KASAMATSU VERSUS TSUKAHARA VAULT

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Original article

Abstract

In the gymnastics vault, many male gymnasts presently perform vaulting of the Kasamatsu type in competitions. The purpose of this study was to clarify the characteristics of the vaulting motion of the Kasamatsu vault in comparison with the Tsukahara vault. Six male college gymnasts performed the Kasamatsu and Tsukahara vaults. Their vaulting motion was captured by the 3-dimensional optical motion capture system MAC3D. For both the Kasamatsu and Tsukahara vaults, horizontal velocity of the center of mass decreased, vertical velocity increased, and angular momentum was produced in the board contact phase. In addition, horizontal and vertical velocity decreased in the vault contact phase. However, no significant difference was observed between both vaults. The contribution of the upper limbs to angular momentum about the center of mass was significantly higher for the Kasamatsu vault than that for the Tsukahara vault at vault takeoff. These results suggest that the turn during the Kasamatsu vault was performed with rotation of the lower limbs being suppressed and angular momentum being maintained using the upper limbs.

Keywords: *biomechanics, gymnastics, kinamtics, upper limbs, lower limbs.*

INTRODUCTION

The vaulting motion is composed of the run-up, board contact, pre-flight, vault contact, post-flight, and landing phases. Among them, it is possible to alter the mechanical parameters in the board and vault contact phases, but the force that can be adjusted in the vault contact phase is slight, and it is difficult to make up for an error by the vault contact phase if it occurs during the board takeoff motion (Prassas, 1999). The force in the board contact phase is important to the success of vaulting performance (Takei, Dunn, & Blucker, 2003).

There are 3 types of vaults: front handspring, sideways handspring, and Yurchenko. With respect to the front handspring type, it has been reported that there is a positive correlation between distance of the post-flight phase and horizontal velocity of the center of mass at board takeoff (Cheetham, 1983), velocity and angular velocity in the pre-flight and vault contact phases are important determinants for the success of the 'handspring and somersault forward tucked' (King, Yeadon, & Kerwin, 1999; Takei, 1988), the force in the vault contact phase affects the height of the center of mass and the number of rotations of the somersault (Takei, 1991a, 1991b), and the force in the board contact phase is an important factor

(Takei, Dunn, & Blucker, 2003). With respect to the Yurchenko type, it has been reported that touching down on the springboard by raising the upper body and increasing the vertical velocity of the center of mass by block motion in the vault contact phase affect the height and distance of the post-flight phase (Uzunov, 2010). As noted, there have been many studies showing the importance of the board contact and vault contact phases in vaults of the front handspring and Yurchenko types. However, with respect to the Kasamatsu type, which is a sideways handspring type of vault that many male gymnasts have been performing in competitions in recent years, although it has been reported for hand placement (Kerwin et al., 1993) and kinematic parameters of Kasamatsu vault with 1 turn (Akopian) (Farana, Uchytil, Jandacka, Zahradnik, & Vaverka, 2014), biomechanical study of vault of the Kasamatsu type is less than the front handspring type.

The Kasamatsu vault was first pioneered by Shigeru Kasamatsu at the 1974 World Cup. This vault is performed by a handspring with 1/4 turn in pre-flight and a backward somersault with 3/4 turn in post-flight. In the vaults of the Kasamatsu type, the D-score is incremented by 0.4 for each additional 1/2 turn in the post-flight phase. Kasamatsu vault with 2 turns (Lopez, D-score 6.0) is described in the code of points of men's artistic gymnastics as the vault of the highest difficulty among the Kasamatsu-type vaults (FIG, 2013). The motions of board contact and vault contact are also important factors for the success of Kasamatsu-type vaults, and it is important to clearly teach the motions and techniques in order to effectively improve performance. Therefore, the present study aimed to clarify the characteristics of the vaulting motion of the Kasamatsu vault by comparison with the Tsukahara vault, which is a sideways type that does not have a turn in the post-flight phase.

METHODS

Subjects

Six male college gymnasts (age: 20.0±1.5 years, height: 1.64±0.04 m, body mass: 59.6±3.7 kg, competition history: 11.5±2.3 years) volunteered to participate in this study. After explaining the purpose, measurement content, risks, and data management of the study, informed consent was obtained from each subject. This study was conducted in accordance with the Declaration of Helsinki and approved by the ethics committee of the National Institute of Fitness and Sports in Kanoya.

Measurement methods and data processing

After sufficient warm-up, subjects performed the Kasamatsu vault (D-score 4.4, Figure 1) and Tsukahara vault (D-score 3.6, Figure 2) each twice randomly. All trials were recorded using the 3-dimensional optical motion capture system MAC3D (Motion Analysis Corp., USA, 400Hz), and the performance was scored by a certified judge of the Japan Gymnastics Association. A higher trial of E-score, indicating the quality of the performance, was selected for analysis for each vault. A reflective marker with a diameter of 18mm, which was attached to the body portion of the subject, was captured by synchronized Raptor 12 cameras, and 3-dimensional coordinates were recorded by Cortex 3.1.1 (Motion Analysis Corp., USA) key software. The reflective makers were attached to the parietal, front head, rear head, acromion (left and right), lateral epicondyle of the humerus (left and right), ulnar styloid process (left and right), third metacarpal bone (left and right), lower end of the scapula (right), sacrum, lower rib (left and right), anterior superior iliac spine (left and right), greater trochanter (left and right), lateral epicondyle of the femur (left and right), heel bone (left and right), external condyle fibula (left and right), and third metatarsal bone (left and right). The coordinate system was set to a static coordinate system consisting of X-axis vector in the horizontal direction with respect to the advancing direction, Y-axis vector in the advancing direction, and Z-axis vector in the vertical direction. The plus X-axis represented the direction in which each subject turned. The 3-dimensional coordinate values obtained by MAC3D were smoothed using a fourth-order lowpass Butterworth filter with 10.3-19.5Hz cut-off frequency calculated by residual analysis (Winter, 2009) .

Evaluation items

Based on the smoothed 3-dimensional coordinates, the body was regarded as a rigid body composed of 15 segments, and velocity of the center of mass, angular velocity of trunk and lower limbs, and angular momentum about the center of mass (Hay et al., 1977) were calculated using the inertia coefficient of the body segments in Japanese athletes (Ae et al., 1992). In addition, angular momentums of the head, trunk, right upper limbs, left upper limbs, right lower limbs, and left lower limbs were calculated, and their contribution was calculated by dividing by the angular momentum of the whole body. The performance of the vault was divided into four phases: board contact phase (to board takeoff from board touchdown), pre-flight phase (to vault touchdown from board takeoff), vault contact phase (to vault takeoff from vault touchdown), and post-flight phase (to landing from vault takeoff). The time of each phase was calculated.

Statistical analysis

Descriptive data are presented as mean and standard deviation. After the tests of normality and equal variance, two-way ANOVA with repeated measures (vaults vs. phases) was used to test changes in the velocity and angular momentum of the two vaults. If significant main effects were found, Bonferroni post-hoc test was used to identify the differences. The paired t-test was used to compare the two vaults. This statistical analysis was performed using the IBM SPSS Statistics 22 (IBM Corp., USA) and the significance level was set at $p<0.05$.

RESULTS

Motion time of each phase

Table 1 shows the results of the time of each phase. There was no significant difference in the times of board support, pre-flight, vault support, and post-flight phases between the two vaults.

Velocity of the center of mass

Horizontal velocity of the center of mass was not an observed interaction between vaults and phases. A main effect was not observed for the vaults, but was observed for phases ($F=268.846$, $p<0.001$). The post-hoc tests showed horizontal velocity of the center of mass significantly decreased in board takeoff from board touchdown ($p<0.001$) and in vault takeoff from vault touchdown ($p<0.01$, Table 2). Vertical velocity of the center of mass was not an observed interaction between vaults and phases. A main effect was not observed for the vaults, but was observed for phases ($F=1798.924$, $p<0.001$).

The post-hoc tests showed vertical velocity of the center of mass significantly increased in board takeoff from board touchdown ($p<0.001$) and decreased in vault touchdown from board takeoff, vault takeoff from vault touchdown, and landing from vault takeoff ($p<0.001$, Table 2).

Angular momentum about the center of mass

Angular momentum about the center of mass was not an observed interaction between vaults and phases. A main effect was not observed for the vaults, but was observed for phases ($F=452.77$, $p<0.001$). The post-hoc tests showed the absolute value of angular momentum significantly increased in board takeoff from board touchdown and decreased in vault takeoff from landing ($p<0.001$, Table 2).

Regarding the contribution of each body segment in angular momentum, there was no significant difference between the vaults at board touchdown, board takeoff, or vault touchdown (Table 3). On the other hand, the contribution of the upper limbs in the Kasamatsu vault was significantly higher than that in the Tsukahara vault ($p<0.05$), and the contribution of the right lower limbs in the Kasamatsu vault was significantly lower than that in the Tsukahara vault at vault takeoff ($p<0.05$, Table3). The contribution of the left upper limbs in the Kasamatsu vault was significantly lower than that in the Tsukahara vault ($p<0.05$, Table 3).

Angular velocity of trunk and lower limbs

Angular velocity of the trunk was not an observed interaction between vaults and phases. A main effect was not observed for the vaults, but was observed for phases ($F=66.865$, $p<0.001$). The post-hoc tests showed the absolute value of angular velocity of the trunk significantly increased in board takeoff from board touchdown ($p<0.01$, Table 4). On the other hand, angular velocity of the lower limbs was an observed interaction between vaults and phases ($F=8.133$, $p<0.001$). A simple main effect was observed for the vaults at vault takeoff ($F=16.635$, $p<0.01$). In addition, a simple main effect was observed for phases ($F=876.824$, $p<0.05$), changing significantly in board takeoff from board touchdown ($p<0.05$), vault touchdown from board takeoff ($p<0.05$), and landing from vault takeoff ($p<0.001$, Table 4).

Table 1
Motion time of each phase

	Kasamatsu vault	Tsukahara vault	t-test
Board contact phase (s)	0.124 ± 0.008	0.128 ± 0.007	n.s.
Pre-flight phase (s)	0.067 ± 0.023	0.069 ± 0.022	n.s.
Vault contact phase (s)	0.283 ± 0.036	0.296 ± 0.029	n.s.
Post-flight phase (s)	0.865 ± 0.026	0.842 ± 0.030	n.s.

Table 2
Velocity of the center of mass and angular momentum about the center of mass.

Variables	Kasamatsu vault	Tsukahara vault	Vaults vs. Phases	Vaults	Phases
Horizontal velocity (m/s)					F=268.846 ***
Board touchdown	7.24 ± 0.23	7.21 ± 0.17			] ***
Board takeoff	4.89 ± 0.23	4.91 ± 0.21			] n.s.
Vault touchdown	4.68 ± 0.31	4.77 ± 0.31	F=0.993 n.s.	F=0.585 n.s.	] **
Vault takeoff	3.10 ± 0.24	3.00 ± 0.40			] n.s.
Landing	3.01 ± 0.47	2.96 ± 0.41			
Vertical velocity (m/s)					F=1798.924 ***
Board touchdown	-1.46 ± 0.14	-1.51 ± 0.15			] ***
Board takeoff	4.23 ± 0.18	4.17 ± 0.14			] ***
Vault touchdown	3.43 ± 0.18	3.28 ± 0.17	F=0.884 n.s.	F=5.043 n.s.	] ***
Vault takeoff	2.47 ± 0.09	2.14 ± 0.27			] ***
Landing	-3.75 ± 0.56	-3.63 ± 0.71			
Angular momentum (kgm^2/s)					F=452.779 ***
Board touchdown	-5.9 ± 1.5	-5.3 ± 2.3			] ***
Board takeoff	-79.6 ± 4.1	-78.3 ± 6.2			] n.s.
Vault touchdown	-79.0 ± 5.1	-78.0 ± 6.5	F=0.643 n.s.	F=0.002 n.s.	] n.s.
Vault takeoff	-82.7 ± 8.1	-81.6 ± 6.0			] ***
Landing	-44.0 ± 6.6	-48.8 ± 10.3			

** : p<0.01, ***: p<0.001

Table 3
Contribution of each body segment to angular momentum.

Variables	Kasamatsu vault	Tsukahara vault	t-test
Board touchdown (%)			
Head	-16.4 ± 13.5	-22.9 ± 20.8	n.s.
Trunk	-3.3 ± 4.3	-9.4 ± 14.3	n.s.
Upper limbs (Right)	-15.5 ± 32.7	-13.2 ± 44.5	n.s.
Upper limbs (Left)	-35.6 ± 31.3	-36.8 ± 49.9	n.s.
Lower limbs (Right)	75.3 ± 31.7	95.1 ± 46.9	n.s.
Lower limbs (Left)	95.5 ± 41.4	87.1 ± 69.1	n.s.
Board takeoff (%)			
Head	12.7 ± 0.8	12.6 ± 0.7	n.s.
Trunk	11.2 ± 0.8	11.5 ± 0.8	n.s.
Upper limbs (Right)	9.3 ± 1.6	9.3 ± 1.7	n.s.
Upper limbs (Left)	8.9 ± 1.5	8.2 ± 2.3	n.s.
Lower limbs (Right)	25.2 ± 8.9	23.7 ± 7.1	n.s.
Lower limbs (Left)	32.7 ± 9.8	34.7 ± 8.5	n.s.
Vault touchdown (%)			
Head	11.4 ± 1.4	11.8 ± 1.3	n.s.
Trunk	10.4 ± 1.2	10.5 ± 0.6	n.s.
Upper limbs (Right)	8.2 ± 0.8	8.2 ± 1.3	n.s.
Upper limbs (Left)	7.2 ± 1.5	7.0 ± 1.6	n.s.
Lower limbs (Right)	26.3 ± 12.9	25.4 ± 9.6	n.s.
Lower limbs (Left)	36.6 ± 14.0	37.1 ± 10.8	n.s.
Vault takeoff (%)			
Head	13.3 ± 1.5	11.8 ± 2.1	n.s.
Trunk	10.7 ± 1.4	11.5 ± 0.5	n.s.
Upper limbs (Right)	7.1 ± 3.2	3.6 ± 1.8	*
Upper limbs (Left)	7.8 ± 1.3	5.8 ± 1.5	**
Lower limbs (Right)	30.8 ± 2.4	34.9 ± 2.5	*
Lower limbs (Left)	30.4 ± 3.7	32.3 ± 3.1	n.s.
Landing (%)			
Head	25.5 ± 5.4	24.5 ± 6.3	n.s.
Trunk	20.7 ± 3.3	19.1 ± 4.7	n.s.
Upper limbs (Right)	5.9 ± 3.2	6.5 ± 3.0	n.s.
Upper limbs (Left)	2.9 ± 2.9	6.7 ± 3.3	*
Lower limbs (Right)	21.0 ± 3.6	20.3 ± 1.6	n.s.
Lower limbs (Left)	24.0 ± 3.7	22.9 ± 2.9	n.s.

* : $p<0.05$, **: $p<0.01$

Table 4

Angular velocity of trunk and lower limbs.

Variables	Tsukahara vault	Kasamatsu vault	Vaults vs. Phases	Vaults	Phases	
Trunk angular velocity (deg/s)					F=56.865 ***	
Board touchdown	193.8 ± 30.2	185.0 ± 26.4				
Board takeoff	-397.7 ± 42.5	-403.6 ± 40.7			] ***	
Vault touchdown	-352.8 ± 49.8	-365.8 ± 39.6	F=1.451 n.s.	F=1.212 n.s.	] n.s.	
Vault takeoff	-471.0 ± 35.5	-302.4 ± 55.8			] n.s.	
Landing	-443.3 ± 161.6	-458.3 ± 235.3			] n.s.	
Lower limb angular velocity (deg/s)					Kasamatsu	Tsukahara F=76.824 ***
Board touchdown	-365.0 ± 40.0	-334.1 ± 70.9		F=1.757, n.s.		
Board takeoff	-534.0 ± 29.4	-532.6 ± 66.7		F=0.002, n.s.		] ***
Vault touchdown	-605.3 ± 101.7	-578.3 ± 66.9	F=8.133 ***	F=1.387, n.s.	F=16.891 n.s.	] n.s.
Vault takeoff	-500.5 ± 65.7	-722.8 ± 54.9		F=16.635, **		] **
Landing	-78.2 ± 117.6	-83.7 ± 83.5		F=0.035, n.s.		] ***

** : p<0.01, ***: p<0.001

DISCUSSION

The motion time of post-flight affects the acquisition of sufficient height and distance in the air, and it is important to perform somersaults and turns. In studies comparing high-score and low-score gymnasts among gymnasts performing a ‘handspring and somersault forward tucked’, it has been reported that the motion time of post-flight of high-score gymnasts is longer (Takei, 1991a, 1991b). However, in a study carrying out a similar comparison in a ‘handspring and two somersaults forward tucked (Roche)’, no significant difference was found between the two groups (Takei, Dunn, & Blucker, 2003). The difference in the difficulty of the vaults affected the results of these studies.

Roche is a vault that has an additional somersault compared to the ‘handspring with somersault forward tucked’, and it has a D-score of 6.0 under the current rules (FIG, 2013). In addition, the motion time of post-flight in these studies was 0.95 seconds when performing the ‘handspring with somersault forward tucked’ and 1.02 seconds when performing the Roche. Therefore, vaults of high difficulty require a longer motion time in the post-flight phase. In other words, it is estimated that the motion time of the Kasamatsu vault is longer because the Kasamatsu vault is a technique that has an additional turn compared to the Tsukahara vault. However, no significant difference was observed in the motion time of the post-flight phase (Table 1). In the present study, the gymnasts performed both the Tsukahara and Kasamatsu vaults, and their performance levels were higher when performing the former, which is less difficult.

In the board contact phase, horizontal velocity of the center of mass decreased, vertical velocity of the center of mass increased, and angular momentum about the center of mass was produced (Table 2). This result is consistent with many previous studies (Dillman, Cheetham, & Smith, 1985; Takei, 1988; Takei & Komi, 1990; Takei, Dunn, & Blucker, 2003; Uzunov, 2010). The block motion executed during the board contact phase, with the lower limbs tilting backwards, may have enabled the gymnasts to add a large anterior force to the springboard during the initial jump-off phase and effectively use it, in order to convert the horizontal velocity of the center of mass into the vertical velocity. At this time, the direction of the force applied to the body deviates from the direction of the center of mass. The lower limbs can easily swing up and the rotation required for the somersault of the post-flight phase is produced. It was shown that angular velocity of the lower limbs has a higher absolute value than that of the angular velocity of the trunk at board takeoff (Table 4). This suggests too that quickly swinging up the lower limbs can also be performed.

In the vault contact phase, vertical velocity of the center of mass significantly decreased (Table 2). It has been reported that vaults of the front handspring type are shorter contact time than vaults of the sideways handspring type (Farana et al., 2014), and vertical velocity of the center of mass increases in vault touchdown of vaults of the front handspring type (Dillman, Cheetham, & Smith, 1985; Takei, 1988; Takei & Kim, 1990; Takei, 1991a, 1991b; Takei, Dunn, & Blucker, 2003). Because both hands touch down at the same time in vaults of the front handspring type, the vault contact time is short and vault contact motion can be performed effectively by using block motion of the shoulder. On the other hand, vaults of the sideways handspring type have a long vault contact time and force is absorbed in the first vault touchdown because the hands touch down one at a time. Therefore, in the sideways handspring type, vault contact motion is not performed effectively. In vaults of the sideways handspring type, accelerating the velocity before and preventing it from decreasing during the vault contact phase may be key to successful performance. A new vault was introduced in 2001, in which the width between the hands in vault touchdown is narrower than that of vaults of the sideways handspring type. When the motion of the Lopez performed by Yang Huk-Seon, who won a gold medal in the Olympics, is observed with video, it involves a narrow width between the hands, a short time touching the vault with only one hand, and contact motion with the vault similar to that of the front handspring type. The vault contact motion makes it possible to convey force effectively and enables acquiring sufficient height in post-flight.

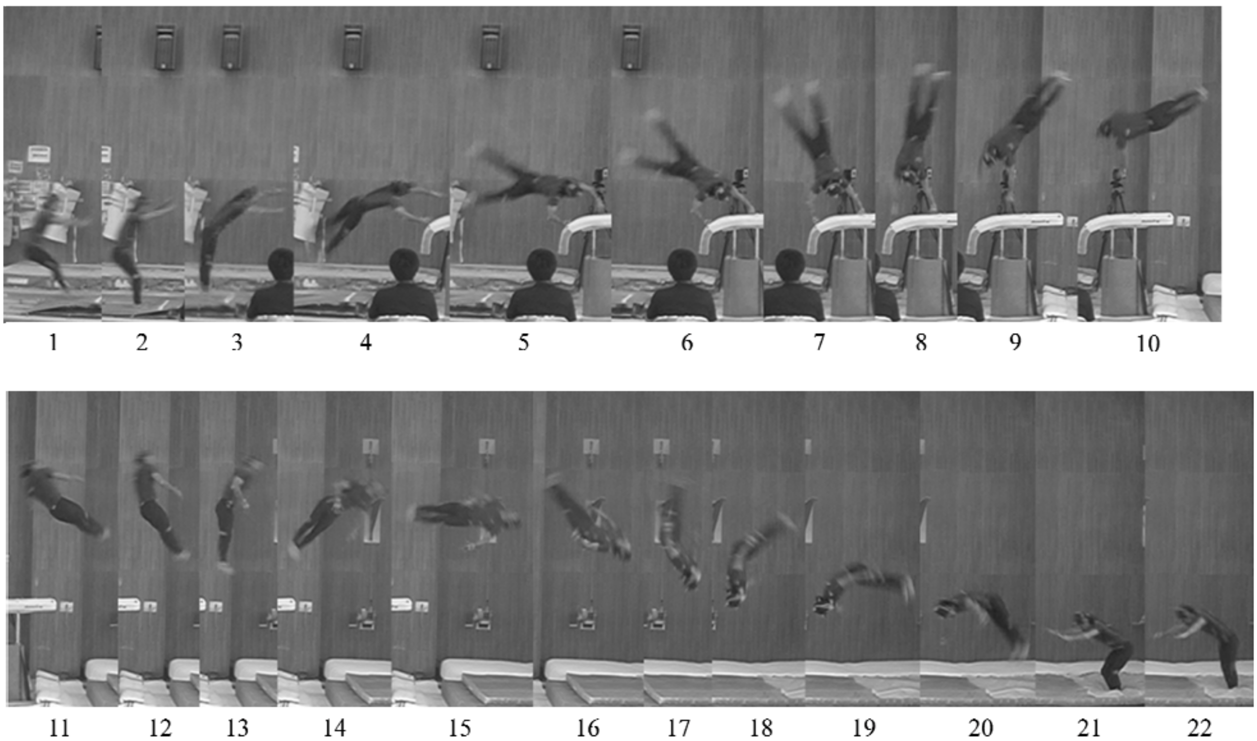

Figure 1. The sequence of the Kasamatsu vault.

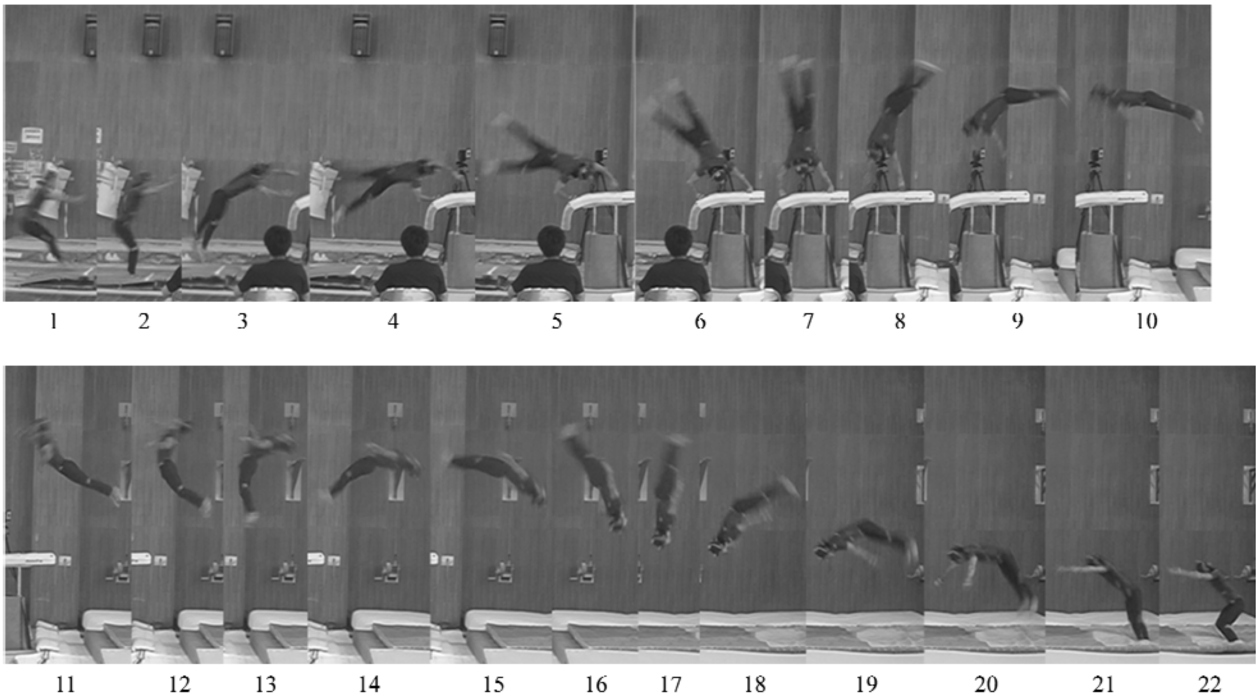

Figure 2. The sequence of the Tsukahara vault.

There was no significant difference in angular momentum about the center of mass between vaults (Table 2). No difference in the results of the present study was observed from the lateral axis of the body because the number of rotations of the somersault is the same in the Tsukahara and Kasamatsu vaults. On the other hand, the previous study comparing the 'handspring and somersault forward straight with 3/2 turns (Lou Yun)' and the Akopian has shown that the Akopian is more 1/2 turn in the post-flight and higher angularvelocity about the longitudinal axis than the Lou Yun (Farana et al. 2014). From this, here may be differences in the angular momentum based on the longitudinal body axis between two vaults. In vault takeoff, the contribution of the upper limbs in the Kasamatsu vault was significantly higher than that of the Tsukahara vault, and the contribution of the lower limbs in the Kasamatsu vault tended to be lower than that of the Tsukahara vault (Table 3). Looking at frames 8-11 in Figures 1 and 2, after vault takeoff, the arms were kept close to the side of the trunk when performing the Tsukahara vault, while they were lifted when performing the Kasamatsu vault. In addition, in the Kasamatsu vault there seems to be suppression of rotation of the lower limbs (Figure 2, frame 10). That is, no difference was observed between vaults in angular momentum of the whole body, but the factors maintaining angular momentum during the vault may be different. The Kasamatsu vault creates an additional turn by suppressing the rotation of the lower limbs and making use of the upper limbs. The contribution of the left upper limbs to angular momentum in the Kasamatsu vault was significantly lower at landing (Table 3). This may be explained by the influence of the twist-releasing motion to prepare for landing as seen in frames 16-20 of Figure 2.

CONCLUSIONS

The purpose of this study was to clarify the characteristics of the vaulting motion of the Kasamatsu vault in comparison with the Tsukahara vault. According to the results, the characteristics of the Kasamatsu vault are as follows:

1) In the board contact phase, horizontal velocity of the center of mass was converted to vertical velocity, and angular momentum was produced.

2) In the vault contact phase, vertical velocity of the center of mass decreased.

3) Angular momentum about the lateral axis of the Kasamatsu vault was comparable to the Tsukahara vault.

4) Suppressing the rotation of the lower limbs and performing a turn with the upper limbs swinging up was effective in order to maintain angular momentum about the lateral axis and obtain angular momentum about the longitudinal axis at vault takeoff.

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