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Taekwondo roundhouse kick leg technique biomechanical feature research and application

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ABSTRACT

With progress of times, Taekwondo has also been rapidly developing, and become formal event in Olympic Games. In order to find out Chinese athletes' shortcomings and defects, the paper analyzes mechanical relations and dynamical relations when athletes make roundhouse kicking; it gets athletes' potential energy generated when they make roundhouse kicking. And analyzes athletes data, it gets that when athletes make roundhouse kicking, their hip joint, knee joint and ankle joint kinematic features. Finally it gets that when athletes make roundhouse kicking, in case that quadriceps femoris and hamstrings fully contraction, they should try to reduce hip abduction angle and hip inflection angle as much as possible, shorten each phase completion time, improve motions' speed and motions surprise, so that arrives at anticipative effects and let own party get advantage.

KEYWORDS

Dynamical analysis;
Lagrange dynamical function;
Data analysis;
Roundhouse kick leg technique;
Taekwondo.

INTRODUCTION

Taekwondo originated from Korean peninsula above two thousand years ago, in the beginning it appeared in ancient Korean people wild animals defending and hunting, subsequently it had gradually formed a kind of self-defense attack and defense combat technique with routines. In Korean ancient three kingdoms period, due to three kingdoms mutual invading generated Goguryeo, Silla, Paekche the three kingdoms during mutual contending, each country military skills had been rapidly developed, neither military officers' examination nor folk mutual exchanging, all became prototype of subsequent taekwondo. After 1955, South Korea formally named previous Korean peninsula and foreign introduced military skills integrated self-defense art as "Taekwondo". In 1966, the first international taekwondo organization international taekwondo federation was founded in South Korea. In1995, China formally founded taekwondo association. From then on, taekwondo has been rapidly developing in China.

Taekwondo is a combating way with fists and feet, from which leg technique moves occupy 70% of total moves, thereupon, taekwondo is a combating way major in leg techniques. The reason is that athletes leg attacking range is larger with full force, while by comparing, fists attacking strength is weaker, range is smaller, which let athletes in taekwondo competition, mainly attack with leg technique while supplement with fists technique, fists moves are major in parry and defending opponents. In training, taekwondo highlight sounding, resonant and with deterrent roar can impose pressure to opponents. And research shows that human body muscle, when works without burden, 10% muscle by body sounding can speed up its 9% contraction speed; when works with burden, the rising is more remarkable that improves around 14% contraction speed, therefore when competition athletes will mutual let out a shout. In motions technique, taekwondo more focus on strength and speed promoting, taekwondo all motions and techniques are major in attack and defense combating, which is particular about fiercely power, fast speed, obvious striking effects and so on. Taekwondo is a leg technique that subduing unyielding with unyielding, so athletes in competitions are mostly direct stroking direct fighting, and with coherent leg techniques block skills to fight against opponents, its basic techniques types are technical type, free of hand type, strength type, attack type and counter attack type. Its pomade divides into lots of kinds, basically have Corea, King Kong and Tai Ji so on. Taekwondo common basic motions have front kick, side kick, back kick, roundhouse kick, hook kick, downward kick, and reverse kick, push kick, jump kick, double kick, double turning kick and so on. The paper makes research on relative faster, precise roundhouse kick method from them.

MODEL ESTABLISHMENT AND SOLUTION

Roundhouse kicks technical analysis

Leg technique of roundhouse kick, first pedal right foot to shift gravity center to left foot, two hands make a fist and put in the front of chest, right foot takes hip joint as axis, bend knees and lifts up; left foot sole makes a grinding rotation, hip joint rotates left, left knee inner buckles; in the following, left foot continues to inner rotate $180°$, right leg knee joint lifts to horizontal position, and fast kicks shank out towards front of left; after hitting, fast return shank, finally athlete places actual combat postures. Figures 1, Figure 2 are roundhouse kick leg techniques demonstrative graphs

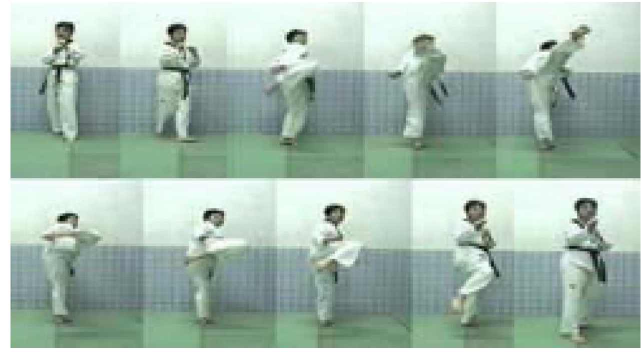

Figure 1 : Roundhouse kick leg techniques front schematic diagram

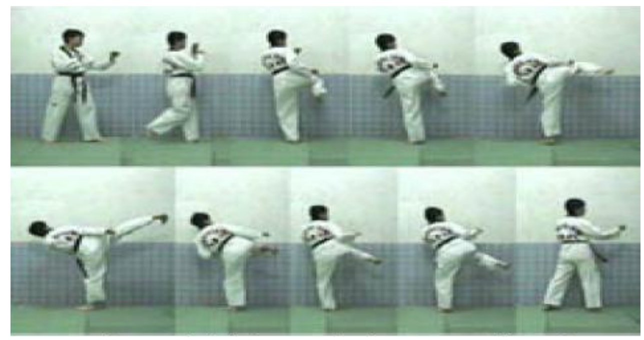

Figure 2 : Roundhouse kick leg techniques profile schematic diagram

Roundhouse kick leg technique dynamical analysis

Due to when athlete makes roundhouse kicking, he should twist hip joint, let hip joint drive right leg kick out in the front of left side, right shank kicks out forward with knee joint as axis, and finally it is in stretch tight state. In the process, it can simplify thigh and shank into two rigid bodies surrounding fixed axis rotating problems, as Figure 3 shows.

Driven by hip joint, thigh in rotation process will produce a resultant moment M_1, formula is as following:

$$M_1 = I_1 \bullet \beta_1$$

In formula I_1 is right thigh rotational inertia, β_1 is

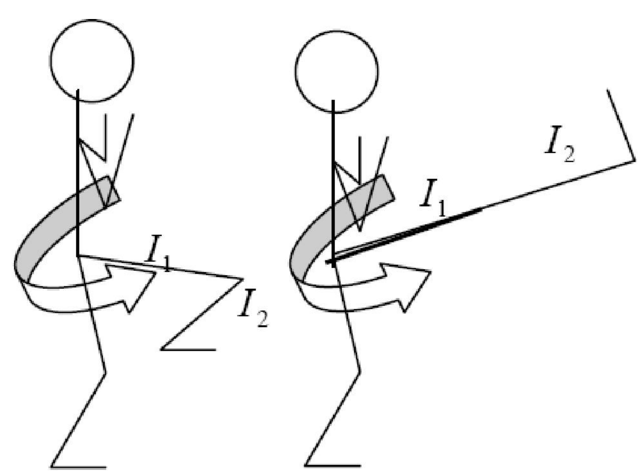

Figure 3 : Right leg rotation profile

right thigh angular accelerated speed. Regard right leg as a cylinder rigid body, then its rotational inertia I_1 is:

$$I_B = \frac{m_1 r_1^{\,2}}{2}$$

Among them, m_1 is right thigh mass, r_1 is right thigh radius, angular accelerated speed β_1 is:

$$\beta_1 = \frac{dw_1}{dt} = \frac{d^2\theta_1}{dt^2}$$

Right shank, during rotation, except for itself would generate angular accelerated speed, it will have a initial angular speed β_1, therefore right shank angular speed β_2 is:

$$\beta_2 = \frac{dw_2}{dt} + \frac{dw_1}{dt} = \frac{d^2\theta_2}{dt^2} + \frac{d^2\theta_1}{dt^2}$$

Establish right leg into surrounding hip joint and knee joint two rigid bodies' two freedom degree models, as Figure 4 show.

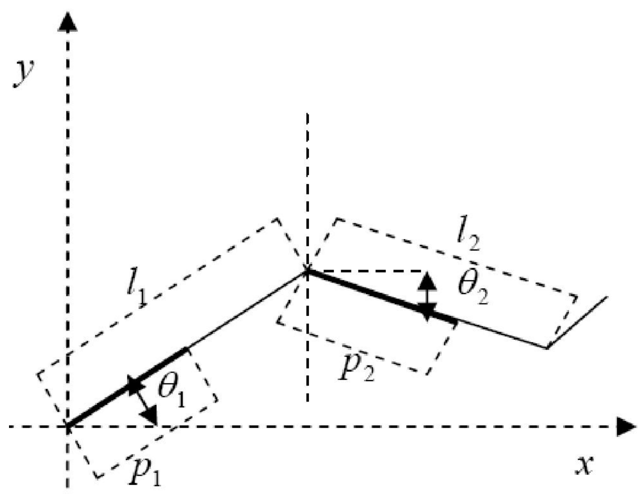

Figure 4 : Human body right leg rigid body freedom degree model

After that, make use of Lagrange equation write out right leg restrained particle dynamical equation; define L as right leg Lagrange function's system kinetic energy K and position energy P difference:

$$L = K - P$$

Right leg Lagrange dynamical equation is:

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

Among them, $\dot{q}_i$ is particle corresponding speed, q_i is particle position energy and system kinetic energy coordinate, F_i represents right leg the i coordinate particle acting force sizes, thigh and body axis included angle as well as shank and axis included angle are respectively θ_1, θ_2, thigh and shank length are respectively l_1, l_2, distance between thigh mass center and hip joint is p_1, distance between shank and knee joint is p_2, therefore, it can solve thigh mass center coordinate (X_1, Y_1) as :

$$\begin{cases} X_1 = p_1 \sin\theta_1 \qquad Y_1 = p_1 \cos\theta_1 \\ X_2 = l_1 \sin\theta_1 + p_2 \sin(\theta_1 + \theta_2) \\ \quad Y_2 = -l_1 \cos\theta_1 - p_2 \cos(\theta_1 + \theta_2) \end{cases}$$

Similarly, it can also solve shank mass center coordinate (X_2, Y_2). System potential energy E_p and system kinetic energy E_k expression is:

$$\begin{cases} E_k = E_{k1} + E_{k2}, E_{k1} = \frac{1}{2} m_1 p_1^2 \dot{\theta}_1^2 \\ E_{k2} = \frac{1}{2} m_2 l_1^2 \dot{\theta}_1^2 + \frac{1}{2} m_2 p_2^2 (\dot{\theta}_1 + \dot{\theta}_2)^2 \\ + m_2 l_2 p_2 (\dot{\theta}_{01}^2 + \dot{\theta}_1 \dot{\theta}_2) \cos\theta_2 \\ E_p = E_{p1} + E_{p2}, E_{p1} = \frac{1}{2} m_1 g p_1 (1 - \cos\theta_1) \\ E_{p2} = m_2 g p_2 [1 - \cos(\theta_1 + \theta_2)] + m_2 g l_1 (1 - \cos\theta_1) \end{cases}$$

Convert above formula into Lagrange function expression, it can get hip joint and knee joint in Lagrange system dynamical equation torque M_h and M_k as:

$$\begin{bmatrix} M_h \\ M_k \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} \begin{bmatrix} \ddot{\theta}_1 \\ \ddot{\theta}_2 \end{bmatrix} + \begin{bmatrix} D_{111} & D_{122} \\ D_{211} & D_{222} \end{bmatrix} \begin{bmatrix} \dot{\theta}_1^2 \\ \dot{\theta}_2^2 \end{bmatrix} + \begin{bmatrix} D_{112} & D_{121} \\ D_{212} & D_{221} \end{bmatrix} \begin{bmatrix} \dot{\theta}_1 \dot{\theta}_2 \\ \dot{\theta}_2 \dot{\theta}_1 \end{bmatrix} + \begin{bmatrix} D_1 \\ D_2 \end{bmatrix}$$

In torque, D_{ijk} is expressed as:

$$\begin{bmatrix} D_{111} = 0 \quad D_{222} = 0 \quad D_{121} = 0 \quad D_{22} = m_2 p_2^2 \\ D_{11} = m_1 p_1^2 + m_2 p_2^2 + m_2 l_1^2 + 2 m_2 l_1 p_2 \cos\theta_2 \\ D_1 = (m_1 p_1 + m_2 l_1) g \sin\theta_1 + m_2 p_2 g \sin(\theta_1 + \theta_2) \\ D_{12} = m_2 p_2^2 + m_2 l_1 p_2 \cos\theta_2 \quad D_{21} = m_2 p_2^2 + m_1 l_1 p_2 \cos\theta_2 \\ D_{122} = -m_2 l_1 p_2 \sin\theta_2 \quad D_{211} = m_2 l_1 p_2 \sin\theta_2 \\ D_{112} = -2 m_2 l_1 p_2 \sin\theta_2 \quad D_{212} = D_{122} + D_{211} \quad D_2 = m_2 p_2 g \sin(\theta_1 + \theta_2) \end{bmatrix}$$

ATHLETES' ROUNDHOUSE KICK DATA ANALYSIS

In order to further find out Chinese taekwondo athletes' defect and shortcomings, the paper adopts DV photogrammetry, records athletes roundhouse kick whole process, put them into three dimensional coordinates, analyzes athletes' roundhouse kick motion from the perspective of three dimensional space, extracts athletes head, shoulder, hand, elbow, hip and knee as well as other joints three dimensional coordinates in image, after smoothing and through statistics and analysis, it gets athletes data when making roundhouse kick.

Hip joint movement features when making roundhouse kick

When athletes make roundhouse kick, in knee lifting phase, they complete hip bending motion by iliopsoas, rectus femoris, tensor fasciae latae and Sartorius as well as other muscle group contraction. In the following, let trunk lean left and contract right hip gluteus mediums, gluteus minimums and other muscles to let right thigh inner rotate. Finally, during shank flick phase, under hip joint surrounding muscle group common acting, let thigh keep below $60°$ flexion. TABLE 1 is athlete's hip joint movement features when making roundhouse kick.

From TABLE 1, it is clear that when ankle joint speed arrives at maximum, hip joint abduction angle and hip flexion angle are in negative correlation with ankle joint maximum speed that $\rho_1 = -0.53$, $\rho_2 = -0.56$, $p < 0.005$. Therefore offensive leg during whipping phase, its abduction angle is so big that it will affect ankle joint forward extension speed. If hip flexion angle is too big, then it will increase thigh swinging range, further increase movement time, and influence ankle joint maximum speed. That shows when athletes make roundhouse kick, if hip joint abduction angle and hip flexion angle are too big, it is harmful for ankle joint achieving maximum speed. However, if hip flexion angle is too small, it will cause insufficient quadriceps femoris initiative contraction and insufficient hamstrings passive contraction, which will also affect ankle joint maximum speed. Therefore, when athletes make roundhouse kick, in case that quadriceps femoris and hamstrings can sufficient contract, try to reduce hip abduction angle and hip flexion angle as much as possible so that arrive at ankle joint maximum speed.

Knee joint movement features when making roundhouse kick

In the whole process of roundhouse kick, offensive leg's knee joint experiences movement process as firstly flexion then extension and at last return to flexion. After ankle joint arriving at maximum sped, due to inertia, knee joint continues to extend, but different from traditional roundhouse technique shank finally should straightly kick such situation, knee joint never keeps straight in taekwondo roundhouse kick process.

When taekwondo athletes make roundhouse kick, knee joint completes contraction mainly by semitendinosus, biceps femoris and semimembranosus as well as other muscle group acting, then let it extend by quadriceps femoris, so that complete whipping motion. TABLE 2 is athletes' knee joint movement features when making roundhouse kick.

From TABLE 2, it is clear that athletes during roundhouse kick moment knee lifting phase, in order to reduce knee lifting rotational inertia, and provide better exerting force condition for whipping phase, knee joint should make fast flexion. TABLE 2 shows that athletes appeared maximum flexion angular speed time is in negative correlation with ankle joint maximum speed that $\rho = -0.61, p < 0.05$. And roundhouse kick completion time is also in negative correlation with ankle joint maximum speed, which also shows that athletes should shorten whole process completion time by shorten every phase spending time so as to achieve the purpose of increasing speed. Besides, it also can know that knee

TABLE 1 : Athlete roundhouse kicking moment hip joint movement features ($n = 13$)

	Hip flexion maximum angular speed		When ankle joint at maximum speed	
	Angular speed(°/s)	**Time(s)**	**Hip abduction angle°**	**Hip flexion angle°**
Average value	596.45	0.065	52.94	50.11
Standard deviation	87.70	0.024	17.44	9.17
Correlation coefficient	0.37	-0.63	-0.54	-0.56

TABLE 2 : Athlete roundhouse kicking moment knee joint movement features ($n = 13$)

	Maximum flexion angle		Maximum flexion angular speed		Maximum extension angular speed		Maximum speed		Ankle joint maximum speed	
	Angle (°)	Time (s)	Angular Speed (°/s)	Time (s)	Angular Speed (°/s)	Time (s)	Speed (m/s)	Time (s)	Knee joint angle (°)	Knee joint angular speed (°/s)
Average value	68.10	0.068	783.60	0.19	1631.5	-0.009	8.88	0.094	112.35	1463
Standard deviation	8.18	0.012	188.79	0.027	251.22	0.007	0.79	0.019	11.06	255.3
Correlation coefficient	0.49	0.093	-0.19	-0.61^{*}	-0.096	0.067	0.71^{**}	-0.59^{*}	0.12	0.42

joint appeared maximum speed time and ankle joint maximum speed as well as knee joint maximum speed and ankle joint maximum speed are in significant positive correlations, and appeared time and ankle joint maximum speed are in significant negative correlation. It is not hard to see that knee joint mainly increase speed by hip joint flexor group contraction, which is very similar to whipping technique large joint driving facet joint principle. Knee joint maximum extension angular speed and time are in insignificant difference correlations with ankle joint maximum speed, and only after ankle joint maximum speed showing up, knee extension maximum speed would show up, which shows ankle joint speed is up to athletes' whole body each motion mutual coordination degree, it cannot improve ankle joint speed just by promoting knee joint speed.

Ankle joint movement features when making roundhouse kick

Ankle joint movement is the end link in roundhouse kick process, its movement is driven by shank movement, and ankle joint maximum speed is also the result of athletes' whole body each motion overlapping. TABLE 3 is athletes' ankle joint movement features when making roundhouse kick.

By TABLE 3, it is clear that athlete ankle joint maximum speed average value is $14.78\,m/s$, relative movement trajectory length is $1.07m$. Though TABLE 3 shows that movement trajectory and ankle joint maximum speed correlations is not remarkable, when athlete makes roundhouse kick, try to shorten each phase completion time, which not only can increase speed, but also can improve motion surprise let opponents be caught unprepared and achieve advantage.

TABLE 3 : Athlete roundhouse kicking moment ankle joint movement features

Item	Ankle joint maximum speed(m/s)	Ankle joint Movement trajectory(m)	Ankle joint relative movement trajectory (trajectory length/height)	Movement Completion time(s)
Average value	14.78	1.89	1.07	0.26
Standard deviation	1.35	0.20	0.11	0.04
Correlation coefficient		-0.028	-0.067	-0.56

CONCLUSIONS

This paper gets athlete roundhouse kick moment generated potential energy by analyzing athlete roundhouse kick moment mechanical relations and dynamical relations. And analyzes athlete data, obtains athlete roundhouse kick moment hip joint, knee joint and ankle joint movement features. It gets that athlete during roundhouse kick moment; in case that quadriceps femoris and hamstrings can sufficient contract, try to reduce hip abduction angle and hip flexion angle as much as possible, after ankle joint arriving at maximum sped, due to inertia, knee joint continues to extend, and it gets that different from traditional roundhouse technique shank finally should straightly kick such situation, knee joint never keeps straight in taekwondo roundhouse kick process. And in order to reduce knee lifting rotational inertia, and provide better exerting force condition for whipping phase, it should shorten each phase completion time and let knee joint make fast flexion. It corrects people thought of improving ankle joint speed just relying on promoting knee joint speed, and it should improve ankle joint speed by improving athletes' whole body each motion mutual coordination degrees. In overall aspect, athlete should also improve motion speed and motion surprise, which arrives at anticipative result let own party get advantages.

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