BIOMECHANICS ANALYSIS OF FORWARD HANDSPRING AND SALTO STRETCHED WITH 5/2 TWIST IN VAULTING

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The purpose of this study was to provide biomechanical analysis of the vault, Handspring Forward and Salto Forward Stretched with 5/2 Twist (Vault Number 2538). This routine was considered one of the most superior moves in recent international gymnastics competitions. It has a high degree of difficulty and its execution results in a base score of 10. In this paper, analysis of the Conservation of Angular Momentum was obtained. In addition, Coriolis's moment of inertia momentum and conical-curve movement of the legs in opposite direction of this movement was calculated to obtain the technique for approach and for technical requirements. The data collected would provide information for athletes in their training.

KEY WORDS: angular momentum, Coriolis's moment of inertia momentum, conical-curve movement of the legs in opposite direction

INTRODUCTION: Despite incorporating characteristics that are both difficult and creative, the movement of men's vault forward handspring and salto stretched with 2 1/2 turns, was considered the most superior movement in recent international gymnastics competitions. According to the requirements of International Gymnastic Regulations, the base score of this movement is 10 marks. This paper presents a study on the technical principles of the movement. Through this study, it was hoped that the data would elevate the standards of this vault through the improvement, enhancement and development of the technical aspects of this movement.

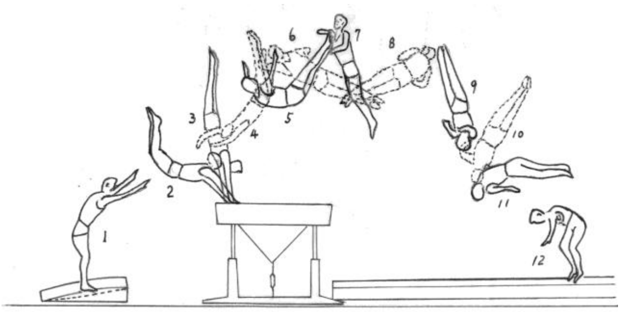

Figure 1 - Sketch map of the Movement.

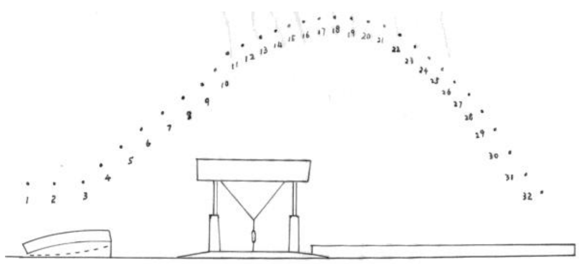

Figure 2 – Sketch map of CG of body gravity movement trace.

METHODS: The routine performed in a gymnastic competition in 1998 was chosen as the subjects for study. Referring to Figures 1 & 2, it can be seen that the movement is suitable for study because it is of high technical calibre. The technical study and analysis were conducted in the following stages (1) Scan of motion images of the movement by a fixed position high-speed camera (80 pictures per second, Model S-V) manufactured in Lanzhou of PRC and develop images into pictures. (2) Calculation of the mechanics of movement based on i) mass ratio among various parts of human body measured by Professor Hidichi Matsui of Japan; ii) theoretical mechanics calculations of the turning inertia of human body; iii) the Coriolis inertial principles and iv) motion analyzer (Model GP-2000) manufactured in Japan. (3) Analysis and discussion of the technical principles.

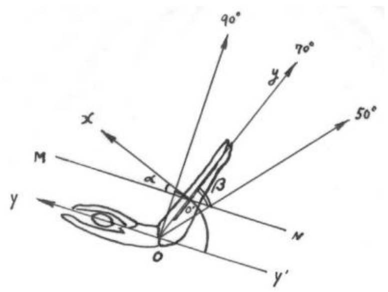

Figure 3 - Graph of relations between the hip joint bending and the body twisting around the longitudinal axle of upper body.

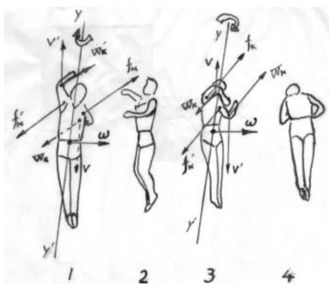

Figure 4 – Sketch map of Coriolis inertia.

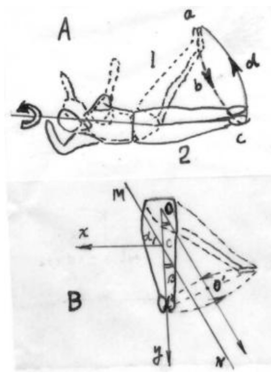

Figure 5 - Sketch map of leg movement toward upper body and related calculation.

RESULTS AND DISCUSSION: The major technical essence of this movement is the body twisting technique during the second flight. Through measurement, calculation and analysis shows that the twisting of the human body in this flight is the combination of 3 dynamic forces:

1. After handspring forward from the horse, the gymnast entered into the second flight. While the upper body piked and twisted forcefully, the initial angular velocity was generated. This is the first dynamic force for the twisting technique. See point No.4 - 5 in Figure 1 and refer to Figure 3 and Table 1 for the principles. At that moment, the body piked at 70°. Considering the longitudinal axle of human body, the J_{lower} of the lower body is larger than the J_{upper} of the upper body by 9.95 times. According to the rules of conservation of angular momentum, the ω_{upper} of the upper body is 9.95 times smaller than the ω_{lower} of the lower body, and opposite in direction. This means that even when there is no external force applied while the human body is in the air, there will be no effect on the twisting of human body when the center of mass passes the center of gravity (CG) of human body. In other words r=0), the lower body can sustain a counter-rotation twist of the upper body thus generating a large angular velocity. For the piked angle at the hip joint, it can be varied from the maximum of 90

°to the minimum of 0°. The piked angle is governed by the technical capability of the gymnast.

Table 1 Relationship between the Piked Angle of Hip Joints and the Longitudinal (y-axis) Rotational Inertia of the Upper and Lower Bodies

Values of Φ / Values of J / Descriptions	Angle of the Hip Joints 0°	50°	70°	90°
Twisting of J_{upper} around yy'	78.77m	78.77m	78.77m	78.77m
Twisting of J_{lower} around yy'	24.02m	586.3m	783.84m	932.22m
J_{upper}/J_T	1/0.3	1/7.41	1/9.95	1/11.83
ω_{upper}/W_T	0.3/1	7.41/1	9.95/1	11.83/1

Notes: J is the rotational inertia (metric system); m is the mass of the gymnast; ω is the angular velocity around the yy'.

2. During the second flight phase, the arms of the gymnast were swinging thus generating the Coriolis's moment of inertia momentum. This is the second dynamic force involved in the twisting technique. See points No.5 –8 in Figure 1. Refer to Figure 2 and Table 2 for details. According to Coriolis's formula for the moment of inertia momentum,

$$H = 2\omega V \sin\alpha \ m_{arm} d\Delta t,$$

where ω is the angular velocity; V is the relative linear velocity; α is the angle of arms; m_{arm} is the mass of arms of the gymnast; d is the distance between the 2 shoulder joints; Δ t is the time duration of the action.

From the above formula, it can be seen that H is in direct proportion with other factors and the main factors are ω and V. In order to obtain the maximum ω, the gymnast must run up as fast as possible. For the gymnast in the present study, the speed just before the vaulting board was 8.8m/s. If the takeoff and hand-spring forward actions were correct, the gymnast should be able to obtain the mechanical indicators as shown in Table 3. The maximum value of ω during the second flight was 7.85l/s. This is the basic source of dynamic forces for human body twisting. That means ω converted the energy for X-axis rotation into Y-axis rotation. V is the relative speed of the arms' up and down actions. The arms actions should be rapid and strong in order to achieve the best result. Please note that, the changeover between the 2 swings of arms occurred when the human body rotated 180°, thus the force generated through the arms' action is in the same direction. The m_{arm} shall be as large as possible and the mass of the shoulders can be included as well. When the angle is at 90°, sinα is at the maximum value. Therefore, actions of the arms shall be performed when ω and V at the angle of 90°. To obtain the most effective d value, the shoulders should be stiffened during the body rotation. Δt depends on the level of twisting technique and shall not be changed freely.

Table 2 Statistics of Mechanical Indicators provided in Figure 3

Phase	First round of arm actions				Second round of arm actions			
Action	Action No.1 in Fig 3				Action No.3 in Fig 3			
Detail	Right arm downwards		Left arm upwards		Right arm upwards		Left arm downwards	
Indicator Values	ω	6.28(l/s)	ω	6.28(l/s)	ω'	6.89(l/s)	ω'	6.89(l/s)
	V	2.40(m/s)	V'	2.0(m/s)	V	1.2(m/s)	V'	2.6(m/s)
	W_k	30.14(m/s^2)	W_k'	25.12(m/s^2)	W_k	16.54(m/ s^2)	W_k'	35.83(m/s^2)
	f_k	1.54m(kg)	f_k'	1.28m(kg)	f_k	0.844m(kg)	f_k'	1.827m(kg)
Moment	Leftward rotating M_k =0.245m(kgm)				Leftward rotating M_k=0.202m(kgm)			

Notes: W_k is Coriolis acceleration; f_k is Coriolis inertia; m is the body mass of the gymnast.

Table 3 Mechanical Indicators of the Human Body in the Second Flight

Indicators / Values / Flights	$V_{horizontal}$	$V_{vertical}$	ω while back uprise	
			Minimum	Maximum
First Flight	5.3(m/s)	4.5(m/s)	8.03(l/s)	10.12(l/s)
Second Flight	3.8(m/s)	3.1(m/s)	5.06(l/s)	7.85(l/s)

Notes: $V_{horizontal}$ is the horizontal linear velocity; $V_{vertical}$ is the vertical linear velocity; ω is the angular velocity; m/s is meter per second; l/s is the radian per second.

3. During the body rotation, if the legs perform rapid conical-curve movements in the opposite direction, this will generate a rotation force. This is the third dynamic force involved in the twisting technique and it is the best assisting force for rotation. Referring to Figure 5, A is the sketch map of the trace motion and B is the map for calculation. After calculation, it shows that this force can provide a moment of 0.32814m (kg.m.s) for the upper body, where

m is the mass of the gymnast.

DISCUSSION: In general, the rotation technique during the second flight phase can be divided into three sub-phases. The first is the force-generating phase (see Figure 1 for actions No.3-8 and Fig 2 for actions No.9-21). During this phase, the body shall turn by 248° around the X axis and 450°around the Y axis, with the driving of the 3 dynamic forces described above. The second is the energy-utilizing phase (see actions No.8-10 in Figure 1 and actions 21-27 in Figure 2). During this phase, the body rotated 225°. The third is the adjusting phase before landing. See actions No.10-12 in Figure 1 and actions 27-31 in Figure 2. The stretching and contracting of the arms and the extending and bending of the hip joints were used to adjust the angular velocity of rotation so that the gymnast was able to land steadily. During the three phases described above, the turning of the head is very important for the rotation of the body, because it can cause favorable position reflection and the inertia of movement for the actions.

CONCLUSION: The analysis of the study can be concluded in three main points:

1. It is crucial for the body rotation that the maximum ω and a high and distance parabolic trace for movement of center of gravity can be achieved during the second flight phase. Therefore, this demands a fast run up, forceful takeoff and a rapid back uprise. After handspring from the horse, the piked upper body contributed to the increase of ω.

2.The three dynamic forces for the body rotation are: A. the rotation of the upper body caused by the hip joints; B. The Coriolis inertia caused by the arms' actions; and C. the conical-curve movement of the legs in opposite direction.

3.The correct piking move and extension of human body and the turning of the head contribute to the improvement of the rotation technique.

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