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# Aerobics kick dynamical model and injury parts research

Junhong Yang
Sports Department, Tianjin Polytechnic University, Tianjin 300387, Tianjin, (CHINA)

## ABSTRACT

With social progress, people's life quality gradually improving, aerobics as a kind of sports event that can build up one's body and also nurture spirituality, it is favored by masses; in order to reduce people's body injury when taking aerobics training, the paper makes research and gets that aerobics players kick instant dynamical relations and right leg rotational inertia, it can get by above that aerobics players right leg generated potential energy's size when they make kick movement, and according to near-end to far-end transitive momentum theory, athletes can increase knee joint momentum by hip joint effective braking effects, and transfer momentum to ankle joint by knee joint braking, which plays a role in accelerating at the end. And get when aerobics players kick, due to it is required to let shank angular speed to be bigger than thigh angular speed to drive knee joint acceleration, when athletes land, ankle joint speed is too big and buffer time is too little that causes ankle joint injury rate to be higher and knee joint will also get injured, but relative to ankle joint, knee joint injury rate is lower. Therefore when broad masses take aerobics' kick training, they should focus on ankle joint and knee joint's protection.


## KEYWORDS

Dynamical analysis;
Rotational inertia;
Moment equation;
Mechanical transmission;
Sports injury.

## INTRODUCTION

Aerobics as a kind of sports event that can build up one's body and also nurture spirituality, due to it can build fitness and has good lose weight effects; it is favored by many women. By aerobics, it can not only build health body, but also let people's figure become more and more even and perfect at the same time of taking aerobics. Aerobics is originated in 1960s, but more exactly, it has prototype as earlier as above 2000 years ago. Ancient Greek people advocate building their body with each kind of throwing, running and jumping as well as other athletics events, gymnastics and aerobics. And ancient Indian yoga highlights human body postures and their own willpower together with breath mutual combination, by adjusting postures, breath and thought; it builds body's muscle groups so as to get the effects of building fitness and prolonging life. These are modern aerobics premise and basis.

Modern aerobics initially is physical training contents that are designed to astronauts by human race to pedal to space. And in 80s, with information globalization, aerobics as a kind of entertainment and fitness event has been rapidly developed in global and formed into fitness upsurge. Due to aerobics absorb lots of jazz, disco dance and break dance body movements, meanwhile it also mixes with many folk dance movements, it can be divided into lots of types. It mainly divides into competitive aerobics and fitness aerobics.

Competitive aerobics is athlete with accompaniments, making comparison between his completion movement difficulty coefficient and perfection; it requires athletes have relative high strength that constant shows high difficulty movement; in the whole process, it requires higher continuity, creativeness and music accompaniments conjunctions. Aerobics is mainly spread in the folks that used for people physical exercising and character molding. Therefore, movements from them are mostly simple and easy to learn, and rhythm is slower which are fit for every age phase people. Its main types can be divided into aero-Latino, hip-hop, kickboxing, gentle aerobics and aerobics so on. Though there are differences in types, property is to improve one's own physique, cultivate the mood, perfect figure and keep mental health so on. Aerobics requires that movements might as well to be standard and flexible and should have better sense of rhythm. Free gymnastics movements are aerobics basic movements, which are composed of head and neck, chest, waist, as well as upper and lower limbs these five parts, basic forms are extension, flexion, surrounding, rotating, swinging, lifting and shaking. Among them, they are showed as wave movements, swinging, flexion and extension, turning, circling, leapfrog and dance steps so on. The paper mainly analyzes and researches on aerobics leapfrog's kick.

## MODEL ESTABLISHMENT AND SOLUTION

### Aerobics pace basic steps

Aerobics pace basic steps is stipulated as seven that are respectively march, knee lift, kick, jog, skip, jumping jack and lunge. Among them, when athletes kick, they are firstly leaping, meanwhile another leg should stretch straight and kick in front or side, in kicking stage, it requires athletes to exert to accelerate and kick, and maintain upper body upright, waist erecting. Figures 1, Figure 2 are aerobics pace basic steps' whole process.

**Figure 1 : Athlete march, knee lift and kick**

### Aerobics kick dynamical analysis

Rotational inertia refers to a rigid body generated inertia measurement when it makes fixed-axis rotation surrounding axis, it is only related to rigid body's shape, mass and axis location, and is uncorrelated to angular speed and other parameters. When aerobics athlete kick, upper body is upright, leaping, meanwhile another leg stretch straight and kicks toward the front, in the process, it can regard athlete's right leg as rigid body that makes fixed-axis rotation surrounding hip joint, Figure 3 is athlete's right leg rotating schematic diagram.

Aerobics athlete generated rotational inertia is:

$$\mathbf{I = \Sigma M_i P_i^2}$$

But due to people each body part is continuous, regard aerobics athlete's body as mass continuous distribution rigid body, so:

$$\mathbf{I = \iiint_v P^2 dm = \iiint_v P^2 \rho dV}$$

Among them, $M_i$ is human body each part mass, athlete each part to axis distance is $P$, $\rho$ is human body density. Aerobics athlete right leg hip joint surrounding rotation's rotational tensor $\overleftrightarrow{L_c}$ is:

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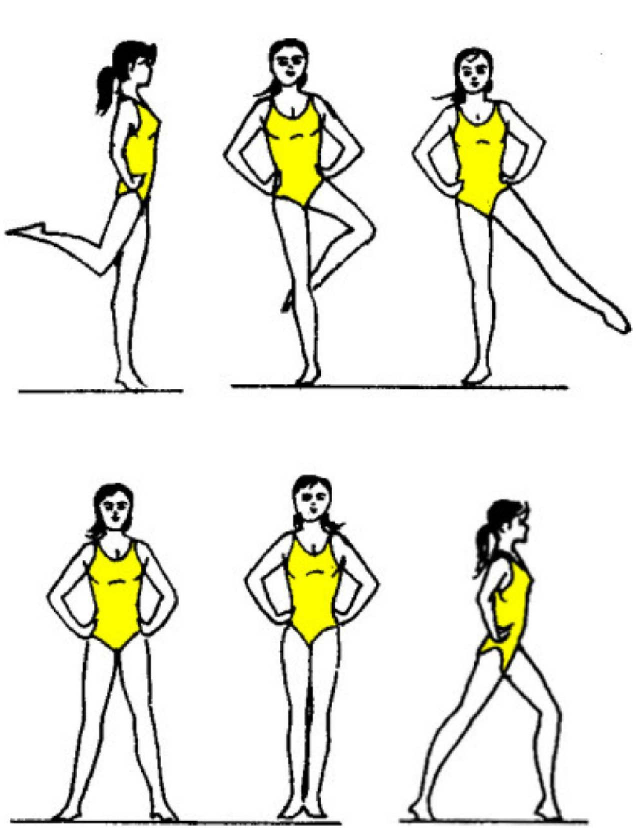

**Figure 2 : Athlete jog, side kick, jumping jack, and lunge**

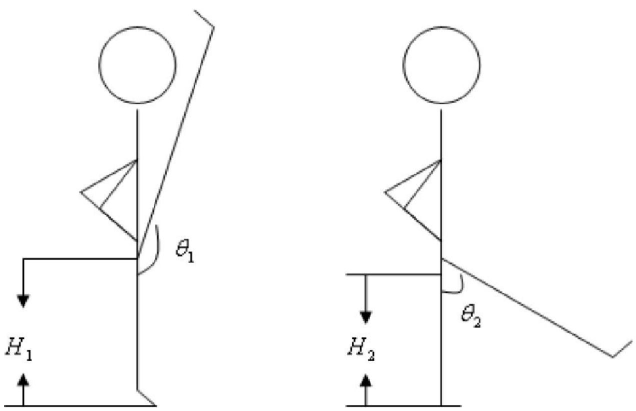


**Figure 3 : Athlete right leg fixed-axis rotation schematic diagram**

$$\overset{\leftrightarrow}{\mathbf{L}}_{\mathbf{c}} = \iiint_{\mathbf{v}} \rho(\mathbf{P}^2 \overset{\leftrightarrow}{\mathbf{E}} - \vec{\mathbf{P}}\vec{\mathbf{P}})\mathbf{dV}$$

In formula $\vec{P} = P_1 \vec{e}_1 + P_2 \vec{e}_2 + P_3 \vec{e}_3$ is athlete body any point $O$ radius vector; two vectors' product is $\vec{P}\vec{P}$; Athlete body's unit tensor is:

$$\overset{\leftrightarrow}{\mathbf{E}} = \begin{bmatrix} \mathbf{1} & & \\ & \mathbf{1} & \\ & & \mathbf{1} \end{bmatrix}$$

Therefore, unit orthogonal curvilinear frame is $(C; \vec{e}_1, \vec{e}_2, \vec{e}_3)$.

**Athlete kicking right leg rotational tensor moment equation**

When aerobics athlete is kicking, right leg hip joint surrounding rotation's resultant moment vector is $\sum \vec{v}_c$, $\vec{\omega}$ is athlete inertia rotating system's angular speed vector, angular accelerated speed vector is $\vec{\alpha}$, so when athlete is kicking, the rotational tensor moment equation is:

$$\sum \vec{\mathbf{v}}_{\mathbf{c}} = \overset{\leftrightarrow}{\mathbf{L}}_{\mathbf{c}} \bullet \vec{\alpha} + \vec{\omega} \times \overset{\leftrightarrow}{\mathbf{L}}_{\mathbf{c}} \bullet \vec{\omega}$$

Now project moment equation into three coordinate systems $x, y, z$ axis, which can see athlete right leg moment equation in each coordinate axis direction.

When athlete is kicking and hip joint drives right thigh to rotate, it will produce a resultant moment $T_1$, formula is as following:

$$\mathbf{T_1 = \varphi_1 \bullet I_1}$$

Among them, right thigh rotational inertia is $I_1$, $\varphi_1$ is right thigh angular accelerated speed. And :

$$\mathbf{I_1 = \frac{M_1 r_1^{\,2}}{2}}$$

$M_1$ is right thigh mass, $r_1$ is right thigh radius, right thigh angular accelerated speed $\varphi_1$ is:

$$\boldsymbol{\varphi_1 = \frac{dw_1}{dt} = \frac{d^2\theta_1}{dt^2}}$$

Then right shank final speed except for its own will generate angular speed, it has an initial angular speed that is right thigh angular speed $\varphi_1$, so angular shank angular speed $\varphi_2$ is:

$$\boldsymbol{\varphi_2 = \frac{dw_2}{dt} + \frac{dw_1}{dt} = \frac{d^2\theta_2}{dt^2} + \frac{d^2\theta_1}{dt^2}}$$

When aerobics athlete is kicking, generated gravity potential energy is:

$$\mathbf{W = mg(H_1 - H_2)}$$

Now establish athlete's whole right leg into three degree of freedom model that rotates around hip joint and knee joint, as Figure 4 show.

In Figure 4, $O$ point is hip joint, $O_1$ is knee joint, length of thigh and shank are respectively $l_1, l_2$, anatomic angles are respectively $\gamma_1, \gamma_2$. Among them, $O$ and $O_1$ are three degree of freedom, and trivector is

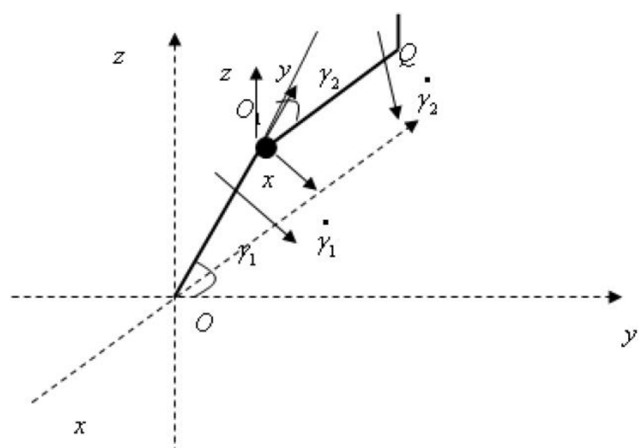


**Figure 4 : Athlete right leg rigid body rotation**

$\dot{\gamma}_1, \dot{\gamma}_2$.

Now take earth as reference system, $\dot{\theta}_1$ and $\dot{\theta}_2$ are athlete right thigh and shank's angular speed relative to reference system, knee joint speed is $\dot{\gamma}_2$, its size is:

$$\dot{\gamma}_2 = \dot{\theta}_2 - \dot{\theta}_1$$

By above formula, it can get when athlete is kicking, ankle angular speed is related to thigh shank angular speed and keen joint angular speed. Due to thigh and shank is rotating, it can get knee joint $O_1$ circular motion process, shank makes rotation and translation in relative coordinate system $O_1 - xyz$. And it is relative independent in rotation and translation that will not influence each other, so the two joints movement vectors sum is shank angular speed. Then $Q$ point speed is related to $Q$ point speed relative to inertia rotation system and node $O_1$ linear speed relative to reference system, that:

$$\vec{C}(\vec{O}_1)_G = \dot{\gamma}_1 \times \vec{Y}_1 = \dot{\theta}_1 \times \vec{Y}_1$$

$$C(\vec{Q})_L = \dot{\gamma}_2 \times \vec{Y}_2$$

In formula $\vec{C}(\vec{O}_1)_G$ is knee joint $Q$ speed vector in reference system, $C(\vec{Q})_L$ is $Q$ point speed relative to knee joint $Q$ point. $\dot{\theta}_1$ is right thigh rotational angular speed, $\dot{\gamma}_1, \dot{\gamma}_2$ are respectively hip joint $O$ and knee joint $Q$ angular speed, $\vec{Y}_1$ is hip joint to knee joint position vector, $\vec{Y}_2$ is knee joint to ankle joint position vector.

Solve $Q$ point relative to earth speed $\dot{q}_G = \vec{C}(\vec{Q})_G$, it should first solve thigh and shank partial movement influences on joints, and get according to vector theorem:

$$\dot{\mathbf{Q}}_G = \dot{\gamma}_1 \times \vec{\mathbf{Y}}_1 + \dot{\gamma}_2 \times \vec{\mathbf{Y}}_2 + \dot{\gamma}_1 \times \vec{\mathbf{Y}}_2$$

According to distribution rate, it gets:

$$\dot{\mathbf{Q}}_G = \dot{\gamma}_1 (\vec{\mathbf{Y}}_1 + \vec{\mathbf{Y}}_2) + \dot{\gamma}_2 \times \vec{\mathbf{Y}}_2$$

Simplify and get:

$$\dot{\mathbf{Q}}_G = \vec{\mathbf{Q}}_G \times \dot{\gamma}_1 + \dot{\gamma}_2 \times \vec{\mathbf{Y}}_2$$

Among them, $\dot{Q}_G$ is ankle joint position vector in reference system, cross product $\vec{Q}_G \times \dot{\gamma}_1$ is hip joint let ankle joint generated speed, and cross product $\dot{\gamma}_2 \times \vec{Y}_2$ is knee joint let ankle joint generated speed.

In order to more precise describe each joint and ankle joint speed relations, now it can write Figure 4 model joint angle and ankle joint positions relations as:

$$\begin{cases} \mathbf{x_p = Y_1 \cos\gamma_1 + Y_2 \cos(\gamma_1 + \gamma_2)} \\ \mathbf{y_p = Y_1 \sin\gamma_1 + Y_2 \sin(\gamma_1 + \gamma_2)} \\ \mathbf{z_p = Y_1 \cos\gamma_1 + Y_2 \sin(\gamma_1 + \gamma_2)} \end{cases}$$

Classify hip joint and knee joint angles into infinitely small displacements, and relations with ankle joint positions vectors can get by above formula derivation:

$$\begin{cases} dX = \frac{\partial X(\gamma_1,\gamma_2)}{\partial\gamma_1}d\gamma_1 + \frac{\partial X(\gamma_1,\gamma_2)}{\partial\gamma_2}d\gamma_2 \\ dY = \frac{\partial Y(\gamma_1,\gamma_2)}{\partial\gamma_1} + \frac{\partial Y(\gamma_1,\gamma_2)}{\partial\gamma_2}d\gamma_2 \\ dZ = \frac{\partial Z(\gamma_1,\gamma_2)}{\partial\gamma_1} + \frac{\partial Z(\gamma_1,\gamma_2)}{\partial\gamma_2}d\gamma_2 \end{cases}$$

Write above formula into matrix form is:

$$\begin{pmatrix} dX \\ dY \\ dZ \end{pmatrix} = \begin{pmatrix} \frac{\partial X(\gamma_1,\gamma_2)}{\partial\gamma_1} & \frac{\partial X(\gamma_1,\gamma_2)}{\partial\gamma_2} \\ \frac{\partial Y(\gamma_1,\gamma_2)}{\partial\gamma_1} & \frac{\partial Y(\gamma_1,\gamma_2)}{\partial\gamma_2} \\ \frac{\partial Z(\gamma_1,\gamma_2)}{\partial\gamma_1} & \frac{\partial Z(\gamma_1,\gamma_2)}{\partial\gamma_2} \end{pmatrix} \begin{pmatrix} d\gamma_1 \\ d\gamma_2 \end{pmatrix}$$

By matrix attributes and vector product method, it can write above formula into: $d\vec{Q}_G = \vec{D}d\vec{\gamma}$, from which $\vec{D}$ is:

$$\vec{D} = \begin{pmatrix} \frac{\partial X}{\partial\gamma_1} & \frac{\partial X}{\partial\gamma_2} \\ \frac{\partial Y}{\partial\gamma_1} & \frac{\partial Y}{\partial\gamma_2} \\ \frac{\partial Z}{\partial\gamma_1} & \frac{\partial Z}{\partial\gamma_2} \end{pmatrix}$$

$\vec{D}$ is current structure infinitely small node angular displacement and ankle joint infinitely small displacement relations. Input matrix relations into above formula and can get: $\frac{d\vec{Q}_G}{dt} = \vec{D}\frac{d\vec{\gamma}}{dt}$ or is $\vec{Q}_G = \vec{D}[\dot{\gamma}_1, \dot{\gamma}_2]^T$, input it into ankle joint relative speed computational formula and can get:

$$\dot{Q}_G = \begin{pmatrix} \frac{\partial X}{\partial\gamma_1} & \frac{\partial X}{\partial\gamma_2} \\ \frac{\partial Y}{\partial\gamma_1} & \frac{\partial Y}{\partial\gamma_2} \\ \frac{\partial Z}{\partial\gamma_1} & \frac{\partial Z}{\partial\gamma_2} \end{pmatrix} [\vec{\gamma}_1, \vec{\gamma}_2]^T \dot{\gamma}_1 + \dot{\gamma}_2 \times \vec{Y}_2$$

By above formula analysis, it can get when aerobics athlete is kicking, he should try to speed up legs speed so that can let $Q_G$ vertical direction projection speed to be accelerated to maximum value, and according to matrix vector theorem, it is clear only when $\gamma_1, \gamma_2$ meet constraint condition $45° < \gamma^1 + \gamma^2 < 90°$, $0 < \dot{\gamma}_1 < \dot{\gamma}_2$, ankle joint speed can get maximum value in sagittal plane. That let athlete kicking movement preliminary phase left thigh and left shank descending flex should try to not surpass $45°$, and its anatomic angle changing speed should be fast so that can arrive at muscle mechanics muscle relaxation feature. If legs descending flex is too big that will cause muscle relaxation due to muscle time contracting.

And because when $\gamma_1, \gamma_2$ meet its constraint conditions, $\dot{\gamma}_1$ and $\dot{\gamma}_2$ increase, when aerobics athlete is kicking, it should let athlete thigh and shanks anatomic angle change rate arrive at maximum value in unit time, and also require athlete shank anatomic angle change rate to be bigger than thigh angle change rate during the process. By rigid body transferability, it can know that when right leg is off the ground, right thigh and shank are nearly in $180°$, force transfers to thigh along thigh axis, but due to thigh and shank are connected, and then it will lead to force attenuation, therefore shank angular speed bigger than thigh angular speed is more beneficial to knee joint acceleration.

By above analysis, it can get when aerobics athlete is kicking, due to it should let shank angular speed to be bigger than thigh angular speed to drive knee joint acceleration, when athlete is landing, ankle joint speed is too big and buffer time is too little that causes ankle joint injury rate to be higher, and knee joint will also get injured, but relative to ankle joint, knee joint injury rate is slightly lower.

## CONCLUSIONS

By researching, the paper gets that aerobics players kick instant dynamical relations and right leg rotational inertia, it can get by above that aerobics players right leg generated potential energy's size when they make kick movement, and according to near-end to far-end transitive momentum theory, athletes can increase knee joint momentum by hip joint effective braking effects, and transfer momentum to ankle joint by knee joint braking, which plays a role in accelerating at the end. Therefore shank angular speed should try to be bigger than thigh angular speed so that it will more beneficial to knee joint acceleration. And get when aerobics players kick, due to it is required to let shank angular speed to be bigger than thigh angular speed to drive knee joint acceleration, when athletes land, ankle joint speed is too big and buffer time is too little that causes ankle joint injury rate to be higher and knee joint will also get injured, but relative to ankle joint, knee joint injury rate is lower.

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