint of the attack leg rapidly, protecting the jaw with the right hand and sweeping with the left hand. Figure 1 is the demonstration of Sanda side kick.

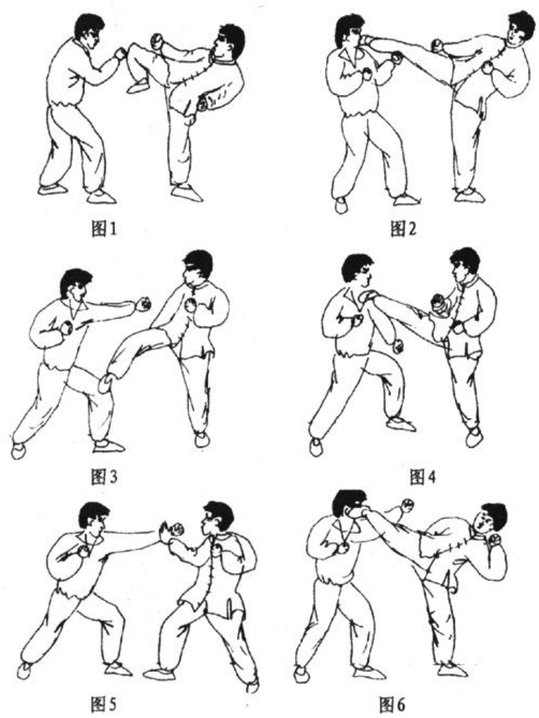


**Fig. 1: Demonstration of head attack of side kick by athletes**

**Fig. 2: Demonstration of abdomen attack of side kick by athletes**

The thigh and calf of Sanda athletes are now considered as two rigid bodies with different volumes while $T$ , $T_1$ and

$T_3$ are built into a model with three degrees of freedom, as shown in figure 3.

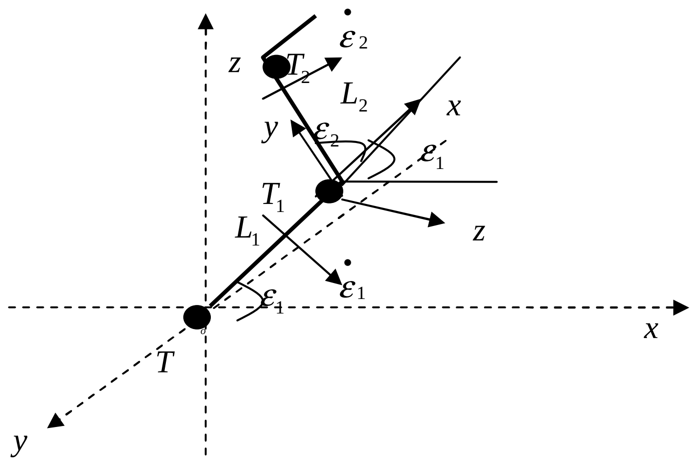


**Fig. 3: Freedom degree demonstration of leg attack of side kick by athletes**

$T$ , $T_1$ and $T_3$ stand for the hip joint, knee joint and ankle joint of Sanda athletes respectively, $\varepsilon_1, \varepsilon_2$ the anatomical angle of the thigh and the calf, and $L_1, L_2$ the length of the leg. Set that the three-dimensional vectors of $T$ and $T_1$ are $\dot{\lambda}_1, \dot{\lambda}_2$, i.e. the actual angular velocity of the thigh and calf of athletes and that the speed of $T_1$ is $\dot{\varepsilon}_2$, then we have $\dot{\varepsilon}_2 = \dot{\lambda}_2 - \dot{\lambda}_1$.

When Sanda athletes do side kick, the ankle's instantaneous velocity of the attacking leg is related to its initial speed. In other words, the angular velocity of $T_3$ is subject to the angular velocity of the thigh and calf of the attacking leg and the angular velocity of $T_1$. Therefore, the speed of $T_3$ and its relative velocity is related to the speed of $T_1$. The expression is

$$\vec{V}(\vec{T}_1)_G = \dot{\varepsilon}_1 \times \vec{D}_1 = \dot{\varepsilon}_1 \times \vec{D}_1, \quad V(\vec{T}_3)_L = \dot{\varepsilon}_2 \times \vec{D}_2$$

$\vec{V}(\vec{T}_1)_G$, $V(\vec{T}_3)_L$, $\vec{D}_1$ and $\vec{D}_2$ represent the actual velocity vector of $T_1$, the speed of $T_3$ relative to $T_1$, the position vector from $T$ to $T_1$ and the position vector from $T_1$ and $T_3$ respectively. According to the vector theorem, the impacts of the local motion of $L_1$ and $L_2$ on $T_1$ are figured out.

$$\dot{T}_{3G} = \dot{\varepsilon}_1 \times \vec{D}_1 + \dot{\varepsilon}_2 \times \vec{D}_2 + \dot{\varepsilon}_1 \times \vec{D}_2, \quad \dot{T}_{3G} = \dot{\varepsilon}_1 (\vec{D}_1 + \vec{D}_2) + \dot{\varepsilon}_2 \times \vec{D}_2$$

Simplified into

$$\dot{T}_{3G} = \vec{T}_{3G} \times \dot{\varepsilon}_1 + \dot{\varepsilon}_2 \times \vec{D}_2$$

In this formula, $\dot{T}_{3G}$ is the position vector of $T_3$ in the reference system, $\vec{T}_{3G} \times \dot{\varepsilon}_1$ the speed of $T_1$ generated by $T$ and $\dot{\varepsilon}_2 \times \vec{D}_2$ the speed of $T_3$ generated by $T_1$.

The relationship between the angles of $T$ and $T_1$ and the position of $T_3$ in figure 3 is decomposed and written as

$$\begin{cases} x_p = D_1 \cos \varepsilon_1 + D_2 \cos(\varepsilon_1 + \varepsilon_2) \\ y_p = D_1 \sin \varepsilon_1 + D_2 \sin(\varepsilon_1 + \varepsilon_2) \\ z_p = D_1 \cos \varepsilon_1 + D_2 \sin(\varepsilon_1 + \varepsilon_2) \end{cases}$$

Then the angles of $T$ and $T_1$ are differentiated and the relationship between the angles and the position vector of $T_3$ can be obtained through the derivation of the above formula.

$$\begin{cases} dX = \dfrac{\partial X(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} d\varepsilon_1 + \dfrac{\partial X(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} d\varepsilon_2 \\ dY = \dfrac{\partial Y(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} + \dfrac{\partial Y(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} d\varepsilon_2 \\ dZ = \dfrac{\partial Z(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} + \dfrac{\partial Z(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} d\varepsilon_2 \end{cases}$$

Transformed into the following matrix form:

$$\begin{pmatrix} dX \\ dY \\ dZ \end{pmatrix} = \begin{pmatrix} \dfrac{\partial X(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} & \dfrac{\partial X(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} \\ \dfrac{\partial Y(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} & \dfrac{\partial Y(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} \\ \dfrac{\partial Z(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_1} & \dfrac{\partial Z(\varepsilon_1, \varepsilon_2)}{\partial \varepsilon_2} \end{pmatrix} \begin{pmatrix} d\varepsilon_1 \\ d\varepsilon_2 \end{pmatrix}$$

In the light of the property of the matrix and vector product method, the above formula can be written as $d\vec{T}_{3\ G} = \vec{W} d\vec{\varepsilon}$. $\vec{W}$ is shown as follows.

$$\vec{W} = \begin{pmatrix} \dfrac{\partial X}{\partial \varepsilon_1} & \dfrac{\partial X}{\partial \varepsilon_2} \\ \dfrac{\partial Y}{\partial \varepsilon_1} & \dfrac{\partial Y}{\partial \varepsilon_2} \\ \dfrac{\partial Z}{\partial \varepsilon_1} & \dfrac{\partial Z}{\partial \varepsilon_2} \end{pmatrix}$$

$\vec{W}$ is the differential relationship between angular displacement of nodes in current structure and infinitesimal displacement of $T_3$. Substitute the matrix equation into the above formula, the following formula can be obtained:

$$\frac{d\vec{T}_{3G}}{dt} = \vec{W}\frac{d\vec{\varepsilon}}{dt} \text{ or } \vec{T}_{3G} = \vec{W}[\dot{\varepsilon}_1, \dot{\varepsilon}_2]^T$$

Substitute it into the calculation formula of the relative velocity of $T_3$, the following formula can be obtained:

$$\dot{T}_G = \begin{pmatrix} \frac{\partial X}{\partial \varepsilon_1} & \frac{\partial X}{\partial \varepsilon_2} \\ \frac{\partial Y}{\partial \varepsilon_1} & \frac{\partial Y}{\partial \varepsilon_2} \\ \frac{\partial Z}{\partial \varepsilon_1} & \frac{\partial Z}{\partial \varepsilon_2} \end{pmatrix} [\vec{\varepsilon}_1, \vec{\varepsilon}_2]^T \dot{\varepsilon}_1 + \dot{\varepsilon}_2 \times \vec{D}_2$$

*2.2 Rotary inertia analysis of shooting basket by basket by basketball athletes*

When Sanda athletes do side kick, their leg movements are shown in figure 4.

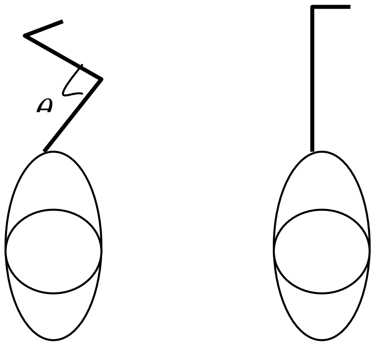


**Fig. 4: Demonstration of leg attack of side kick by Sanda athletes**

As the attacking leg is rotary when athletes do side kick, rotary inertia of the whole body of Sanda athletes can be obtained based on the rotary inertia theorem. That is

$$P = \Sigma m_i r_i^2$$

In this formula, $m_i$ stands for the quality of each participle of human body and $r$ represents the length from each participle to the axis of athletes. The continuous function of the human body is

$$P = \int\int\int_v r^2 dm = \int\int\int_v r^2 \rho dV$$

Thus, when Sanda athletes do side kick, the rotation tensor $\overleftrightarrow{R}_c$ of the attacking leg is

$$\overleftrightarrow{R}_c = \int\int\int_v \rho(r^2 \overleftrightarrow{E} - \vec{r}\,\vec{r})dV$$

Vector expression of any point $O$ in the body of Sanda athletes is $\vec{r} = r_1 \vec{E}_1 + r_1 \vec{E}_2 + r_3 \vec{E}_3$. $\vec{r}\,\vec{r}$ represents the product of two vectors. Then the unit tensor is

$$\overleftrightarrow{E} = \begin{bmatrix} 1 & & \\ & 1 & \\ & & 1 \end{bmatrix}$$

The unit orthogonal curvilinear frame is $(V; \vec{E}_1, \vec{E}_2, \vec{E}_3)$.

When Sanda athletes do side kick, the resultant moment vector of the attacking leg $\Sigma \vec{y}_c$ is represented as

$$\Sigma \vec{y}_c = \overleftrightarrow{R}_c \bullet \vec{\chi} + \vec{\omega} \times \overleftrightarrow{R}_c \bullet \vec{\chi}$$

The moment equation on each coordinate axis of athletes' attacking legs projects the original moment equation onto the three coordinate systems. Therefore, when athletes do side kick, the resultant moment $T_1$ generated by attacking leg rotation is

$$T_1 = \phi_1 \bullet I_1$$

$\phi_1$ represents the angular acceleration of attacking leg in side kick and $I_1$ the rotary inertia of the attacking leg. And there is

$$I_1 = \frac{m_1 i_1^{\,2}}{2}$$

The angular acceleration of the thigh $\phi_1$ is

$$\phi_1 = \frac{dw_1}{dt} = \frac{d^2\chi_1}{dt^2}$$

Then the angular acceleration of the calf $\phi_2$ is

$$\phi_2 = \frac{dw_2}{dt} + \frac{dw_1}{dt} = \frac{d^2\chi_2}{dt^2} + \frac{d^2\chi_1}{dt^2}$$

Through the Lagrange equation, the constrained particle kinetic equation is established, i.e.

$$D = H - P$$

$D$ is the difference between system kinetic energy $H$ and potential energy $P$. The system kinetic equation is

$$F_i = \frac{d}{dt}\left(\frac{\partial D}{\partial \dot{p}_i} - \frac{\partial D}{\partial p_i}\right) \qquad i = 1, 2, \cdots, n$$

In this formula, $\dot{p}_i$ stands for the corresponding velocity of particle, $p_i$ the coordinate of the particle kinetic energy and potential energy and $F_i$ the force exerted on the $i$ coordinate. $\varepsilon_1, \varepsilon_2$ represent the angle between the thigh and the coordinate axis and the angle between the calf and the coordinate axis respectively, $L_1, L_2$ the corresponding length and $q_1, q_2$ the distance between the center gravity position of the thigh and calf and the center of $T$ and $T_1$ respectively. It can thus be seen that areal coordinate of the thigh is $(X_1, Y_1)$.

$$\begin{cases} X_1 = q_1 \sin\varepsilon_1 \qquad Y_1 = q_1 \cos\varepsilon_1 \\ X_2 = q_1 \sin\varepsilon_1 + q_2 \sin(\varepsilon_1 + \varepsilon_2) \qquad Y_2 = -q_1 \cos\varepsilon_1 - q_2 \cos(\varepsilon_1 + \varepsilon_2) \end{cases}$$

Likewise, the areal coordinate of the calf $(X_2, Y_2)$ can be figured out. The expressions of system kinetic energy $E_k$ and system potential energy $E_p$ are

$$\begin{cases} E_k = E_{k1} + E_{k2}, E_{k1} = \frac{1}{2} m_1 q_1^2 \varepsilon_1^2 \\ E_{k2} = \frac{1}{2} m_2 L_1^2 \varepsilon_1^2 + \frac{1}{2} m_2 q_2^2 \left(\varepsilon_1 + \varepsilon_2\right)^2 + m_2 L_2 q_2 \left(\varepsilon_{01}^2 + \varepsilon_1 \varepsilon_2\right) \cos \varepsilon_2 \\ E_p = E_{p1} + E_{p2}, E_{p1} = \frac{1}{2} m_1 g q_1 \left(1 - \cos \varepsilon_1\right) \\ E_{p2} = m_2 g q_2 \left[1 - \cos\left(\varepsilon_1 + \varepsilon_2\right)\right] + m_2 g L_1 \left(1 - \cos \varepsilon_1\right) \end{cases}$$

Therefore, $M_h$ and $M_k$ which represent the moment of $T$ and that of $T_1$ respectively are as follows.

$$\begin{bmatrix} M_h \\ M_k \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \end{bmatrix} + \begin{bmatrix} A_{111} & A_{122} \\ A_{211} & A_{222} \end{bmatrix} \begin{bmatrix} \varepsilon_1^2 \\ \varepsilon_2^2 \end{bmatrix} + \begin{bmatrix} A_{112} & A_{121} \\ A_{212} & A_{221} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \varepsilon_2 \\ \varepsilon_2 \varepsilon_1 \end{bmatrix} + \begin{bmatrix} A_1 \\ A_2 \end{bmatrix}$$

In the above formula, $B_{ijk}$ is

$$\begin{bmatrix} A_{111} = 0 \quad A_{222} = 0 \quad A_{121} = 0 \quad A_{22} = m_2 q_2^2 \\ A_{11} = m_1 q_1^2 + m_2 q_2^2 + m_2 L_1^2 + 2 m_2 L_1 q_2 \cos \varepsilon_2 \\ A_1 = \left(m_1 q_1 + m_2 L_1\right) g \sin \varepsilon_1 + m_2 q_2 g \sin\left(\varepsilon_1 + \varepsilon_2\right) \\ A_{12} = m_2 q_2^2 + m_2 L_1 q_2 \cos \varepsilon_2 \quad A_{21} = m_2 q_2^2 + m_1 L_1 q_2 \cos \varepsilon_2 \\ A_{122} = -m_2 L_1 q_2 \sin \varepsilon_2 \quad A_{211} = m_2 L_1 q_2 \sin \varepsilon_2 \\ A_{112} = -2 m_2 L_1 q_2 \sin \varepsilon_2 \quad A_{212} = A_{122} + A_{211} \quad A_2 = m_2 q_2 g \sin\left(\varepsilon_1 + \varepsilon_2\right) \end{bmatrix}$$

From the above analysis, we know that when athletes do side kick, they should raise the speed of the leg to the maximum as soon as possible. That is to say, the projection speed of $T_3$ on the $Y$ axis is elevated to the maximum at the final stage to maximize the speed of the attacking leg on sagittal plane. Therefore, in the light of the principle of matrix vector product, only when $\varepsilon_1, \varepsilon_2$ meet the constraints of $45^\circ < \varepsilon^1 + \varepsilon^2 < 90^\circ$ and $0 < \dot{\varepsilon}_1 < \dot{\varepsilon}_2$ and $\dot{\varepsilon}_1$, $\dot{\varepsilon}_2$ increase, could the speed of $p$ be the maximum on the sagittal plane. This requires that at the preparatory stage of side kick, the diving flexion of $L_1$ and $L_2$ should not exceed $45^\circ$ and that the anatomical angle change speed of the left thigh and calf must be fast and live up to the muscle relaxation characteristics in muscle mechanics.

If the diving flexion of the left thigh and calf is excessive, muscle relaxation will be caused because of the muscle contraction. Also, $\varepsilon_1, \varepsilon_2$ meet the constrained conditions, which makes $\dot{\varepsilon}_1$, $\dot{\varepsilon}_2$ increase. In can be seen that when athletes do side kick, it is required that anatomical angle change rate of the left thigh and calf should reach the maximum within unit time and that anatomical angle change rate of the left thigh should be greater than that of the left calf. To meet these conditions, the mechanics analysis is conducted on the left legs of athletes doing side kick. Since the calf is considered as a rigid body, athletes are subject to three forces when doing leg whip, i.e. reaction force of the ground to calf, frictional force of the ground and stress of the joint. At the preparatory stage, the speed of each node is 0 and the force of the leg is in a state of equilibrium. Then at the kicking stage, muscle fibers are fully activated, which increases the force on the ground instantaneously, destroys the equilibrium state and changes the speed of each node, thereby altering the angular velocity of the leg. By virtue of the transmission of a rigid body, when the attacking leg goes above the ground, the angle between the thigh and the calf reaches nearly $180^\circ$. The force is transmitted to the thigh along the action line of the thigh. But as the thigh is joined with the calf, the force will fade. Therefore, that the angular velocity of the calf is greater than that of the thigh is more conducive to the acceleration of the knee joint.

## CONCLUSION

This paper firstly obtains the potential energy generated by athletes doing side kick by studying the kinematical equation of basketball shot. And it draws the conclusion that when athletes do side kick, the angular velocity of the left thigh depends on the angular velocity of the hip joint and the speed of the waist while that of the calf is determined by the angular velocity of the knee joint and the left thigh. When athletes prepare for side kick, the diving flexion of the left thigh and calf should try not to exceed $45^\circ$. That the angular velocity of the calf is greater than that of the thigh is more conducive to the acceleration of the knee joint. Then, rotary inertia analysis is conducted to obtain the momentum relationship of each node. Through the Lagrange equation, the constrained particle kinetic equation is established. The resulting side kick model shows that athletes can increase the momentum of knee joint through the effective braking effect of hip joint in accordance with the principle that momentum is transferred from proximal to distal. Then the momentum is transferred to the ankle joint via the braking of knee, resulting in the end acceleration.

**Acknowledgment**
Awarded the Anhui Provincial Department of Physical education research project "The Enlightenment of Taijiquan inheritance experience on development of Wushu" . Project number: ASS2014308

## REFERENCES

[1] Sports biomechanics writing group. *Sports biomechanics* [M].Beijing：Higher Education Press，pp.54, **2000**.
[2] HE Zhigang *et al. Zhejiang Sport Science*，no.4, pp.16-19, **2005.**
[3] LI Yugang. *Combating event group and sports biomechanics* [M].Wuhan: Hubei Science and Technology Press，**2002.**
[4] LI Yugang. *The basis of sports training biomechanics* [M].Wuhan：Hubei Science and Technology Press, no.10, **2003.**
[5] Vladimir, trans. LU Aiyun. *Sports biomechanics* [M]. Beijing：People's Sports Press, pp:377-379, **2004**.
[6]MENG Junqing *et al. Journal of TjIPE*，no.3, pp：78-81, **2003**.