Available online www.jocpr.com

Journal of Chemical and Pharmaceutical Research, 2013, 5(12):284-289

Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Research on the feature of mechanical parameters variation in each step of horse-vaulting landing based on biodynamic

Heng Li

Sports Department, Nanjing University of Aeronautics and Astronautics, Nanjing, China

---

ABSTRACT

This study is intended for analysis on the biomechanical parameters variation in the motor processes of horse-vaulting landing to reduce the athlete's body function damage. Firstly, this paper analyzes the force situation of horse-vaulting landing and its satisfied dynamics equation. Secondly, through advanced measuring instruments and analysis software, we can get the mechanical characteristics of each joint of lower limb in the motor processes of horse-vaulting landing. Finally, take simulation design of different mechanical parameters of cushion to analyze the effect condition of each joint of lower limb. Our paper rejects the traditional research experience, but to use the advanced science and technology to the rational analysis on the horse-vaulting landing and provide some theoretical basis for the training and improvement of horse-vaulting.

Key words: Dynamics parameters, momentum theorem, peak value, each joint of lower limb, simulation data

---

INTRODUCTION

Horse Vaulting is evolved from Trojan horse riding training. In 1896, the men's horse-vaulting competition is induced in the international competitions. With the implementation the new rules of gymnastics from 2001 to 2004, the instruments of horse-vaulting were improved, leading to the revolutionary improvement of the athletic skill. Horse Vaulting is divided into five stages: running-up, jumping, pushing horse with the hand, second flight and landing. The running-up stage does not participate in the given grading session, the movement difficulty in the air and its performance takes the absolute partial completion rates. And the quality of landing procedures has a great impact on athletic performance. Thus, our paper is intended for analysis on the dynamics for the vault landing process.

Many scholars study the process of horse-vaulting landing one after another. Because our country has been able to lead the world's advanced level of Horse Vaulting, the thoughts and analysis of research scholars in the national field of Horse Vaulting will have a great reference value, where Xuhong Li et al (2013) constructed the 19 aspects of personalized mannequin by human motion simulation software LifeMod / ADAMS, the model is then validated through motion capture of the landing process, high-speed video and force platform experiment. And finally they figured out that different mechanical parameters of cushion have different effects on the body damage in Horse Vaulting [1]. Yanlong Zhang et al (2011) do research on the biomechanical parameters variation in the motor processes of horse-vaulting landing based on the method of documentary. They analyze the critical parameters impacting the stability of landing and explore the principle of rationalization actions to clear the current state of the sports skills and lay the foundation for future training and practice [2]. Shang Min (2008) analyzes the factors restricting the stability of Gymnasts from the perspective of sports training and sports psychology, and put forward some countermeasures on how to train Gymnasts landing stability [3].

On the basis of the seniors' research, the article explores the landing process of Horse Vaulting to provide a theoretical basis by the research methods and results.

DYNAMIC MECHANICAL ANALYSIS ON THE LANDING PROCESS OF VAULT ATHLETES

After the completion of sets of actions, vault athletes fall to the ground cushion. The Code of Point for Gymnastics points out that imbalance or lower limb flexion, etc. in the landing process will cause some points, so the landing process needs to maintain body balance and minimize the extent of the leg bearing in Horse Vaulting competition. As followed, we research on the force analysis and dynamics in the process of horse-vault landing.

Force Analysis of Horse-vault Landing Process

Horse-vault landing process is divided into two stages, the first stage is air landing before the toe reaching the ground, and the second one is after the toes touching the ground but before the heel reaching the ground with no movement so far. In the first stage, the athletes only suffer the force gravity, while in the second stage, the athletes suffer the force gravity as well as the support from the ground cushion to human foot. The force of the second stage is not only presents in the vertical direction of the spring force, but also the foot twisting resistance of the cushion. The body force of the two stages is shown in Figure 1.

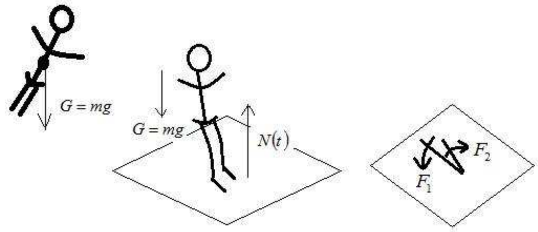

Figure 1: Force Analysis Sketch of Horse-vault Landing Process

Figure 1 shows in the left movement of the body in the air, the force is the gravity only in the case of neglecting the air resistance. The graph in the middle presents the process of foot landing, indicating the counterforce of the cushion to the foot in the vertical component, which is increasing first and then decreasing, and finally be the gravity of the human body. Because athletes have to finish rotation in the air, this leads to a certain rotational angular velocity when athletes hit the ground in the twisting process of the foot on the cushion shown in the figure. According to the rule of the horse-vault race, we can see the body's own energy can stop the rotation, which form the rotary balance process of the two forces in Figure 1.

In Figure 1, G will not change along with the time. The variation trend of $N(t)$ in figure 1 is shown in Figure 2.

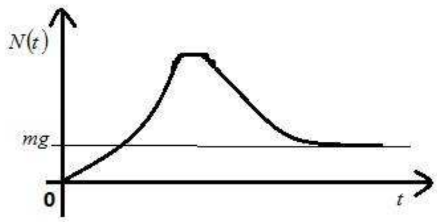

Figure 2: The vertical force of the cushion to human body

Figure 1, F_1 and F_2 don't change in the distance. The relationship between them is equal and opposite. The resistance decreases as the rotational force is reduced, the trend is similar to Figure 2, except that the rotational force is gradually increased from 0, and then gradually decreases and eventually becomes 0.

Dynamics Equations Followed by Horse-vault Landing

The horse-vault process exists the relationship of movement and forces, including changes in the rate of velocity, accelerated velocity, angular velocity and angular acceleration.

Momentum theorem describes the effect of object mechanical motion as the force generated with time accumulation, as shown in equation (1).

$$\int_{t_1}^{t_2} f(t)\,dt = mv_2 - mv_1 \tag{1}$$

Where v_2 represents the final state of object movement, v_1 represents the movement state at the beginning impacting of $f(t)$. Translational velocity variation in the vertical direction in the vault landing process is $\frac{\int_{t_1}^{t_2} f(t)dt}{m}$, Similarly, we can observe the translational velocity variation in the horizontal direction. It is obvious that horse-vaulting landing movement should study every link of the leg movement. Due to the requirements of the athletes remain upright legs, athletes' landing buffers focus on the foot and landing cushions. The motor process is the velocity before the toes touch the ground becoming stationary with the action of landing cushion.

Before landing, the legs of athlete have not only translational velocity but also rotational velocity. The research theory of rotation change is the angular momentum theorem. If the mass of the particle is m, the distance of the particle with the axis is r, the inertia of the particle to the axis is shown in equation (2).

$$I = m \cdot r^2 \tag{2}$$

Any object is constituted by the particles, a whole body motion of the rotary inertia of particles having additive. When rigid body rotates a fixed axis, the product of angular inertia and angular velocity equals the resultant moment stressing the rigid body, as shown in equation (3).

$$\vec{M} = I \cdot \vec{\beta} \tag{3}$$

The accumulation of torque in time is called impulsive moment. The product of angular inertia and angular velocity is called momentum moment. Angular momentum theorem refers to impulsive moment is numerically equal to momentum moment, as shown in formula (4).

$$\int_{t_1}^{t_2} M(t)dt = I\omega_2 - I\omega_1 \tag{4}$$

HORSE VAULTING LANDING DYNAMICS SIMULATION DATA ANALYSIS

Vault landing cushion is the only medium of landing process between athletes and the ground, so we design a personalized mannequin and landing cushion to validate the mechanical characteristics of the system composed of the landing cushion and the athletes. The infrared high-speed motion capture system, eight infrared webcams and two high-speed cameras are used to capture the subject's movement synchronously. Then the parsed dynamics parameters is converted into the human body motion simulation software LifeMod.

Data Acquisition Method and Parameter Optimization

The simulation can obtain vertical GRF of the two video cameras in the process of athlete landing the cushion, and compare it with three dimensional measuring force platform vertical GRF. The correlation coefficient is used as the assessment index describes the degree of similarity among the vertical GRF curves. The correlation coefficient is calculated as formula (5).

$$CMC = \sqrt{1 - \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(x_{ij} - \bar{x}_j\right)^2 \Big/ n(m-1)}{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(x_{ij} - \bar{x}\right)^2 \Big/ (nm-1)}} \tag{5}$$

Where m represents the number of curve, n is the number of data in each curve, x_{ij} is the jth data of curve i. $\bar{x}_j$ represents the average value of the j data in m curves. $\bar{x}$ is the population mean of n data in m curves.

A gymnastics vault landing cushion is created in accordance with the national gymnastic equipment standard (GB/T 23124-2008), and the acquisition parameters must also meet the range of the mechanical characteristics of FIG provisions at the same time. Use simple optimization algorithms to find the mechanical parameters of landing cushion.

In order to analyze the counterforce on the ground and the joint angles observed in the subject's landing process, and carry on the root mean square difference with the ones in simulation situation respectively. The root mean square difference formula is shown in formula (6).

$$\Delta\delta = \sqrt{\frac{x_1^2 + x_2^2 + \cdots x_m^2}{m} + \frac{y_1^2 + y_2^2 + \cdots y_n^2}{n}} \tag{6}$$

where x, y represents the experimental and simulated values respectively. $\Delta\delta$ is the root mean square difference. Its function expression is shown in formula (7).

$$S = \left[\Delta \perp + \Delta // + \frac{1}{4}\sum_{i=1}^{4} \Delta a_i \right] \tag{7}$$

where $\Delta \perp$ represents root-mean-square deviation in vertical direction of GRF. $\Delta //$ represents the root-mean-square deviation in horizontal direction of GRF.

Athletes Landing Simulation Graph Analysis

In this simulation, the entire time of vault landing is120ms, the distinction between the action processes is the toe touching the cushion with 0% to the toe rebounding the surface of the cushion with 100%. The course of the study can be divided into two stages: shock and balance. Figure 3 shows the counterforce of the cushion to the athletes.

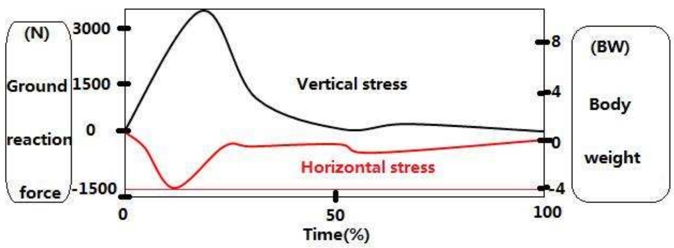

Figure 3: The force of cushion to the athlete

In the vault landing process shown in Figure 3, the maximum in the vertical direction of the counterforce of the cushion to the athletes is shown in sequence with 3463N, that is, 11.40BW. it takes 21ms from the toe touching the ground to the maximum. The average load rate in the vertical direction is approximately 164.94N/ms, shock stage takes 78ms; and in the balance stage, the counterforce of the ground in the vertical direction is approximately 0.91BW. The counterforce of the ground in the horizontal direction first make body gravity forward accelerated movement, until the horizontal velocity drops from the approximately 18ms to 0, the peak of counterforce is about -115N, namely -3.71BW.

Athletes with lower limb musculoskeletal system possesses the function of buffer damping, Figure 4 shows the force situation of ankle, knee and hip within 120ms, the slack time of impact force peak of the three parts appears at 15ms, 17ms and 19ms respectively. The average counterforce of the lower limb joints in the shock stage is 8.75BW, 7.81BW and 5.30BW. Before the leg shocking the ground, each joint is in the state of pull because of their own gravity, while the hip joint buckles actively to ease the impact load.

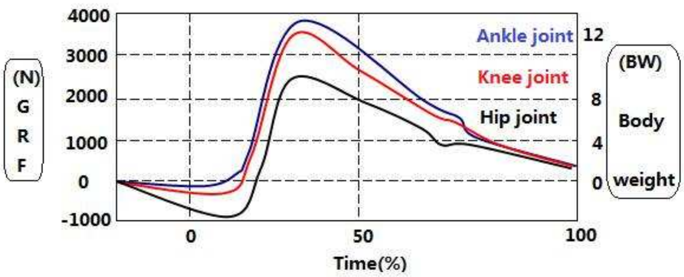

Figure 4: The force of each joint of the leg

A case study of the right leg is on the knee extension torque, hip flexion extension torque and ankle extension torque, the joint torque of each leg joint in sagittal plane and frontal plane in the simulation process within 120ms is shown in Figure 5.

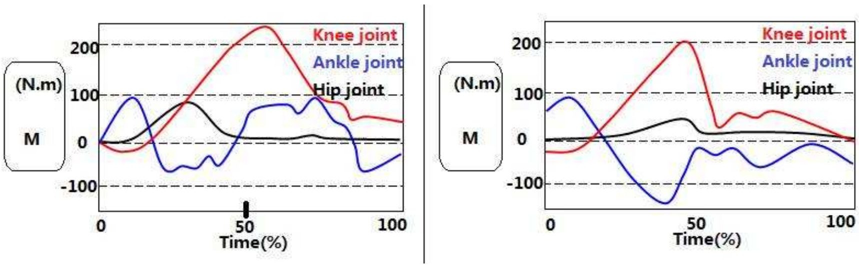

Figure 5: The torque of each leg joint

Figure 5 shows the joint torques, left for sagittal plane, the bigger of the positive value, the greater of the extensor. The negative value indicates the flexor case. The right is for frontal plane, the bigger of the positive value, the greater of the adduction. The negative value indicates the abduction case. In the process of vault landing, peak torque of the right leg knee extensor torque in the sagittal plane is 231.07Nm.The smallest is the peak torque of ankle plantar flexors which is 69.24Nm; and likewise, hip outreach torque is also the maximum in the frontal plane, knee adduction torque is the biggest, and ankle abduction torque is smallest. And there is no abduction moment.

Athletes Landing Mechanical Parameters of Each Link Data Analysis

Mechanical parameters of the cushion have stiffness and damping coefficient, these two parameters have a significant influence on the landing process of internal and external impact load. In the case of cushion stiffness increasing 20%, the peak of GRF in the horizontal direction and the vertical direction will increase by 7% and 8%, respectively. The counterforce peak of the lower extremity's ankle, knee and hip joint will increase by4%, 4% and 4.5%. And the peak torque of ankle plantar flexor muscle group and invertors in the sagittal plane and the frontal plane is an increase of 5%, 14%. The peak torque of knee extensor and adductor increase by 2 %, 14.1 %, respectively, The peak torque of hip extensor and adductor respectively reduce by 3.8% , 14.5%; if the damping coefficient of landing cushion increased by 22 %, every GRF peak in the horizontal and vertical directions will increase to 14.8% and 14.3%. The counterforce peak of lower limb ankle, knee and hip joint increase by 8%, 7 % and 6.5%,

The torque peak of Ankle plantar flexor muscle group and invertors in the sagittal plane and in the frontal plane increase by 14% and 13%. The torque peak of knee extensor and adductor muscle is reduced by 1.6% and increased by 14.0%, respectively. The torque peak of hip extensor and adductor muscle increase by 1%, 16.1%, respectively.
Changes in the ground reaction force, joint reaction force and the peak torque of joints caused by changes in the mechanical parameters of landing cushion is shown in Table 1.

Table 1- Athletes force peak in different landing cushion mechanical parameters

Landing cushion mechanical parameter (%)		A	B	C		D	E
Stiffness coefficient	100	-1217.06	3463.65	3811.94		3301.97	2188.81
	110	-1257.43	3590.34	3885.96		3371.53	2265.38
	120	-1292.79	3741.17	3965.43		3440.70	2287.58
	130	-1338.14	3843.83	4042.60		3509.68	2336.97
	140	-1378.48	3970.57	4123.37		3579.77	2386.09
Damping coefficient	95	-1262.06	3587.57	3882.02		3361.12	2224.54
	100	-1307.04	3711.48	3956.95		3421.29	2260.19
	105	-1352.02	3835.40	4030.94		3482.72	2295.91
	110	-1396.98	3959.31	4103.72		3542.45	2333.11
Landing cushion mechanical parameter (%)		F	G	H	I	J	K
Stiffness coefficient	100	69.24	231.07	92.62	34.48	151.54	-219.78
	110	71.13	233.33	90.97	36.93	162.29	-234.86
	120	73.02	235.68	89.14	39.26	172.90	-251.65
	130	74.92	239.21	87.38	41.63	183.96	-269.56
	140	76.79	242.75	86.47	43.05	190.90	-281.43
Damping coefficient	95	71.72	229.14	92.80	36.18	159.06	-230.85
	100	74.17	228.42	93.40	37.77	166.64	-243.47
	105	76.59	227.53	93.52	38.96	172.83	-255.17
	110	78.98	227.43	94.54	39.22	173.64	-255.55

Note: A, B represents the horizontal peak and vertical peak of GRF; C,D,E represents counterforce peak of ankle, knee and hip joint; F,G,H is the torque peak of ankle, knee and hip joint in sagittal plane; I,J,K is the torque peak of ankle, knee and hip joint in frontal plane.

CONCLUSION

This paper first introduces the force and the dynamical equations satisfied by the human body in the process of horse-vault landing; to further analyze the mechanical characteristics of the athletes vault landing, advanced measurement technique is used to interpret the dynamical parameters of human lower limb in the motor process; in the context, we design and simulate the movement of each lower limb joint under different cushion mechanical parameters, and gather the appropriate mechanical parameter data, through data analysis, we obtain the different impact on each joint of athletes lower limb with different mechanical parameters of the cushion.

REFERENCES

[1] Li Xuhong, et al. *Sports Science*, **2013**.33(3):81-88.
[2] Wu Chengliang, et al. *China Sport Science and Technology*. **2011**.47(6):25-29.
[3] Yao Xiawen. Modern vault techniques and teaching training. **1993**.