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Biomechanical analysis-based aerobics athletes' athletic ability fuzzy comprehensive evaluation

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ABSTRACT

The paper firstly applies Lagrange equations to solve restricted particle kinetic equations, combines with theoretical formulas to analyze athlete hand joint mechanical movement, and combines with shoulder joint, elbow joint mechanical analysis to study on aerobics taking-off, rotation and other motions. Establish fuzzy comprehensive evaluation model, define weights, and then establish fuzzy relation matrix, finally calculate. Result shows that aerobics cooperative ability occupies 30%, innovation attainment occupies 25%, and aesthetic level occupies 18%. Among them, cooperative ability, innovation attainment, and aesthetic level belong to humanistic education and cultivation range, the paper can clearly get that aerobics such event is a kind of sports discipline with stronger cultural atmosphere.

KEYWORDS

Lagrange equations;
Fuzzy comprehensive evaluation;
Aerobics;
Biomechanics.

INTRODUCTION

Chinese aerobics undertakings are rapidly developing, research on the aspect of aerobics basic mechanics are fewer; the paper carries out mechanical research on aerobics according to aerobics difficulty rules, until 2000, China totally published above 1000 pieces of aerobics papers and textbooks as well as works, which indicated Chinese research on aerobics was gradually developing, and gradually formed into system. By mechanical researching, it explored inherent law and biological motion law. It included sportsmen movement speed and body each part muscle movement, movement technical expression of technique is equal to action form. As TABLE 1 show.

Secondly, according to international aerobics judgment criterion, as TABLE 2, analyze an aerobics athlete or an aerobics team, utilize evaluation model to calculate.

MODEL ESTABLISHMENTS

By Lagrange equations, the paper gets restricted particle kinetic equations, from which Lagrange function L is difference generated between system kinetic energy K and potential energy P : $L = K - P$

System kinetic equation is: $F_i = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i}\right) \quad i = 1,2,\ldots,n$

In above formula, $\dot{q}_i$ is corresponding speed, q_i is kinetic energy and potential energy coordinate, F_i is

TABLE 1 : Classification of competitive aerobics elements of difficulty

Classification of aerobics elements of difficulty	Dynamic motion	Jumping type	
		Twisting type	
		Inverting type	
		Leg swinging type	
		Picked type	
	Static posture and vigorous motion	Vigorous motion	
		Static posture	Balance
			Support
			Split
			Lift

TABLE 2 : International aerobics competition rules' difficulty table

Type of group	Motion	Quantity	Highest difficulty value
A	Group push up	27 pieces	0.7
	Free fall	29 pieces	0.8
	Leg circle and cut	18 pieces	0.6
B	Group support type	39 pieces	0.8
C	Group jumps and leaps	164 pieces	0.9
D	Group flexibility and various	30 pieces	0.6

the i coordinate acting force, thigh and shank included angles with coordinate axis are respectively θ_1, θ_2, lengths are respectively l_1, l_2, distances that arm front and back gravity center position from elbow joint center and knee joint center are respectively p_1, p_2, thereupon it is clear that arm gravity center coordinate $(X_1, Y_1)$is:

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

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

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

Write above formula into Lagrange function expression, by Lagrange system kinetic equation, it can get hip joint and knee joint moment 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:

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

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

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

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

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

$$D_{122} = -m_2 l_1 p_2 \sin\theta_2 , \quad D_{211} = m_2 l_1 p_2 \sin\theta_2 ,$$

$$D_{112} = -2 m_2 l_1 p_2 \sin\theta_2 , \; D_{212} = D_{122} + D_{211}$$

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

Combine with theoretical formula, analyze aerobics athlete hand joint mechanical movement, and combine with shoulder joint, elbow joint mechanical analysis.

Establish moment of momentum theorem model

When apply mechanical conservation law to solve problems, firstly it should select reasonable research objects, and make correct force analysis of researched objects, secondly on the basis of force analysis, reference conservation law to check problem, finally according to conservation law, establish equation and solve problems.

Set I is one rigid body rotational inertia, it suffers moment M acting, among them, angular accelerated speed β is constant, the rigid body at t_1 instant angular speed is ω_1, rigid body at t_2 instant angular speed is ω_2, it gets: $M = I\beta = I\dfrac{\omega_2 - \omega_1}{t_2 - t_1}$

Deform 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 impulsive moment variable quantity is equal to moment of momentum variable quantity.

In moment of momentum theorem, time and moment product is equal to impulsive moment; it represents object rotational accumulative effect under external force moment effects. Angular speed and rotational inertia product is state when rigid body rotates. With external force moment increasing and acting time enlarging, rigid body rotational state changes are increasing accordingly.

When human body moves, human body generated rotational inertia is changing, due to rotational variable changes, different time rotational inertia is different, set t_1 instant rotational inertia is I_1, t_2 moment rotational inertia is I_2, therefore, above formula can be changed as: $M(t)(t_2 - t_1) = I_2\omega_2 - I_1\omega_1$)

For human body sports rules, it should meet: $I\omega = 0, \sum M\Box t = 0$

Now it enters into soaring phase, if human body meets: $I_1\omega_1 + I_2\omega_2 = 0$

In addition, it should also meet that human body rotates around $I_1\omega_1$, then tennis service sports form is lengthwise relative movement, during sports process, human body moment of momentum vectors sum is 0, according to correlation law, we get that human body will suffer a reactive force that let people to generate moment of momentum, so that reduce sports process strength size, so it is bad for sports stability, but if in sports process, due to body each part suffered active force effects, it causes rotational inertia increasing, so that it will generate an advancing moment of momentum effect, according to energy conservation law, we know that now human body similarly will generate a reactive force effect, so that let human body to move relative to ball, so that increase arm swinging distance, concentrate whole body strength to serve.

In whole sports process, each limb will generate moment that on the opposite direction but size is the same, and every pair can offset, when athlete lands, sole part rapidly lands to support the whole body, and meanwhile it will occur to abdomen contraction, knees bending and others to buffer diminished strength to make preparation for next motion.

In the air, angular speed changes, when moment of momentum remains unchanged, rotational inertia will reduce with angular speed increasing, when moment of momentum remains unchanged, rotational inertia will reduce with angular speed increasing, when athlete jumps and soars, athlete himself can further control rotational angular speed by changing self-rotational inertia. When athlete takes off and arrives at highest point, athlete should try to adjust body stability, let rotational angular speed to reduce as much as possible, now, athlete should raise two legs backward, let gravity center to be far away from rotational axis, and arrive at state of steady movement.

Fuzzy comprehensive evaluation model summary

Fuzzy mathematics development has already 40 years history up to now, though is a kind of relative new discipline, it has extremely rich contents in theory, and fuzzy mathematics involves natural science, social science and other disciplines. Due to evaluation is a kind of human thinking process, it is not changing in linear, and fuzzy evaluation matrix is a kind of important evaluation method.

Utilize fuzzy comprehensive evaluation, steps are as following:

(1) Establish factor set $U : U = (U_1 \quad U_2 \quad \cdots \quad U_k)$

(2) Establish judgment set V (evaluation set);

(3) Establish fuzzy mapping from judgment matrix U

to judgment matrix V, it gets fuzzy relation as matrix R shows: $R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$

(4) Establish weight set $A=(a_1,a_2,\cdots,a_n)$, it meets conditions: $\sum_{i=1}^{n} a_i = 1 \quad a_i \ge 0$

(5) Fuzzy relation R every line reflects the line influence factors to object judgment extent, and meanwhile, R every column reflects the column influence factors to object judgment extent.

$$\sum_{i=1}^{n} r_{ij} \quad j=1,2,3,\cdots,m$$

$$B=A\cdot R$$

$$=(a_1,a_2,a_3,\cdots,a_n)\cdot\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$

$$=(b_1,b_2,b_3,\cdots,b_n)$$

In V, fuzzy combination is evaluation set B. Based on above described facts, actual change model is:

As Figure 1 show, it gets fuzzy comprehensive evaluation change model, and can establish corresponding every factor grade evaluation transformation function, evaluation factors U_1, U_2, U_3, U_4 membership functions can be expressed as following:

$$u_{v1}(u_1)=\begin{cases} 0.5(1+\frac{u_i-k_1}{u_i-k_2}), & u_i \ge k_1 \\ 0.5(1-\frac{k_1-u_i}{k_1-k_2}), & k_2 \le u_i < k_1 \\ 0 \quad , & u_i < k_2 \end{cases}$$

$$u_{v2}(u_1)=\begin{cases} 0.5(1-\frac{u_i-k_1}{u_i-k_2}), & u_i \ge k_1 \\ 0.5(1+\frac{k_1-u_i}{k_1-k_2}), & k_2 \le u_i < k_1 \\ 0.5(1-\frac{u_i-k_3}{k_2-k_3}), & k_3 \le u_i < k_2 \\ 0.5(1-\frac{k_3-u_i}{k_2-u_i}), & u_i < k_3 \end{cases}$$

$$u_{v1}(u_1)=\begin{cases} 0, & u_i \ge k_2 \\ 0.5(1-\frac{k_1-u_i}{k_2-k_3}), & k_3 \le u_i < k_2 \\ 0.5(1+\frac{k_3-u_i}{k_2-u_i}), & u_i < k_3 \end{cases}$$

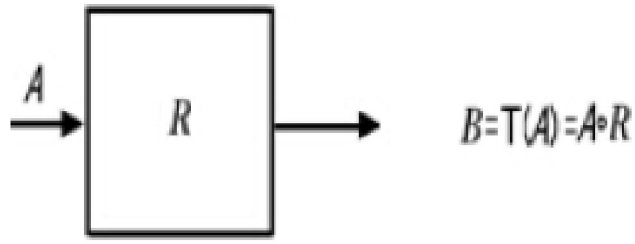

Figure 1 : Change model

Combine with fuzzy evaluation model to evaluate aerobics athlete

Establish factor set U, $U=(U_1 \ U_2 \ U_3 \ U_4)$. Among them, aesthetic level U_1, cooperative ability U_2, physical training U_3, innovation attainment U_4, it gets TABLE 3.

By TABLE 3listed factors, it gets evaluation set:

$$U_1=\{u_{11},u_{12},u_{13},u_{14}\}$$

$$U_2=\{u_{21},u_{22},u_{23},u_{24},u_{25}\}$$

$$U_3=\{u_{31},u_{32},u_{33}\}$$

$$U_4=\{u_{41},u_{42},u_{43},u_{44}\}$$

By collecting data and analyzing, it gets four kinds of factors importance ranking statistics, as TABLE 4 show.

By sorting out TABLE 4, it gets aesthetic level, cooperative ability, physical training, innovation attainment four aspects rank matrix:

$$U_2=\{23,7,4,0\}$$

$$U_2=\{7,18,8\ 0\}$$

$$U_3=\{0,9,13,12\}$$

$$U_4=\{3,0,9,21\}$$

Obtained weighted vector from rank 1 to rank 2: $\beta=\{\beta_1,\beta_2,\beta_3,\beta_4\}=\{0.4,0.3,0.2,0.1\}$

$$U_i^*=U_i\cdot\beta^T$$

$U_1^*=12$, $U_2^*=9.7$, $U_3^*=6$, $U_4^*=5$

The paper takes normalization processing: $U_1^*=0.35$, $U_2^*=0.3$, $U_3^*=0.2$, $U_4^*=0.15$

It gets: $\bar{A}=(0.35 \quad 0.3 \quad 0.2 \quad 0.15)$

By aerobics performance, it gets remarks membership, as TABLE 5 shows.

TABLE 3 : Aerobics athlete evaluation indicator system

Aesthetic level U_1	Cooperative ability U_2	Physical training U_3	Innovation attainment U_4
Motion aesthetics u_{11}	Tactics strategies u_{21}	Endurance u_{31}	Motion innovation u_{41}
Music aesthetics u_{12}	Judgment u_{22}	Speed u_{32}	Formation innovation u_{42}
Formation design u_{13}	Reaction ability u_{23}	Strength u_{33}	Team shirts、 music u_{43}
Team shirts designing u_{14}	Competition experiences u_{24}	Flexibility u_{34}	
Members training u_{15}			

TABLE 4 : Four kinds of factors importance degree ranking statistics

Classification	Rank1	Rank 2	Rank 3	Rank 4
Aesthetic level U_1	23	7	4	0
Cooperative ability U_2	7	18	8	0
Physical training U_3	0	9	13	12
Innovation attainment U_4	3	0	9	21

TABLE 5 : Remarks membership

Evaluation way	Set scores interval			
	0-60	60-80	80-90	90-100
Very good	0	0	0.05	0.95
Good	0	0.05	0.9	0.05
Normal	0.05	0.9	0.05	0
Bad	0.95	0.05	0	0

By one aerobics athlete each indicator obtained evaluation, it gets TABLE 6.

By above model, it gets single layer indicator weight factor fuzzy set is:

$$U_1^* = \{U_{11}, U_{12}, U_{13}, U_{14}, U_{15}\} = \{0.25\ 0.25\ 0.2\ 0.15\ 0.15\}$$

$$U_2^* = \{U_{21}, U_{22}, U_{23}, U_{24}\} = \{0.54\ 0.1\ 0.24\ 0.14\}$$

$$U_1^* = \{U_{31}, U_{32}, U_{33}, U_{34}\} = \{0.4\ 0.3\ 0.1\ 0.2\}$$

$$U_1^* = \{U_{41}, U_{42}, U_{43}\} = \{0.3\ 0.4\ 0.3\}$$

By TABLE 6, and combine with TABLE 3 remarks membership, the paper gets aesthetic level, cooperative ability, physical training, innovation attainment each aspect evaluation set:

Aesthetic level $U_1 = \begin{pmatrix} 0 & 0 & 0.05 & 0.95 \\ 0 & 0 & 0.05 & 0.95 \\ 0 & 0.05 & 0.95 & 0.05 \\ 0 & 0.05 & 0.95 & 0.05 \\ 0 & 0.05 & 0.95 & 0.05 \end{pmatrix}$

Cooperative ability $U_2 = \begin{pmatrix} 0 & 0 & 0.05 & 0.95 \\ 0 & 0 & 0.05 & 0.95 \\ 0 & 0 & 0.05 & 0.95 \\ 0 & 0.05 & 0.9 & 0.05 \end{pmatrix}$

Physical training $U_3 = \begin{pmatrix} 0 & 0 & 0.05 & 0.95 \\ 0 & 0.05 & 0.9 & 0.05 \\ 0 & 0.05 & 0.9 & 0.05 \\ 0.05 & 0.9 & 0.05 & 0 \end{pmatrix}$

Innovation attainment $U_4 = \begin{pmatrix} 0 & 0 & 0.05 & 0.95 \\ 0 & 0.05 & 0.9 & 0.05 \\ 0 & 0.05 & 0.9 & 0.05 \end{pmatrix}$

$$B_i = A_i \cdot R_i$$

Make normalization processing with obtained B_i, it gets fuzzy evaluation matrix:

$$\bar{B} = \begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{pmatrix} = \begin{pmatrix} 0.07 & 0.27 & 0.13 & 0.53 \\ 0 & 0.1 & 0.4 & 0.5 \\ 0.08 & 0.46 & 0.38 & 0.08 \\ 0.14 & 0.2 & 0.3 & 0.36 \end{pmatrix}$$

It gets comprehensive evaluation value: $Z = U^* \cdot B = (0.18 \quad 0.3 \quad 0.24 \quad 0.25)$

TABLE 6 : Aerobics athlete each indicator obtained evaluation value

Each layer indicator	Evaluation value	Each layer indicator	Evaluation value
Motion aesthetics u_{11}	Very good	Endurance u_{31}	Very good
Music aesthetics u_{12}	Very good	Speed u_{32}	Good
Formation design u_{13}	Normal	Strength u_{33}	Good
Team shirts designing u_{14}	Normal	Flexibility u_{34}	Normal
Members training u_{15}	Normal	Motion innovation u_{41}	Good
Tactics strategies u_{21}	Very good	Formation innovation u_{42}	Very good
Judgment u_{22}	Very good	Team shirts、 music u_{43}	Normal
Reaction ability u_{23}	Very good		
Competition experiences u_{24}	Good		

CONCLUSION

In whole sports process, each limb will generate moment that on the opposite direction but size is the same, and every pair can offset, when athlete lands, sole part rapidly lands to support the whole body, and meanwhile it will occur to abdomen contraction, knees bending and others to buffer diminished strength to make preparation for next motion. In the air, angular speed changes, when moment of momentum remains unchanged, rotational inertia will reduce with angular speed increasing, when moment of momentum remains unchanged, rotational inertia will reduce with angular speed increasing, when athlete jumps and soars, athlete himself can further control rotational angular speed by changing self-rotational inertia. When athlete takes off and arrives at highest point, athlete should try to adjust body stability, let rotational angular speed to reduce as much as possible, now, athlete should raise two legs backward, let gravity center to be far away from rotational axis, and arrive at state of steady movement.

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