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# Mathematical analysis of rotational dynamics on rotation techniques in the Martial arts

**Hu Wang**

**Institute of Physical Education, JiangSu Normal University, Xuzhou 221116, Jiangsu, (CHINA)**

**E-mail: tiyuxi@qq.com**

## ABSTRACT

Martial arts action takes the jumping, balance, leg technique, hand technique and other actions as the main elements; the whole body coordinated and formed the climax part of the routine exercise. Meanwhile a lot of actions in martial process will involve rotation, such as roton kick, 720° swivel and so on. This paper takes Newton's laws of motion as a starting point, uses mathematical and statistical analysis method, depicts and analyzes the mechanical state of the rigid body during rotation process, including the total energy, rotational kinetic energy and moment of inertia during the motor process, combining with the case in actual game process, and puts forward a number of problems athletes should pay attention to in the rotational dynamics aspect.



## KEYWORDS

Dynamics;
Martial arts;
Rotation;
Mathematics;
Statistics.

## INTRODUCTION

In martial arts a variety of boxing technique and leg technique have a high demand for explosiveness and flexibility, especially the larger motion range of each joint has a very good workout action on muscle ligaments. Martial arts includes a variety of twisting, pitch, retract, fold and other actions, calling for "hand-to-eye to", "hand-eye hand in hand", "step-go with the body, step into the body", "hand-eye agility step, step eye agility together" and higher coordination requirements; The entire exercise movements are often composed by dozens of actions, and can complete in a certain period of time, so various organ systems of the body can get the comprehensive development. Exercise gentle, slow, brisk boxing, such as tai chi, emphasizing guiding the action by intention, with even and deep breathing, can make the blood circulation of the whole body, which is suitable for patients with chronic diseases as a medical means to adhere to exercise, and has a more significant effect. Confrontational athletic events like San hands push hands, martial arts short weapon and martial arts length weapon are intense sports, in addition to enhancing physical fitness, but also developing courage, quick wit, agility and other fine character. In recent years, with the growing popularity and development of martial arts, there is growing emphasis on the aspects of mechanical nature and function of martial arts.

Yao Chun-hong discussed dynamic Analysis of side kick and teaching methods in martial arts, from the two aspects of physiology and biomechanics, conducted the comprehensive analysis on the side kick in the martial arts, combined with practical experience in teaching, essentially clarified the force principle of side kick in martial arts, has a good guidance on martial arts teaching and training. Ma Wen-hai conducted biomechanical analysis on roton twist and taking down fork technique in martial arts, used the principles and methods of three-dimensional video DLT law and biomechanics, analyzed on 4 master grade athletes' roton twist and taking down fork action, provided theoretical basis and technical parameters for the technological innovation and difficulty innovation of martial arts action. Ma Wentao in the applications of biomechanics principles and research methods in the research of martial arts, through consulting relevant literature, analyzed the application situation of biomechanics principles and research methods in the research of martial arts, described the application of sports biomechanics principle in the martial arts specifically from kinematics, dynamics, rotational kinetics, balance mechanics and other aspects, introduced the applications of biomechanics research methods in the Martial Arts research from the kinematics measurement method, kinetic measurements methods, biological measurement methods and computer movement simulation technology and other aspects.

This paper analyzed and studied the mechanical properties during rotation of the rigid body, introduced rotational kinetics into actual match for martial arts athletes, and pointed out some mechanical problems that the athletes should notice during the race.

## ROTATIONAL KINETIC ANALYSIS OF THE CONTINUOUS ACTION IN MARTIAL ARTS COMPETITIONS

Martial arts dynamics is still based on Newtonian mechanics, and this paper uses mechanics research methods. It should be noted that due to the body's structure, functional status, psychological factors, mental status and other factors plays a very important role on the effect of the human body movement offset, and it is essentially different from the mechanical movement of non-life entity. Some of the biology factors are still unable to be quantitatively described. Only through some direct or indirect measurements can get some indicators reflecting the biological characteristics; analyze and draw some qualitative conclusions. Hence, there are some limitations using the kinetic theory to analyze human motion. For simplicity, in martial arts studies the human body is often simplified as particle or rigid body. Of course, in the study of practical problems, we need to consider its limitations.

### The dynamics principle in Martial arts

The application of dynamics in the martial arts is primarily based on Newtonian mechanics. Newtonian mechanics think that mass and energy exist independently, and respectively conservation, it applies only to the situation when the movement of objects is much smaller than the speed of light speed. Newtonian mechanics use more intuitive geometric approach; in solving simple mechanical problems, it is much convenient and simple than analytical mechanics.

Among this the most widely used is Newton's second law of motion. Newton's second law is with vector nature. Parameter *F* is the vector sum of each force on the particle. Acceleration *a* is acceleration co-produced by external force on the particle, changing the state of motion or velocity of the objects, but this change is related with the state of motion of the object itself. We have equation F = ma.

Wherein: F is combined force; *m* Stands for quality; *a* Stands for acceleration;

In dealing with the problem, often use their components. In a Cartesian coordinate system,

$$F_x = ma_x = m\frac{d_x^2}{dt^2};\ F_y = ma_y = m\frac{d_y^2}{dt^2};\ F_z = ma_z = m\frac{d_z^2}{dt^2}$$

In the natural coordinate system:

$$F_\tau = ma_\tau = m\frac{d_v^2}{dt^2};\ F_n = ma_n = m\frac{v^2}{\rho}$$

When the athletes are in movement, the kinetic energy that athletes have is $E_{k1}$, gravitational potential energy that athletes have is $W_1$, the total energy of the system is $E_1$, its gravitational potential energy is $E_{T1}$. Its value is shown in the following formula:

$$\begin{cases} E_{k1} = \frac{1}{2}mv_1^2 \\ W_1 = mgh \\ E_{T1} = 0 \\ E_1 = E_{k1} + W_1 \end{cases}$$

Dynamics is the science studying the relationship between the mechanical movement of objects and the force. In martial arts, various parts of the athlete body are in motion, the speed and the form of movement is constantly changing. According to mechanics, any object movement or velocity changes are implemented under the force. Force is the reason to change the object's (human) motion state. Since people live in natural environment, the body is in force either at rest or exercise. Under force, the motion state of the human body and exercise equipment driven by the people will change on the value and direction. In order to reveal the cause of movement and the changing situation, we must study the dynamics characteristic of movement. All human actions, such as translational motion like the level boxing sports of martial arts, rotational motion like kicks, jump motion like vacated flying kick, flip action like cartwheel, etc., are all achieved under force, are overall coordination results of internal forces and external forces. For body movement, on the one hand muscle strength (i.e. force) plays a leading role, on the other hand subject to the laws of mechanics; under the joint action of the two it forms complex martial arts actions. Martial arts dynamics is still based on Newtonian mechanics, and uses mechanics research methods. It should be noted that due to the body's structure, functional status, psychological factors, mental status and other factors plays a very important role on the effect of the human body movement offset, and it is essentially different from the mechanical movement of non-life entity. Some of the biology factors are still unable to be quantitatively described. Only through some direct or indirect measurements can get some indicators reflecting the biological characteristics; analyze and draw some qualitative conclusions. Hence, there are some limitations using the kinetic theory to analyze human motion. For simplicity, in martial arts studies the human body is often simplified as particle or rigid body. Of course, in the study of practical problems, we need to consider its limitations.

## The application of rotational dynamics principle in the Martial arts

In the research of mechanical movement of the body, the body has shape and size; it can do translation, rotation, and even more complex motion. The shape change of the bone constituting the human body in motion part is not significant. Therefore in the research of the rotation of the body, without considering the deformation of human muscle and other soft tissue, every segment of the human body can be simplified as a rigid body, that is only consider the size of each segment in motion, regardless of the deformation of each segment, so that the body can be seen as a rigid body system composed of several rigid bodies. The translational motion of rigid body can be treated as a particle. This chapter mainly studies the rotation movement after human body simplified as rigid system, as well as the application of rotation principle in martial arts. Various aspects of human movement is rotating around the joint axis; the body's walking, running, jumping and other actions are implemented through the rotation of the link. So the rotation of various aspects of the human body is the basis of human movement. In martial arts, such as the roton rotation, tai chi Se "circle" and a variety of flip action, some belong to the rotation of the entire human body; some belong to the rotation of the local limb movements. Rotational movement is widespread in Martial Arts.

### (a) The translational and rotational motion in Martial arts

If in the motion process, the position of any straight lines in the rigid body at all times is always parallel to each other, then this movement has become a translational motion. Obviously during translational motion, motion of any point in the rigid body can be representative of the whole rigid body movement, as shown in Figure 1:

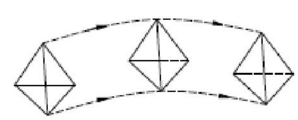

**Figure 1 : The translational motion of rigid body**

In the field of martial arts, we are dealing with rotation of a rigid body, like roton rotation and kicking and so on. For rotation, we define each particle of the rigid body carry through circular movement around the same line; this movement is called rotation, as shown in Figure 2:

In order to better describe the rotation, the angular velocity vector $\varpi$ is the introduced and its size is $\frac{d\theta}{dt}$, the line velocity of any element P on the above rigid can be expressed by angular velocity as:

$v = \varpi \times r$

On the basis of the angular velocity vector, as the angular velocity vector $\alpha$: $\alpha = \frac{d\varpi}{dt}$

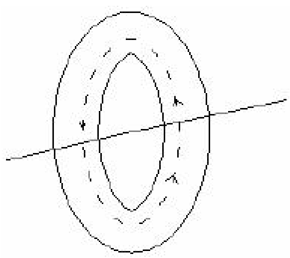

**Figure 2 : The rotational motion of rigid body**

In the fixed axis rotation of rigid body, the rotation speed of the rigid body goes faster, and then $\alpha$ is in the same direction with $\varpi$. The rotation speed of the rigid body goes slower, and then $\alpha$ is in the opposite direction with $\varpi$.

### (b) Rotational kinetic energy of Martial arts athletes

Rigid body moves with angular $\varpi$, rigid body is seen as a system composed of individual particles, suppose the displacement vector of the $i$–th mass point $P_i$ is $r_i$, the mass is $\Delta m_i$, the speed is $v_i$, and its kinetic energy is:

$$E_{ki} = \frac{1}{2}\Delta m_i v_i^2 = \frac{1}{2}\Delta m_i r_i^2 \varpi^2$$

The kinetic energy of the entire rigid body is:

$$E_{ki} = \sum_i \frac{1}{2}\Delta m_i v_i^2 == \frac{1}{2}(\sum_i \Delta m_i r_i^2)\varpi^2$$

Wherein $\sum_i \Delta m_i r_i^2$ is the moment of inertia of a rigid body which can be written as: $E_k = \frac{1}{2}J\varpi^2$

In the formula: $J = \sum_i \Delta m_i r_i^2$

The moment of inertia is shown in Figure 4:

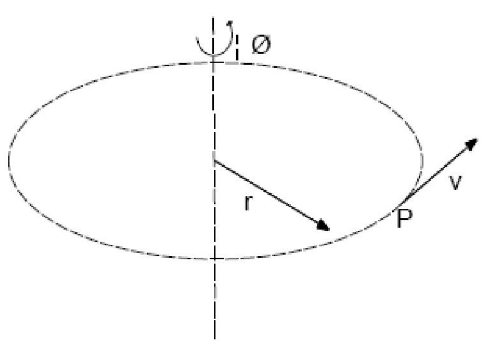


**Figure 3 : The motion of particle P**

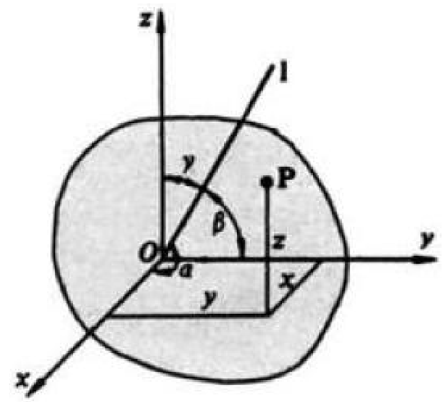


**Figure 4 : The moment of inertia of a rigid body**

Moment of inertia is the inertia measurement of a rigid body rotated around the axis (the rotation object maintains its uniform circular motion or stationary characteristics), indicated with letters I or J. Its value depends on the shape of the object, the mass distribution and the position of the shaft. Moment of inertia of a rigid body has an important physical meaning, is also an important parameter in scientific experiments, engineering, aerospace, electrical, mechanical, instrumentation and other industrial areas.

Moment of inertia depends only on the shape of the rigid body, mass distribution, and position of the shaft, and has nothing to do with the rotation state of rigid body around the axis (such as the size of the angular velocity). For homogeneous rigid body with regular shape, its moment of inertia can be directly calculated by equation. For non-homogeneous rigid body with irregular shape, its moment of inertia is generally measured through experimental method, and thus experimental method is very important. Moment of inertia can be applied to the dynamics calculations of a variety of rigid body movement.

Expression for the moment of inertia is $I = \sum mi * ri^2$. If the rigid body's mass is a continuous distribution, the calculation formula of the moment of inertia can be written as: $I = \int r^2 dm = \int r^2 \rho dv$

Wherein: mi represents a qualitative element's mass of the rigid body, ri indicates the vertical distance from the qualitative element to the axis, $\rho$ means the density of this point.

Dimension of the moment of inertia is in the system of SI units, and the unit is $kg \cdot m^2$.

If an athlete has large weight and thick limbs, it is not easy to complete this action. Ideal routine athletes should have small figure, relatively stout trunk, more slender upper limbs and more thick lower limbs. For these martial arts athlete's theoretical analysis based on biomechanics is ideal. Small figure can successfully complete many difficult Martial Arts actions like tuck, flip action; sturdier trunk can give a powerful feeling. It also does not increase the moment of inertia, you can easily complete the air rotation and other movements; Slender limb can better reflect the effects of flowing, elegant, long and distant. The lower limbs are shorter and rough, which can ensure the stability of the action and sufficient strength, but does not affect the speed of jump, leap and dexterity. By studying and observations we find that the height of male martial arts athletes is 160~179 *cm*, female athletes is 150~160 *cm*, as well as finger span and height can also be used as indicators to evaluate the relative length of the upper limb. However, how to establish a more appropriate method about selection of martial arts athlete through biomechanics indicators has not yet perfect, biomechanics researchers need to conduct in-depth research in this area.

### (c) Torque and angular momentum conservation law

For a rigid body rotation around a fixed axis, the impact of external force on rotation state is related with not only the size of the force, but also the direction and the action position of the force. If the direction of the force is along the axis's direction or force line is intersect with the shaft, and then in any case it cannot change the fixed axis rotation state of the rigid body. We can decompose $F$ into components $F_1$ and $F_2$ within the plane of rotation, as shown in Figure 5:

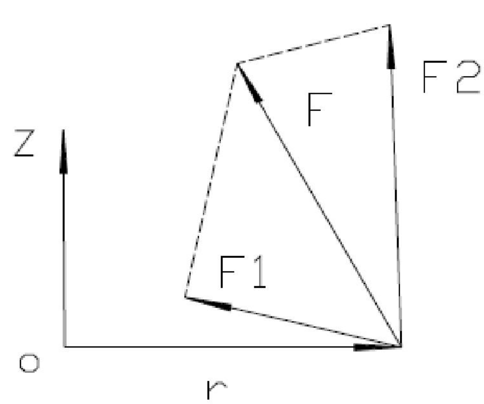


**Figure 5 : Schematic figure of torque**

The torque of force $F$ acting on a rigid body is $M = r \times F = r \times (F_1 + F_2)$. Due to the shaft is parallel to $F_2$, its role is being offset by the constraint action of the shaft, and we only consider the effect of force on the rigid body in the rotational plane.

Suppose the external force $F$ acts at point P, is the displacement vector of P, the vector product of displacement vector $r$ and force $F$ is defined as the torque of force $F$ on the shaft O*z*, represented with $M$, i.e. $M = r \times F$, its size is: $M = rF \sin \varphi$

Wherein $\varphi$ is the angle of $F$ and $r$. The direction of $M$ is the direction of the vector product ($r \times F$). Suppose the $n$ forces act on a rigid body at the same time, the *i*-th force $F_i$ is applied to the point $P_i$, the displacement vector of the point $P_i$ is $r_i$, and the angle of $r_i$ and $F_i$ is $\varphi_i$, the torque of $F_i$ on shaft is $M_i = r_i F_i \sin \varphi_i$ then the combined external torque rigid body suffered is:

$$M = \sum_i M_i = \sum_i r_i F_i \sin \varphi_i$$

The total external torque of fixed axis is equal to the torque algebraic sum of each external force.

If the combined external torque rigid body suffered is $M = 0$, then have: $L = J\varpi$=constant

This is the angular momentum conservation law of rigid body rotation around a fixed axis. It stated that when the total external torque is zero, the angular momentum of the rigid body remains unchanged, in particular when $J$ is constant, the angular velocity does not change with time. In a more extensive study of particle, if combined external torque M = 0, there will be: L= constant

In martial arts competition, aerial body movements of whirlwind rotation 720° to horse stance action become an important factor affecting twist. Analysis from the Perspective of Sports Biomechanics: the human body goes into the flight phase, the body only suffers gravity (ignoring air resistance); regardless of how complicated the form of aerial action is, we must follow the law of angular momentum conservation. ($L = J\varpi$=constant), that is, the product of moment of inertia and the angular velocity is conservation. It is thus clear that the vacated state in order to speed up the twist's angular velocity, we can only change the rotational inertia. Thus, only by changing the body position in the air can athletes reduce the body's moment of inertia, revving, and complete 720° swivel.

## CONCLUSIONS

Through the mathematical analysis of rotational dynamics, we can better understand the effect of forces on the object movement, which provides a good theoretical support for college martial arts athletes training and stability play during the race; meanwhile with this principle, it can better train the comprehensive ability of martial arts athletes.

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