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Volleyball spiking point position and success rate correlation research based on biomechanical geometric model

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ABSTRACT

Spiking accounts for very large proportion in modern volleyball competitiveness, it also can mostly reflect one team's strength. The paper applies mechanical knowledge, mainly analyzes volleyball spiking technique, makes analysis of volleyball spiking moment takeoff, hitting and other motions, and utilizes moment of momentum theorem to research on volleyball spiking technique some rules with an aim to normalize volleyball spiking technique. The paper gets that twist spiking is when athlete takes off and hits, spiking by changing upper body facing direction; when athlete takes off, it should enlarge athlete himself rotational angular speed, let legs arrive at straight, gravity center and body rotational axis come to terms so that can reduce rotational inertia, and then it further achieves the efficiency of increasing rotational angular speed, and at the same time of taking off, twisting upper body can also continue to increase self-rotational angular speed, let contact ball more rapid. When athlete takes off and arrives at top point, athlete should try to adjust body stability and let rotational angular speed reduce as much as possible, at this time, athlete should lift two legs backward, and let gravity center to be far away from rotational axis. Then arrive at stable contacting ball state. By establishing geometric model, it concludes that when athlete spikes, he should try to manage to stretch arms to right ahead and remain vertical to hitting point, athlete take-off height gets higher, and ball over net probability would be larger; by ball located hitting point height differences, presented over net trajectory and landing point are also different.

KEYWORDS

Volleyball spiking;
Moment of momentum theorem;
Geometric model;
Success rate.

INTRODUCTION

In previous foreign volleyball competitions, volleyball plays an important role; in the beginning of 80s, there were lots of excellent scholars made research on volleyball in foreign countries, especially focused on volleyball technique, after entering into 90s, used three-dimensional high speed photograph technology and computer technology combination that let volleyball get better researching and developing.

Take Chinese men's volleyball as an example, in 80s, they had ever won the fifth in the fifth world cup, but with the rising of development countries, our country volleyball level gradually fell behind. In 90s, Chinese men's volleyball entered into fast accelerated era, they got good results as winning the champions in Asian championship in 1997 and the Asian Games in 1998, but by our country's some scholars and experts analyzing, our country volleyball level still kept great paces with developed countries by comparing.

Spiking belongs to volleyball basic techniques, which is also volleyball stronger aggressive segment. According to hitting point vertical heights differences, the paper classifies (2.6, 2.7, 2.8, 2.9, 3.0, 3.1)six different heights phases to analyze. And according to athlete spiking release angle is not in 90°vertical incidence, and ball also does not vertical enter into opponent field such phenomenon, researches that spiking is certain angle hitting, ball oblique hitting and falling to opponent field position's differences. Make mechanical analysis of spiking is to build good foundation for future teaching and training.

VOLLEYBALL BIOMECHANICAL GEOMETRIC MODEL ESTABLISHMENTS

Moment of momentum theorem

Apply mechanical conservation law into solving problems, at first it should select reasonable research objects, and make correct force analysis of researched objects, the next is on the basis of force analysis, refer to conservation law to check problems, and finally according to conservation law, establish equation and solve problems.

Set I is one rigid body rotational inertia, suffered torque M effects, from which angular accelerated speed β is constant, the rigid body at time t_1 angular speed is ω_1, the rigid body at time t_2 angular speed is ω_2, and get:

$$M = I\beta = I\frac{\omega_2 - \omega_1}{t_2 - t_1}$$

Transform and get:

$$M(t_2 - t_1) = I(\omega_2 - \omega_1)$$

When $M = M(t)$, it has:

$$M(t)(t_2 - t_1) = I(\omega_2 - \omega_1)$$

It gets moment of momentum formula, from which $M(t_2 - t_1)$ is impulsive moment, $I\omega$ is moment of momentum, from formula, it is clear that rigid body impulsive moment variable quantity and moment of momentum variable quantity are equal.

In moment of momentum theorem, time and torque product is equal to impulsive moment that represents object rotational accumulation effect under external force moment influences. Angular speed and rotational inertia product is rigid body state when rotating. With external force moment increases and acting time enlarges, rigid body rotational state changes are changing accordingly.

When human body moves, human body generated rotational inertial is changing, due to rotational variables changes, different times rotational inertias are different, set t_1 time rotational inertia is I_1, t_2 time rotational inertia is I_2, therefore, above formula can be revised into:

$$M(t)(t_2 - t_1) = I_2\omega_2 - I_1\omega_1)$$

Human body basic movement rules mainly is lengthwise relative movement, its initial condition should meet:

$$I\omega = 0, \sum M\square t = 0$$

Now it enters into soaring phase, assume human body meets:

$$I_1\omega_1 + I_2\omega_2 = 0$$

Besides, it should also meet human body surround $I_1\omega_1$ to rotate, then the kind of movement form is lengthwise relative movement, in spiking process, solve the sum of human body moment of momentum's vectors is 0, according to correlation law, we get that human body will suffer ball acted a reaction force that let people produce moment of momentum, so that reduce spiking process strength sizes and it is bad for spiking stability, but if the spiking process, due to body each part suffered active force effects, which causes rotational inertia increase, it will further produce an advancing moment of momentum effects; according to energy conservation law, we know that human body also will produce a reverse active force effects at this time, so that let human body move relative to ball, based on which it increases arms swinging distance and concentrates on whole body strength to hit the ball.

In the whole hitting process, each limb will produce opposite direction but equal size torque, and every pair can offset, when athlete lands, sole part fast landing to support whole body, meanwhile it will occur to contract abdomen, bend knees and others to buffer reduction strength and make preparation for next motions.

Air angular speed changes, in case moment of momentum remains unchanged, rotational inertial will reduce with angular speed increases, when athlete springs and soars, athlete himself can further control rotational angular speed by changing self-rotational inertia.

Twist spiking is when athlete takes off and hits, spiking by changing upper body facing direction; when athlete takes off, it should enlarge athlete himself rotational angular speed, let legs arrive at straight, gravity center and body rotational axis come to terms so that can reduce rotational inertia, and then it further achieves the efficiency of increasing rotational angular speed, and at the same time of taking off, twisting upper body can also continue to increase self-rotational angular speed, let contact ball more rapid.

When athlete takes off and arrives at top point, athlete should try to adjust body stability and let rotational angular speed reduce as much as possible, at this time, athlete should lift two legs backward, and let gravity center to be far away from rotational axis. Then arrive at stable contacting ball state.

Hitting instant arms rotational inertia calculation

The paper applies Lagrange equation to establish restricted particle dynamical equation, define Lagrange function L as difference between system kinetic energy K and potential energy P:

$$\mathbf{L = K - P}$$

System dynamical equation is:

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

In above formula $\dot{q}_i$ is corresponding speed, q_i is dynamic energy and potential energy coordinate, F_i is the i coordinate acted force, thigh and shank included angles with coordinate axis are respectively θ_1, θ_2, lengths are respectively l_1, l_2, Arms front part and arms post part gravity center position distances with elbow joint center and knee joint are respectively p_1, p_2, therefore it is clear that arms gravity center coordinate (X_1, Y_1) is:

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

Similarly, arms gravity center coordinate (X_2, Y_2) can also be solved. System dynamic energy E_k and system potential energy E_p expressions are:

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

Write above formula into Lagrange function expression, by Lagrange system dynamical equation, it can get hip joint and knee joint torques 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 above formula, D_{ijk} is as following result:

$$D_{111} = 0 \quad D_{222} = 0 \quad D_{121} = 0$$

$$D_{22} = m_2 p_2^2$$

$$D_{11} = m_1 p_1^2 + m_2 p_2^2 + m_2 l_1^2 + 2m_2 l_1 p_2 \cos\theta_2$$

$$D_{12} = m_2 p_2^2 + m_2 l_1 p_2 \cos\theta_2 \quad D_{21} = m_2 p_2^2 + m_1 l_1 p_2 \cos\theta_2$$

$$D_1 = (m_1 p_1 + m_2 l_1) g \sin\theta_1 + m_2 p_2 g \sin(\theta_1 + \theta_2)$$

$$D_{122} = -m_2 l_1 p_2 \sin\theta_2$$

$$D_{211} = m_2 l_1 p_2 \sin\theta_2$$

$$D_{112} = -2m_2 l_1 p_2 \sin\theta_2$$

$$D_{212} = D_{122} + D_{211}$$

$$D_2 = m_2 p_2 g \sin(\theta_1 + \theta_2)$$

Combine with theoretical equation, analyze when volleyball players spike, hand joint mechanical movement combines with shoulder joint, elbow joint mechanical analyses to research on volleyball spiking technique.

Geometric model establishment

(1) Spiking trajectory and hitting drop point under

geometric model

According to geometric principle, it establishes volleyball spiking model, according to high hitting and low hitting differences, it gets ball trajectory graph and hitting drop point position, as Figure 1 shows.

When athlete spikes, he should try to manage to stretch arms to right ahead and remain vertical to hitting point, athlete take-off height gets higher, and ball over net probability would be larger; with ball located hitting point height differences, presented over net trajectory and landing point are also different, therefore it gets long ball and short ball; according to hitting point vertical heights differences, the paper classifies six different heights phases that are respectively(2.6, 2.7, 2.8, 2.9, 3.0, 3.1).And it gets TABLE 1 according to hitting point to net vertical distance differences.

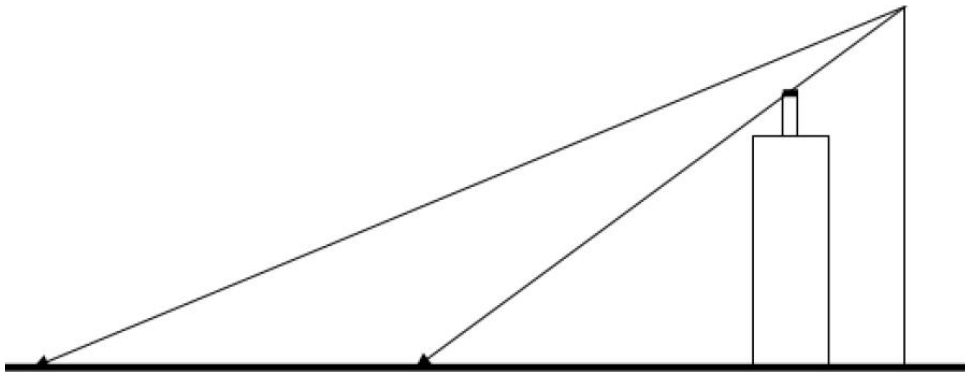

Figure 1: High hitting and low hitting differences obtained ball trajectory

TABLE 1: Ball flies across lowest net point's landing point data

Vertical height/H	2.6	2.7	2.8	2.9	3.0	3.1
Hitting point and net distance 0.75m	17.23	9.07	6.15	4.65	3.74	3.12
Hitting point and net distance 0.5m	10.55	6.05	4.10	3.10	2.49	2.08
Hitting point and net distance 0.25m	5.78	3.02	2.05	1.55	1.25	1.04

By TABLE 1, it is clear that athlete hitting points positions differences can cause spiking over lowest net point positions differences and hitting point to net distances differences, volleyball landing points are also different.

(2) Low dropping ball's spiking trajectory and hitting drop point improvement under geometric model

Similarly, as Figure 2 show, the paper according to hitting point vertical heights differences, it classifies six different heights phases that are respectively(2.6, 2.7, 2.8, 2.9, 3.0, 3.1), and according to hitting point to net vertical distances differences and get TABLE 2.

By TABLE 2 and Figure 2, it is clear that shorten hitting point to net vertical distance 0.1m, which can clearly get to low hitting, though only shorten hitting point to net 0.1m vertical distance, ball hitting drop point positions have great differences. Hitting drop point in opponent area occurs to great changes.

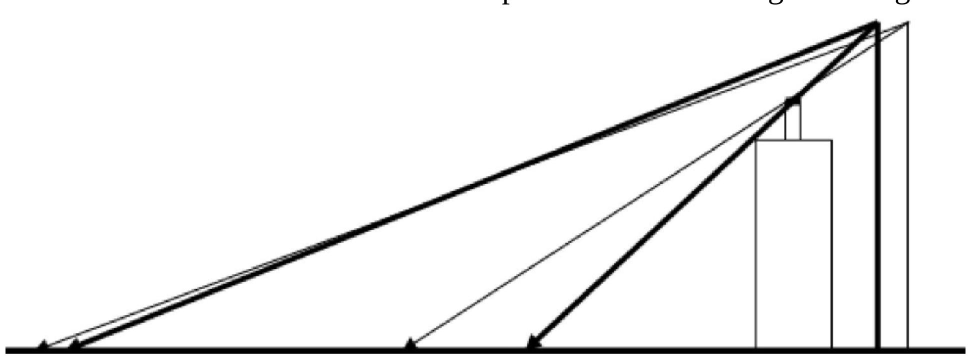

Figure 2 : Low dropping ball spiking trajectory under geometric model

TABLE 2 : After shortening hitting point to vertical net 0.1m ball flying across lowest net point landing point data

Vertical height/H	2.6	2.7	2.8	2.9	3.0	3.1
Hitting point and net distance 0.75m	85.16	41.01	16.73	10.45	7.6	6.15
Hitting point and net distance 0.5m	9.32	4.89	3.68	2.48	1.98	1.87
Hitting point and net distance 0.25m	10.66	6.49	4.09	3.15	2.48	2.08

(3)Change hitting angle

Spiking release angle is not in 90° vertical incidence, and ball also not vertical enters into opponent field, generally speaking, when athlete hitting, it will hitting at certain angles, and oblique hit ball down to opponent field.

Set hitting point and field edge vertical distance is 0.5m, when athlete hits, deflects rightward 45° to release and hit, and get hitting point to drop point distance S is:

$$S=\frac{0.5}{\cos 45^\circ}=\frac{0.5}{\sqrt{2}/2}=0.7072m$$

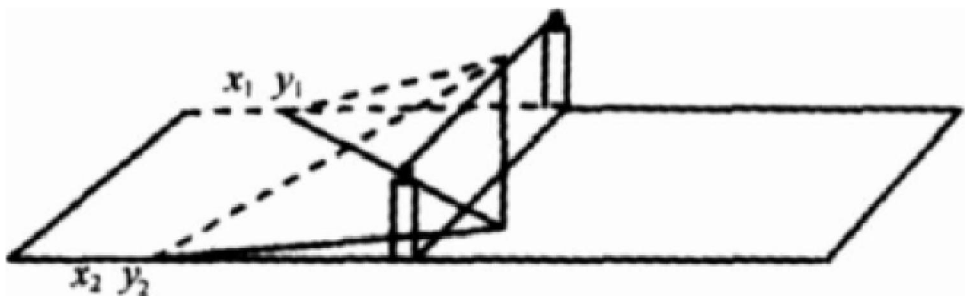

Figure 3 : Angle changes hitting drop point schematic

TABLE 3 : 6 different hitting points over net lowest point drop point data

Angle	Vertical angle	45°	Drop point coordinate $\begin{pmatrix} x \\ y \end{pmatrix}$	30°	Drop point coordinate $\begin{pmatrix} x \\ y \end{pmatrix}$
2.65m	10.45m	16.52m	$\begin{pmatrix} 11.15 \\ 11.15 \end{pmatrix}$	13.56m	$\begin{pmatrix} 11.45 \\ 6.24 \end{pmatrix}$
2.75m	6.04m	8.54m	$\begin{pmatrix} 6.05 \\ 6.05 \end{pmatrix}$	6.98m	$\begin{pmatrix} 6.02 \\ 3.476 \end{pmatrix}$
2.85m	4.2m	5.6m	$\begin{pmatrix} 4.12 \\ 4.12 \end{pmatrix}$	4.75m	$\begin{pmatrix} 4.08 \\ 2.356 \end{pmatrix}$
2.95m	3.15m	4.37m	$\begin{pmatrix} 3.25 \\ 3.25 \end{pmatrix}$	3.64m	$\begin{pmatrix} 3.08 \\ 1.86 \end{pmatrix}$
3.05m	2.49m	3.52m	$\begin{pmatrix} 2.18 \\ 2.18 \end{pmatrix}$	2.89m	$\begin{pmatrix} 2.48 \\ 1.42 \end{pmatrix}$
3.15m	2.11m	2.98m	$\begin{pmatrix} 1.95 \\ 1.95 \end{pmatrix}$	2.41m	$\begin{pmatrix} 2.05 \\ 1.47 \end{pmatrix}$

Similarly when deflection angle is 30°, it gets hitting point to dropping point distance S is:

$$S = \frac{0.5}{\cos 30} = \frac{0.5}{\sqrt{3}/2} = 0.574m$$

As Figure 3 show:

According to Figure 3, it gets data to analyze as TABLE 3.

By TABLE 3, it is clear that diagonal spiking increases ball landing flight distance, but meanwhile it also increases ball over net distance. It may have connections with environment in competition that can make reasonable spiking to opponent field.

CONCLUSIONS

The paper applies mechanical knowledge, mainly analyzes volleyball spiking technique, makes analysis of volleyball spiking moment takeoff, hitting and other motions, and utilizes moment of momentum theorem to research on volleyball spiking technique some rules with an aim to normalize volleyball spiking technique. By establishing geometric model, it concludes that when athlete spikes, he should try to manage to stretch arms to right ahead and remain vertical to hitting point, athlete take-off height gets higher, and ball over net probability would be larger; by ball located hitting point height differences, presented over net trajectory and landing point are also different, therefore according to hitting point vertical heights differences, the paper classifies (2.6, 2.7, 2.8, 2.9, 3.0, 3.1)six different heights phases to analyze. And according to athlete spiking release angle is not in 90°vertical incidence, and ball also does not vertical enter into opponent field such phenomenon, researches that spiking is certain angle hitting, ball oblique hitting and falling to opponent field position's differences. Spiking belongs to volleyball basic technique, and is also volleyball stronger aggressive segment. Make mechanical analysis of spiking is to build good foundation for future researching and making high efficiency competition strategic deployment.

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