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ORIGINAL

Kinematical Analysis of Somersault with Twist in Men's Vault: Focusing on the Lou Yun and Akopian Motions

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Objective: The aim of this study was to determine the kinematical characteristics of somersault with twist in the Lou Yun and Akopian motions and to provide useful information to gymnastic athletes in men's vault.

Method: The study subjects were 12 male adult top athletes. After 12 trials (7 Lou Yun and 5 Akopian trials) filmed by using two digital high-speed camcorders set at 90 frames/sec, kinematical data were collected through the direct linear transformation (DLT) method. The mean differences in biomechanical variables were compared during the second flight upward phase. The kinematic characteristics of somersault with twist in the Lou Yun and Akopian motions were identified.

Results: In Lou Yun motion, the vertical release velocity through horse breaking was not difficult to obtain, so the athletes had enough time to prepare for the twist. Therefore, the Lou Yun motion has an advantage to make a cat twist in the pike posture. In the Akopian motion, obtaining the horizontal velocity through horse pushing was so easy that the Akopian athletes attained a large angular impulse and angular momentum. Therefore, the Akopian motion has an advantage to making a tilt twist in the body tilting posture.

Conclusion: This study suggests that gymnastic athletes should control their body segment movements in order to increase the twisting angular velocity of the whole body, which requires regulation of the longitudinal moment of inertia of the body. Moreover, athletes should prepare for the shoulder and hip twists early in order to make the landing position in advance.

Keywords: Somersault, Twist, Lou Yun motion, Akopian motion, Men's vault

INTRODUCTION

Vaulting should be performed with all the technical motions required in gymnastics, such as board contact, horse contact, takeoff, somersault, twist, and landing. The degree of difficulty of a technique is determined based on the type of takeoff, the body position during somersault, and the number of turns (International Gymnastics Federation [FIG], 2013).

The FIG has classified the types of vault into 5 groups according to the entry types established through the regulatory reform in 2013. The first group includes the forward handspring and Yamashita-style vault; the second group, the handspring with a one-fourth or half turn in the first flight phase (phase from the board takeoff to horse contact); the third group, the round-off entry vaults with a one-fourth turn in a backward direction in the second flight phase (phase from horse takeoff to mat landing); the fourth group, the round-off entry vaults with a half turn in the first flight phase; and the fifth group, the round-off entry vaults with three-fourth or full turn in the first flight phase (FIG, 2013).

In the first group, forward somersault technique with a half turn and landing toward the vault is called Cuervo vault, where a technique score is given for every turn made. In other words, 1 turn in addition to the Cuervo vault is the Lou Yun vault, with 5.2 points, and 1 turn in addition to the Lou Yun vault becomes Yeo 2 vault, with 6.0 points (FIG, 2013). In addition, landing by backward somersaulting in group 2 is called the Tsukahara vault, and a half turn and forward somersaulting after the takeoff at this motion is the Kasamatsu vault. The technique score increases as the number of turns increases. Landing after 1 more turn with the body stretched as in the Kasamatsu vault is the Akopian motion, with 5.2 points. A half turn in addition to this technique is the Driggs vault, with 5.6 points, and a half turn in addition to this and landing to the vault is the Lopez vault, with 6.0 (FIG, 2013). As mentioned earlier, the techniques with a greater degree of difficulty in the first and second groups should be based on the accurate performance of the Lou Yun and Akopian motions. As discussed earlier, the scores in the two techniques are the same, and the motions in full and half turns with the body stretched during aerial movement are also identical.

Contact with the vault is made after a side turn in the Akopian motion, causing a time difference between the vault landings with the two hands, with the load being inclined to one arm (Dilman, Cheetham, and Smith, 1985). Therefore, increasing momentary elasticity is challenging (Lee, Park, & Lee, 2006; Back et al., 2005). In addition, Lim (2005) argued that

"Reaction force is generated by controlling horizontal velocity at vault contact with the characteristic of Lou Yun, large linear momentum should be generated by increasing vertical velocity using this, and rapid twist can be performed by adding appropriate amount of turn using the acquired angular momentum, and landing can be prepared at ease".

In their previous study about the first group and Lou Yun vault, Kang (2004) calculated the impact force at horse contact in the Lou Yun motion. Lim (2005) argued that the ability to control horizontal velocity should be favorable to properly perform the Lou Yun motion, and a tilt twist needs to be performed in combination with a cat twist in "the biomechanical analysis of the Cuervo salto forward straight vaults with twists". Kim (2006) discussed that sufficient angular momentum is required to succeed in landing, as the angular momentum of the one succeeding in landing is greater than that of a failed landing. Park (2011) argued that the Lou Yun motion is relatively advantageous for an athlete who can obtain a large vertical velocity by breaking the vault horizontally.

According to previous studies about the second group and Akopian motion, Ryu, Park and Han (2000) performed the kinematical analysis of the Cuervo single twist motion. Meanwhile, Park (2001) calculated velocity, acceleration, and vault reaction force of the Akopian motion. Back et al. (2005) generated the variables of linear and angular motions in the first and second flights, with 2 trials in same athlete, by performing a kinematical analysis of the Lopez motion. Lee, Park, and Lee (2006) analyzed the difference in linear motion, and each motion difference between the Akopian high- and low-score groups. The authors' argument is as follows:

The angular velocity of the vertical axis of the upper body was the greatest before and after the peak. The angular velocity change from negative to positive is a reverse turn motion from clockwise to counterclockwise. Moreover, the motion of reverse turn to the direction of turn and the opposite direction at landing cannot help but be a great challenge to subjects. Therefore, the motion to turn a body to reverse direction while landing requires strong momentary blocking to change the rotational inertia of a body, and a technique to increase vertical velocity by this blocking (Lee et al., 2006).

Although previous studies presented similar data, most of their analyses focused on kinematic variables and momentum in the whole phase from board contact to mat landing. In addition, they did not discuss aerial twist and lack explanatory power.

Considering that the time when the angular velocity of the vertical axis of the upper body during aerial motion is greatest is before and after the peak height, at which the height of the body center is greatest (Lee et al., 2006), analyzing aerial movement to the point of a half twist (HTW), including peak height, is important. Providing feedback particularly about athletes' turns by analyzing the degree of shoulder and cervical twist is necessary.

Therefore, the aim of this study was to provide useful information by investigating the kinematic characteristic of twist according to somersault with the Lou Yun and Akopian motions.

METHODS

1. Participants

In the male athletes who performed Lou Yun and Akopian motions in the final vault game in the 37th gymnastic championship sponsored by the Ministry of Culture, Sports, and Tourism, 12 trials were conducted, in which landing was stable after counterclockwise twist following horse takeoff (HTO). After selection, the athletes were divided into two groups (Lou Yun motion, 7 trials and Akopian motion, 5 trials). Twelve participants who provided consent regarding the feedback after the analysis after receiving an explanation about the aims of this study and the experiment procedures were included in the study and assigned to the Lou Yun group (age: 24.7 ± 3.8 years; height: 1.67 ± 0.02 m; mass: 61.0 ± 1.1 kg; score: 14.6 ± 0.1) and Akopian group (age: 29.6 ± 1.5 years; height: 1.70 ± 0.02 m; mass: 62.2 ± 1.9 kg; score: 14.1 ± 0.5).

2. Measurement

In order to film the male vault trial, 2 digital high-speed camcorders (VFC-300), 4- × 4-m control poles, and 1 SOKKIA EZS21S theodolite were used. The sampling rate was set as 90 frames/s. Lou Yun and Akopian motions were included by filming from the beginning of the vault. The control pole was recorded immediately after the competition, and the angle was measured. The origin of the global coordinates was set up as the lowest point of the pole. Performance direction was set as the Y axis, vertical direction as the Z axis, and the left/right direction as the X axis.

3. Data processing

Eighteen body landmarks from before board touchdown to 5 frames after mat landing were to be analyzed. Location coordinates were generated by using the direct linear transformation (DLT) method (Abdel-Aziz & Karara, 1971) with the Kwon3D 3.1 motion analysis program, and Hanavan-Kwon data were used for the body segment parameter (Visol, 2005). The cutoff frequency for smoothing data was set as 6.0 Hz.

In order to achieve the objective of this study, 4 events were established as follows: (1) the instant of horse takeoff (HTO); (2) the instant to prepare for the twist when the body is closest to the Y axis in the supine position in the air after takeoff (preparation: PP); (3) the instant that the center of gravity (COG) of the body is the highest after takeoff (peak height: PH); and (4) the instant of HTW when the trunk longitudinal angular velocity is the greatest (Figure 1).

For major variables according to the events, first, body COG velocity, moment arm (the Y-axis distance between the center of one or two hands and the body COG at the moment of HTO) and X-axis body angular momentum were generated at HTO, which determines the linear and angular momenta in aerial movement. Second, during twist PP, the lapse time after HTO, the degree of cervical twist, hip joint angle (the angle between the mid-foot- and the mid-shoulder-centered vectors at the mid-hip), the Z-axis hip joint angle (the angle at which the joint angle is projected on the XY surface), and the perpendicular angular

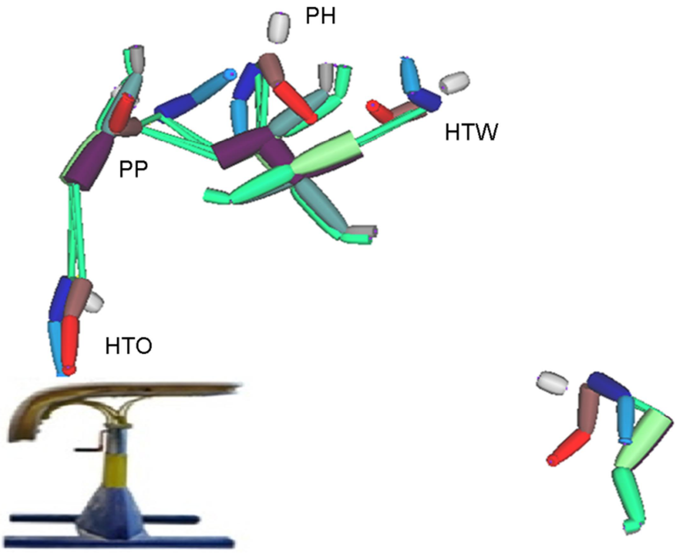

Figure 1. Events during the second flight of the Lou Yun motion

velocity of the upper body, shoulder angular velocity (the local reference frame made of the trunk vector [*Z* axis] and the vector from the left to the right shoulder [*X* axis], with the origin being the center of both shoulders), and hip angular velocity (the local reference frame made of the trunk vector [*Z* axis] and the vector from the left to the right hips [*X* axis], with the origin being the center of both hips) were generated. Third, at the PH, where body COG is the highest, the lapse time after HTO, hip joint angle and *X*-axis hip joint angle (the angle at which the hip joint angle is projected on the YZ surface), shoulder and hip angular velocity, and the angular momentum of the entire body were suggested. Fourth, at HTW, HTW of the body, lapse time after HTO, hip joint angle and *Y*-axis hip joint angle (the angle at which the hip joint angle is projected on the XZ surface), and shoulder and hip angular velocities were generated. The *Z* tilt angle of the global coordinates (the angle between the mid-foot- and mid-shoulder-centered vectors and where the *Z* axis is projected on the XZ surface) was also generated. In addition, angular momentum was normalized by dividing by the square of body mass and height of the study subjects, but as the value was too small, 1,000 was multiplied.

4. Statistical analysis

For the statistical analysis in this study, the means and standard deviations were processed by using descriptive statistics with SPSS 18.0. An independent two-sample *t* test was performed for the verification of variables between the two techniques at the significance level of .05.

RESULTS

1. Descriptive statistics and mean differences between the Lou Yun and Akopian motions at HTO

The results of the major variables at the time of HTO and the mean differences are shown in (Table 1).

Table 1. Descriptive statistics and mean differences between the Lou Yun and Akopian motions at HTO

Variables	Motion	Mean ± SD	*t*
Horizontal velocity of body COG (m/sec)	Lou Yun	2.87 ± 0.19	**-4.063****
	Akopian	3.30 ± 0.15	
Vertical velocity of body COG (m/sec)	Lou Yun	2.98 ± 0.22	**3.546****
	Akopian	2.56 ± 0.17	
Moment arm of body COG (m)	Lou Yun	0.09 ± 0.03	1.008
	Akopian	0.06 ± 0.05	
X-axis angular momentum of the whole body (10^{-3}/sec)	Lou Yun	-410.5 ± 15.5	**6.415*****
	Akopian	-488.4 ± 26.6	

Significant at **$p < 0.01$, ***$p < 0.001$.

As shown in (Table 1), the Lou Yun motion had a smaller horizontal projection velocity ($p = 0.002$), a larger vertical projection velocity ($p = 0.005$), and a smaller *X*-axis angular momentum of the entire body in the clockwise direction ($p = 0.000$) than the Akopian motion at HTO. No significant difference was observed between the moment arms.

2. Descriptive statistics and mean differences between the Lou Yun and Akopian motions at PP

The results of the major variables at twist PP and the mean differences are shown in (Table 2).

As shown in (Table 2), Lou Yun motion had a shorter lapse time from HTO to twist PP ($p = 0.001$), a smaller hip joint angle ($p = 0.000$), a

Table 2. Descriptive statistics and mean differences between the Lou Yun and Akopian motions at PP

Variables	Motion	Mean ± SD	*t*
Lapse time from HTO (sec)	Lou Yun	0.15 ± 0.02	**-4.537*****
	Akopian	0.22 ± 0.02	
Hip joint angle (degrees)	Lou Yun	128.4 ± 12.2	**-5.483*****
	Akopian	162.2 ± 7.2	
Z-axis hip joint angle (degrees)	Lou Yun	161.0 ± 13.1	-1.468
	Akopian	170.4 ± 6.3	
Z-axis shoulder angular velocity (rad/sec)	Lou Yun	3.39 ± 1.83	**-10.390*****
	Akopian	15.12 ± 2.05	
Z-axis hip angular velocity (rad/sec)	Lou Yun	4.56 ± 3.10	**-5.755*****
	Akopian	15.74 ± 3.62	

Significant at ***$p < 0.001$.

smaller *Z*-axis angular velocity of the shoulder (p = 0.000), and a smaller *Z*-axis angular velocity of the hip (p = 0.000) than the Akopian motion at the twist PP. No significant difference was observed between the *Z*-axis hip joint angles.

3. Descriptive statistics and mean differences between the Lou Yun and Akopian motions at PH

The results of the major variables at peak height, where a body reaches the maximum height and the mean differences are shown in (Table 3).

Table 3. Descriptive statistics and mean differences between the Lou Yun and Akopian motions at PH

Variables	Motion	Mean ± SD	*t*
Lapse time from HTO (sec)	Lou Yun	0.27 ± 0.03	**2.559***
	Akopian	0.23 ± 0.01	
Maximum height of body COG (m)	Lou Yun	2.80 ± 0.07	1.729
	Akopian	2.73 ± 0.06	
Hip joint angle (degrees)	Lou Yun	147.5 ± 15.5	**-2.500***
	Akopian	164.4 ± 3.3	
X-axis hip joint angle (degrees)	Lou Yun	149.1 ± 14.4	**-2.357***
	Akopian	165.6 ± 2.1	
Z-axis shoulder angular velocity (rad/sec)	Lou Yun	12.85 ± 3.99	-1.569
	Akopian	15.75 ± 0.96	
Z-axis hip angular velocity (rad/sec)	Lou Yun	10.17 ± 4.26	**-2.304***
	Akopian	15.31 ± 2.99	
Total angular momentum of the whole body (10^{-3}/sec)	Lou Yun	384.3 ± 23.7	**-4.267***
	Akopian	435.2 ± 13.9	

Significant at *p < 0.05.

As shown in (Table 3), the Lou Yun motion had a longer lapse time from HTO to PH (p = 0.028), a smaller hip joint angle (p = 0.031), a smaller *X*-axis hip joint angle (p = 0.040), a smaller *Z*-axis hip angular velocity (p = 0.044), and a smaller total angular momentum of the entire body (p = 0.002) than the Akopian motion at PP. However, no significant differences were observed between the maximum heights and *Z*-axis shoulder angular velocities.

4. Descriptive statistics and mean differences between the Lou Yun and Akopian motions at HTW

The results of major variables at HTW, where a body reaches ½ twist, and mean differences are shown in (Table 4).

As shown in (Table 4), the Lou Yun motion had a smaller whole-body total angular momentum (p = 0.037) than the Akopian motion at HTW. No significant differences were observed between the lapse times, *Y*-axis tilt angles, hip joint angles, *Y*-axis hip joint angles, *Z*-axis shoulder velocities, and *Z*-axis hip angular velocities.

Table 4. Descriptive statistics and mean differences between Lou Yun and Akopian motion at HTW

Variables	Motion	Mean ± SD	*t*
Lapse time from HTO (sec)	Lou Yun	0.41 ± 0.04	0.113
	Akopian	0.41 ± 0.05	
Y-axis body tilt angle (degrees)	Lou Yun	8.7 ± 5.1	-0.597
	Akopian	10.8 ± 6.9	
Hip joint angle (degrees)	Lou Yun	167.5 ± 4.4	0.611
	Akopian	164.8 ± 10.9	
Y-axis hip joint angle (degrees)	Lou Yun	164.1 ± 8.4	-0.880
	Akopian	170.0 ± 14.6	
Z-axis shoulder angular velocity (rad/sec)	Lou Yun	17.37 ± 4.45	0.307
	Akopian	16.70 ± 2.28	
Z-axis hip angular velocity (rad/sec)	Lou Yun	19.16 ± 2.86	-0.532
	Akopian	20.08 ± 3.08	
Total angular momentum of the whole body (10^{-3}/sec)	Lou Yun	411.2 ± 19.4	**-2.403***
	Akopian	438.4 ± 19.0	

Significant at *p < 0.05.

5. Patterns of angular velocity with the highest scores during the second flight upward phase in each motion

The changes in *Z*-axis shoulder and hip angular velocity patterns of the Lou Yun and Akopian athletes with the highest scores are shown in (Figure 2) and (Figure 3).

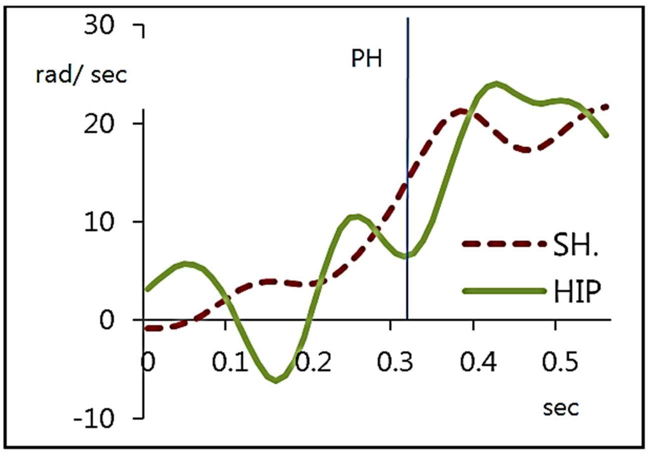

Figure 2. Angular velocity with the highest score during the second flight upward phase in the Lou Yun motion

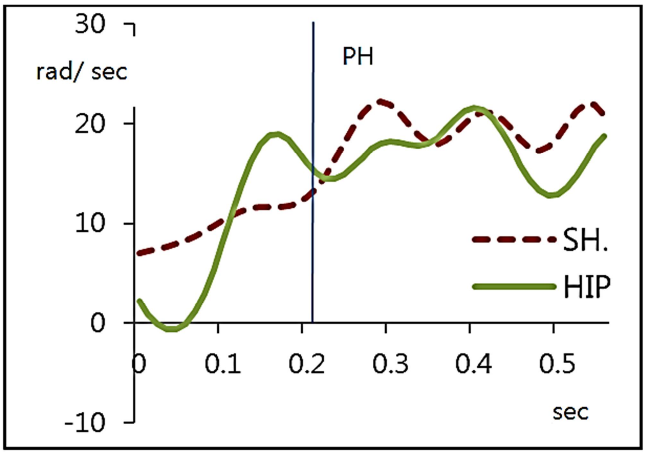

Figure 3. Angular velocity with the highest score during the second flight upward phase in the Akopian motion

As shown in the figures, the pattern of *Z*-axis angular velocity changes in both techniques before and after the peak height in the upward phase appears to be similar. In other words, once in the early upward phase, the shoulder turn leads to a twist; in the later upward phase, the hip turn leads to a twist and then passes at peak height. However in Lou Yun athletes, the contribution of hip turn to twist was temporarily large after peak height. The Akopian athletes showed the pattern of the shoulder turn leading to a twist. Therefore, although the patterns of the shoulder and hip twists in both techniques were similar in the upward phase, it was different in the downward phase.

DISCUSSION

Most sports involve aerial movements, which have been included in the evaluation of vault performance in artistic gymnastics. As the body-centered vertical velocity decreases while athletes are moving upward to the peak after HTO, they need to have a sense and timing of twist motion. In particular, the balance mechanism of the inner ear in the section of freefall does not normally work (Graybiel, 1970), but it is relatively easy for athletes to control twist according to somersaulting in the upward phase to peak height.

This study analyzed the kinematic and kinetic variables of the Lou Yun and Akopian motions in the second flight upward phase in top athletes who participated in the gymnastic competition sponsored by the Ministry of Culture, Sports, and Tourism, which is similar to a pre-national championship. As previous studies with comparable results as those of this study, the studies by Lim (2005) and Kim (2006) on the Lou Yun motion, and those by Park (2001) and Lee et al. (2006) on the Akopian motion were reviewed.

As shown in (Table 1), we supposed that the athletes who performed the Lou Yun motion obtained sufficient aerial height (2.80 m) by using their breaking ability to convert horizontal velocity to vertical velocity, and that the athletes who performed the Akopian motion showed the ability of linear motion to obtain horizontal distance and aerial time (0.98 sec) by pushing the vault sufficiently. When the horizontal velocities in the Lou Yun and Akopian motions at horse take off (2.87 and 3.30 m/sec, respectively) in this study were compared with those in the studies of Lim (2005) and Kim (2006) (3.30 and 2.74 m/sec, respectively), and Park (2001) and Lee et al. (2006) (3.82 and 4.00 m/sec, respectively), the horizontal velocity of the Lou Yun athletes in this study was about moderate, and that of the Akopian athletes was not high. Moreover, the vertical velocities in the Lou Yun and Akopian motions at horse take off in this study (2.98 and 2.56 m/sec, respectively) were compared with those in the studies of Lim (2005) and Kim (2006) (3.10 and 3.29 m/sec), and Park (2001) and Lee et al. (2006) (2.72 and 3.66 m/sec). The study subjects obtained sufficient aerial time, although their vertical velocities were not high.

As shown in (Table 2), the preparation for the Lou Yun twist occurred in a short period (15 sec) after HTO. Hip twist is prepared by making a pike posture in order to prepare for the cat twist through a handspring. As Akopian motion precedes the side-turn movement and twist preparation can be achieved only by performing a shoulder twist (15.12 rad/sec) and hip twist (15.74 rad/sec), relatively plenty amount of time (22 sec) is required.

As shown in (Table 3), in the Lou Yun motion, the athlete rapidly prepares for a twist, providing sufficient time (0.27 sec) to reach the peak. The cat twist is attempted in pike posture at about 150° angle with the body stretched at height, and smaller shoulder (12.85 rad/sec) and hip twists (10.17 rad/sec) than in the Akopian motion are performed. It is supposed that in the Akopian motion, shoulder twist (15.75 rad/sec) leads to hip twist (15.31 rad/sec) owing to the influence of the side turn and that the large total angular momentum is a result of the *X*-axis angular momentum produced during HTO. When the body COG maximum height in the Lou Yun and Akopian motions at the second flight in this study (2.80 and 2.73 m, respectively) were compared with those in the studies of Lim (2005) and Kim (2006) (2.97 and 2.74 m, respectively), and Park (2001) and Lee et al. (2006) (2.69 and 2.73 m, respectively), we found that the subjects in our study obtained sufficient aerial height.

As shown in (Table 4), considering that the lapse time in the Lou Yun and Akopian motions finally became the same at HTW after vault takeoff, successful landing position relies on the number of twists. As no significant difference in tilt angle was found between the two techniques and the tilt angle is within 10°, it is desirable for athletes to increase the angular velocity of the upper body twist by tilting the body as much as they can. Yeadon (1990) reported that about 8° of body tilt could cause a twist by tilting the entire body with an arm motion during somersaulting. When the whole-body total angular momentum in the Lou Yun and Akopian motions at the second flight in this study (411.2 and 438.4 10^{-3}/sec, respectively) were compared with those in the studies of Lim (2005) and Kim (2006) (421.2 and 374.1 10^{-3}/sec), we found that the subjects of this study obtained sufficient angular momentum. In addition, when the second flight times in the Lou Yun and Akopian motions in this study (1.06 and 0.98 sec, respectively) were compared with those in the studies of Lim (2005) and Kim (2006) (0.97 and 0.98 sec, respectively), and Park (2001) and Lee et al. (2006) (0.87 and 0.89 sec, respectively), we found that the subjects in this study obtained sufficient aerial time.

As such, it is supposed that the linear and angular momenta were sufficient in the second flight of the subjects of this study. However, considering that the pattern of timing for the shoulder and hip twists varied by athletes, shoulder and hip twists need to be prepared more rapidly in order to prepare for landing after successful performance in the upward phase.

Overall, the Lou Yun motion provides sufficient time to prepare for a twist compared with the Akopian motion and has the advantage of a cat twist, in which vault takeoff is accomplished by breaking and the hip is twisted. However, in order to avoid score penalties when the body is not stretched, athletes will need to attempt to compromise at a certain point. In addition, because in the Akopian motion, vault entry occurs by a side turn, it is desirable to reduce angular impulse time by reducing the distance between two hands resting on the vault in order to obtain large angular impulse. As the whole-body total angular momentum is relatively large, the whole-body longitudinal moment of inertia should be controlled to transfer this to the number of twists. Therefore, even if aerial height is not established due to insufficient vertical velocity after vault takeoff, we suppose that the ability to transfer to angular motion spontaneously is significant.

CONCLUSION

Among male athletes who performed the Lou Yun and Akopian motions in the final vault game of the 37th gymnastic championship sponsored by the Ministry of Culture, Sports, and Tourism and whose landing was stable after making a counter-clockwise twist following HTO were selected as study subjects and participated in 12 trials (Lou Yun motion, 7 trials and Akopian motion, 5 trials). The Lou Yun and Akopian techniques were filmed at a sampling rate of 90 frame/sec. The location coordinates were generated by using the DLT method. As the result of the mean of the kinematic and kinetic variables of half twist after HTO was calculated and compared, the characteristics of twist according to somersault were obtained.

In the Lou Yun motion, vertical velocity by horse breaking was easy to obtain, leading to sufficient time to prepare for a twist. It has the advantage of the cat twist, in which the hip is twisted by making the pike posture in aerial movement.

In the Akopian motion, vault entry is achieved by making a side turn; thus, it is easy to obtain horizontal velocity by horse pushing, which produces a large whole-body total angular momentum. In addition, shoulder twist is easy owing to the inertia of the side turn; thus, body tilt is favorable, making a body tilt twist easy to perform.

Both the Lou Yun and Akopian motions should be able to control the longitudinal moment of inertia of the entire body by controlling the motions of body segments in order to increase the number of twists in aerial movement, and shoulder and hip twists should be prepared more rapidly to prepare for landing in the upward phase.

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