BIOMECHANICAL ANALYSIS OF ROTATION STRATEGY OF BACKWARD SOMERSAULT IN ARTISTIC GYMNASTICS

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The purpose of this study was to examine the rotation strategy used by gymnasts to successfully land after a backward somersault. Nine male university gymnasts (1.66 ± 0.03 m, 61.2 ± 0.75 kg) performed a backward-tucked somersault from a box (0.3 m height). Three-dimensional coordinate data was collected by a Vicon MX+ system. We compared the trials in which the landing succeeded and trials in which the landing failed. There was a difference in the moment of inertia during the airborne phase and the phase time. The results of this study suggest that changing the moment of inertia during the airborne phase has a significant effect on the body rotation. In particular, it is considered that the timing at which the phase is switched by changing the moment of inertia determined the body rotation.

KEY WORDS: landing, motion analysis, moment of inertia, angular momentum.

INTRODUCTION: Landing skill after somersault is important to minimize point deduction in artistic gymnastics. The posture and movement of the body at the instant of landing have very large influence on success or failure of landing, which means that a gymnast does not move after landing or moves after landing. As no external forces except the gravity act on the body during the airborne phase, the angular momentum of the entire body is conserved during the airborne phase. To perform a successful landing, it is necessary for a gymnast to control the rotation of the body by changing the moment of inertia of the body during the airborne phase. Hwang et al. (1990) examined the biomechanical profiles during the takeoff phase of double backward somersaults. McNitt-Gray et al. (2001) examined the multi-joint control of the reaction force during landings. The previous biomechanical studies during the airborne phase are less than those of takeoff and landing phases. The purpose of this study was to examine the rotation strategy used by gymnasts to successfully land backward somersault.

METHODS: Nine male university gymnasts (1.66 ± 0.03 m, 61.2 ± 0.75kg, 20.1 ± 1.9 years) participated in this study. Three-dimensional data of the gymnasts performing backward-tucked somersault from a box (height: 0.3m) were collected using 20-camera Vicon MX+ system (Vicon Motion Systems Ltd., UK) operating at 250 Hz. Coordinate data of the body were smoothed using a Butterworth digital filter. Optimal cut-off frequencies (15-35 Hz) were identified using the residual method proposed by Wells & Winter (1980). This study was approved by an ethics committee in university of Tsukuba.
Gymnasts performed somersault ten times; two trials for each gymnasts were selected for the analysis of the airborne phase: one trial with successful landing and the other trial with failure landing. We defined the trial in which the gymnast moved with forwards step or hop after landing as "Forward", backwards step or hop as "Backward", no step or hop as "OK".
The instant in which the moment of inertia of the whole body reached the minimum value was used to divide the airborne phase into `Close phase` (CL) and `Open phase` (OP) (Figure 1). Figure 1 shows the definition of segment angle. The inertial parameters were estimated with the inertia coefficients proposed by Ae et al. (1992). The angular momentum in the global coordinate system was calculated by using the method proposed by Dapena (1978). The angular momentum about the center of gravity (CG) was normalized by both the square of body height and the body mass (the unit of normalized angular momentum was s^{-1}). The moment of inertia about CG was normalized by both the square of body height and the body mass.

The angular momentum about CG was divided by the moment of inertia about CG to calculate the conceptional angular velocity of the body. The conceptional angular velocity of the body was time-integrated to calculate the body rotation. The paired t-test was used to compare variables at takeoff, landing and that of during the airborne phase between “Forward” or “Backward” and “OK”.

RESULTS: Table 1 show the duration time and the body rotation of each phase. The CL time of “Backward” was longer than that of “OK”, and the OP time of “Backward” was shorter than that of “OK”. In the same way, the CL rotation of “Backward” was larger than that of “OK” and the OP rotation of “Backward” was smaller than that of “OK”. There was no difference among duration times of all phases between “Forward” and “OK”. On the other hand, the rotation of “Forward” was smaller than that of “OK” in all phase.
Table 2 shows each segment angle at the takeoff and landing. There was no difference among all segment angles at takeoff except the shank angle of “Forward.” On the other hand there was a large difference at landing. All segment angles of “Forward” were smaller than those of “OK.” The angles of thigh and shank of “Backward” were larger than “OK.”
Figure 2 shows the vertical CG velocity and the normalized angular momentum about CG at takeoff. There was no difference between either “Forward” or “Backward” and “OK” in the CG velocity, and there was no difference in the angular momentum.
Figure 3 shows the moment of inertia during the airborne phase of four typical subjects. The change in the moment of inertia of CL was also similar, but the change in that of OP was different compared with “OK”. The duration time of each phase were almost same as “OK”, but the change rate of the moment of inertia during the OP was different. The change rate of moment of inertia during the OP of subject A (Figure 3, top left) was larger than “OK”, so the body rotation of “Forward” was smaller than “OK”. On the other hand, that of subject B (Figure 3, top right) was smaller than “OK”, so the body rotation of “Backward” was larger than “OK”. The moment of inertia during the airborne phase of subject C (Figure 3, bottom left) was smaller than "OK". The minimum value of the moment of inertia of subject D (Figure 3, bottom right) was smaller than "OK".

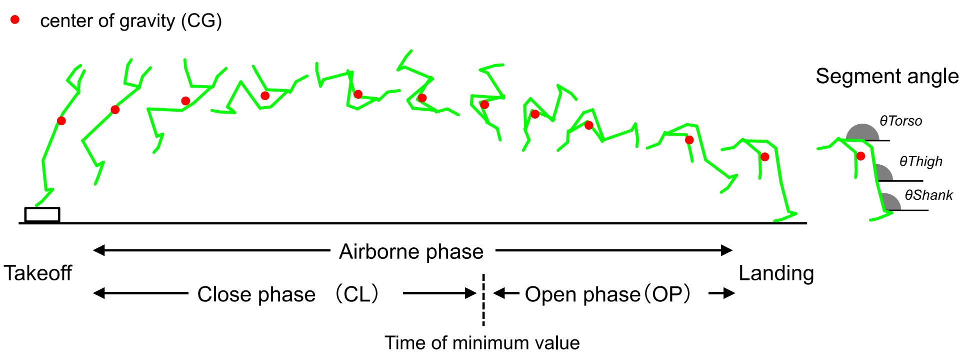

Figure 1: Phase definition of moment of inertia about CG and segment angle definition.

Table 1: The duration time and body rotation of each phase.

	Duration time (s)		**Body rotation (deg)**	
	CL	**OP**	**CL**	**OP**
Forward	0.388±0.016	0.267±0.010	160.7±15.5	130.1±4.49
OK	0.386±0.016	0.272±0.015	165.4±15.5	133.7±5.58
	n.s.	n.s.	* Forward < OK	* Forward < OK
Backward	0.415±0.035	0.225±0.010	184.1±5.69	115.9±4.01
OK	0.408±0.034	0.241±0.019	178.7±8.29	121.4±2.60
	* Backward > OK	* Backward < OK	* Backward > OK	* Backward < OK

n.s. : not significant   * $p < 0.05$

Table 2: Each segment angle at takeoff and landing.

	Takeoff (deg)			Landing (deg)		
	Torso	Thigh	Shank	Torso	Thigh	Shank
Forward	49.5±2.25	67.5±2.51	98.8±1.55	174.6±2.15	98.3±0.36	114.7±2.48
OK	47.9±2.45	66.8±1.32	97.4±1.78	168.8±1.75	90.3±2.31	107.3±4.03
	n.s.	n.s.	* Forward > OK	* Forward > OK	** Forward > OK	** Forward > OK
Backward	44.5±4.25	67.5±4.93	93.5±5.91	167.6±4.87	86.4±2.04	103.1±4.97
OK	47.4±6.40	68.6±7.45	93.8±6.87	171.4±9.66	89.6±3.67	106.7±6.78
	n.s.	n.s.	n.s.	n.s.	* Backward < OK	* Backward < OK

n.s. : not significant * $p < 0.05$ ** $p < 0.01$

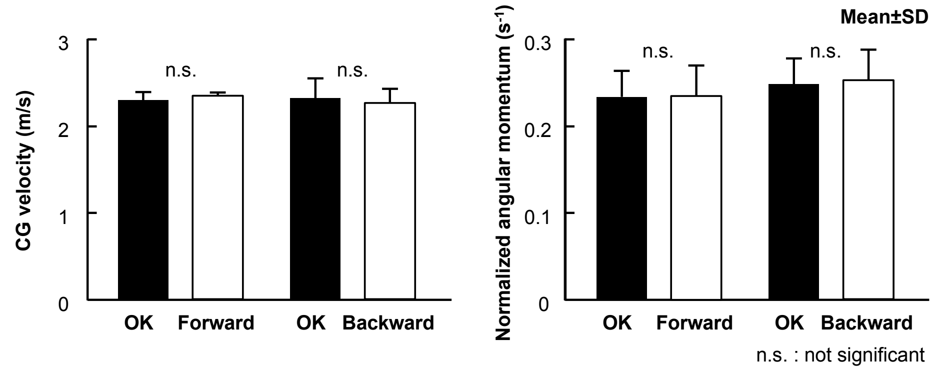

Figure 2: The vertical CG velocity and angular momentum about CG at takeoff.

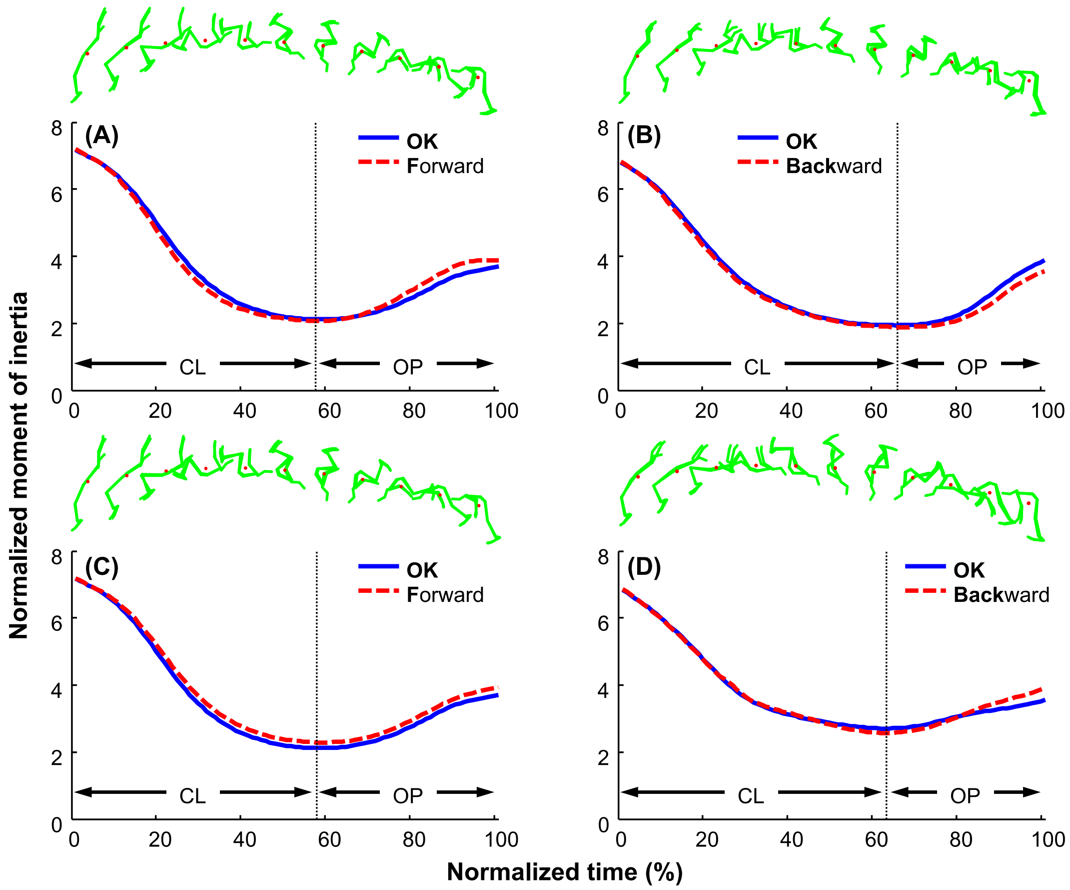

Figure 3: Moment of inertia during the airborne phase of typical subjects.

DISCUSSION: As no external forces except the gravity act on the body during the airborne phase, the angular momentum of the entire body is conserved. So the factors determining the body rotation during the airborne phase are the angular momentum, the posture at takeoff, the duration time from the takeoff to the landing, and the change in the moment of inertia during the airborne phase.
The parameters (posture, CG velocity, angular momentum) at takeoff had a little difference between “Forward” or “Backward” and “OK” (Table 2, Figure 2). The posture at landing was tilted either backward or forward. Therefore, it was suggested that the change in the moment of inertia during the airborne phase had greatly affect the success or failure of landing. Since the results of phase rotation and phase time showed similar in the case of “Backward”, it was considered that the difference of the body rotation by moment of inertia was dependent on the timing of switching from CL to OP (Table 1). On the other hand, there was no difference in the phase time but the phase rotation was smaller than that of "OK" in the case of “Forward”. Since there was little reduction of the moment of inertia after takeoff, body rotation was small. In other words, it was suggested that landing was successful by controlling the change in the moment of inertia. As mentioned above, there were various factors that determined the body rotation. In addition, there was also affected by landing motion may or may not be more successful.

CONCLUSION: The result of this study suggested that a change in the moment of inertia during the airborne phase had a greatly effect on the body rotation. In particular, it was considered that the timing of switching from the close phase to open phase determined the body rotation.

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