A CASE STUDY OF THE GENERATION OF ANGULAR MOMENTUM AND ANGULAR VELOCITY IN SOMERSAULT BACKWARD STRETCHED WITH 2/1 AND 3/1 TWISTS PERFORMED BY A SINGLE VARSITY MALE GYMNAST

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The purpose of this study was to compare the angular momentum and angular velocity in somersault backward stretched with different number of twists performed by a single varsity male gymnast. The 3D motion captured system (Qualisys, 250Hz) was used to collect kinematic data of a single varsity male gymnast A who performed the somersault backward stretched with a double (2/1) and a triple (3/1) twist. The angular momenta and angular velocities of the body segments and whole body were calculated by the Tang's method. More than a half of the twist angular momentum of the whole body in both 2/1 and 3/1 twists was generated during the take-off phase, which indicated that the gymnast A was classified as a contact twist type. In case of the gymnast A there seemed no difference in angular momenta of 2/1 and 3/1 twists, although he generated the angular momentum of the twist earlier in 3/1 than 2/1. He controlled the number of twists by his body maneuver before landing. Since these findings were obtained from a single gymnast, we need to investigate twist techniques and angular momentum date of various gymnasts.

KEYWORDS: angular momentum, angular velocity, gymnastics, twists

INTRODUCTION: In the final floor exercise of the Men's Gymnastics Championships at the Tokyo 2020 Olympics and 2021 World Championships, many gymnasts employed twist techniques in their performance. The Olympic Games floor exercise in the final, three of eight gymnasts had performed a double twist (2/1 twist) in a somersault and five gymnasts had performed a triple twist (3/1 twist) in a somersault. Nowadays, there were many gymnasts who combined backward twists and forward twists. Most of international gymnasts have included twist techniques into their performance, which means that twisting in a somersault is an important technique for advanced-level gymnasts. A biomechanical research has classified twisting techniques in trampolining using computer simulation (Yeadon, 2017) and investigated the twisting generation mechanisms (Hay J.G., 1989). Nagano (1982) investigated a somersault backward stretched with 2/1 twists of a male gymnasts using two video cameras to identify the body maneuver involved in good and poor twists. However, little study has been compared techniques with different number of twists to examine which phase of the technique changes the number of twists. Comparative study of the phases of twist generation and detailed the body maneuver may help to develop effective coaching methods and to prevent injuries. The purpose of this study was to compare the angular momentum and angular velocity in somersault backward stretched with different number of twists for a single varsity male gymnast.

METHODS: A single varsity male gymnast A (age, 19 yrs; height, 1.59 m; body mass, 53.4 kg; career, 12 yrs) belonging to the gymnastics team of the University of N, Japan performed the somersaults backward stretched with 2/1 and 3/1 twist on the floor several times. The gymnast A has mastered both the 2/1 and the 3/1 twist, and has participated in the finals of the All-Japan Gymnastics Championships. The gymnast A rated his own performance on a scale of 1 to 5 (1 = poor, 2 = below average, 3 = average, 4 = good, 5 = excellent). Trials rated 4 or 5 by the gymnast A and judged by a single official judge to have least points deduction were chosen for analysis. After obtaining the informed consent of the coach before the measurement, the purpose of this study and the method were explained to the subjects, and then informed consent was obtained. The present study was approved by the Research Ethics Committee of Nippon Sport Science University (No. 020-H111).

Three-dimensional coordinate data of 47 reflective markers on the body were collected by using 12 cameras of the optical three - dimensional motion capture system (Qualisys) operating at 250 Hz. The 3D coordinate data were smoothed by a Butterworth digital filter at cut-off frequencies ranging from 10 to 18 Hz, which were determined by the residual method (Winter, 2009). A fifteen-segment model was used to obtain angular momenta of the body segments and whole body, which were calculated by the Tang's method (1995).

$$\boldsymbol{H_i} = \boldsymbol{r_{i/G}} \times \boldsymbol{m_i V_{i/G}} + \boldsymbol{I_i \omega_i},$$

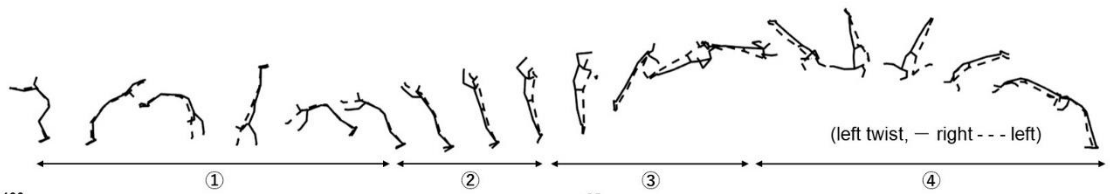
where H_i is the angular momentum of a segment i, $r_{(i/G)}$ is the relative vector of a segment center of gravity (CG) i to the whole body CG, m is mass, $V_{(i/G)}$ is the relative velocity vector of a segment i to CG, I is moment of inertia, and ω is angular velocity of a segment. The center of gravity and inertia parameter for each segment were estimated often Ae's body segments (1996).

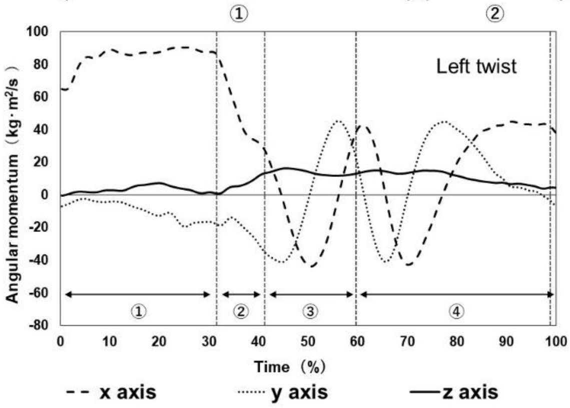
In the present study, the primary variable was the twist angular momenta of the segments and whole body, which were defined as the angular momentum about the longitudinal axis of the trunk coordinate system, i.e. quasi-twist axis. We compared patterns of the twist angular momenta of the segments and whole body, and the magnitudes of the angular momenta and angular velocities in 2/1 and 3/1 twists.

RESULTS:

1. The angular momentum and angular velocity of the whole body in the trunk coordinate system for a somersault backward stretched with 2/1 twist (Left twist, Figure 1 and 2)

The maximum height of the center of mass, for the gymnast A for 2/1 twists was 2.04m. Large angular momentum of the whole body about the x axis of the trunk coordinate system (Figure 1) was observed during the round-off and the backward phase (Figure 1, ①), followed by quick decrease during the take-off phase (Figure 1, ②). During the take-off phase, the angular momentum about the z axis was generated, and the maximum value during the take-off phase





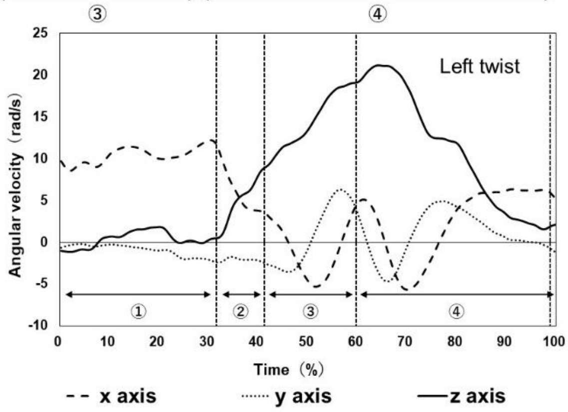


Figure 1. The angular momentum of the whole body in the trunk coordinate system for a somersault backward stretched with 2/1 twist (left twist). ① the round-off to the backward phase, ② the take-off phase, ③ the somersault backward stretched with the first twist, ④ the somersault backward stretched with the second twist to landing

Figure 2. The angular velocity of the whole body in the trunk coordinate system for a somersault backward stretched with 2/1 twist (left twist), movement phase, as shown in Figure 1.

was14.93 kg・m^2/s (Figure 1, 40%). During the twist in the airborne phase, lateral rotation and backward sagittal rotation were alternative, and the angular momentum about the x axis(somersault) and y axis (lateral rotation) of the trunk coordinate system changed out of phase (Figure 1, ③ and ④). The maximum of the z axis angular momentum generated during the first twist phase was 16.68 kg・m^2/s (Figure 1, 45%). With the angular momentum varying, it was maintained during the airborne phase. The y and x axes angular momenta decreased towards the landing phase (Figure 1, 70%), through that of the z axis increased.
As shown in Figure 2, the angular velocity of the whole body about the z axis (twist) of the trunk coordinate system rapidly increased during the take-off phase. After, it further increased in the second twist, it decreased to about 6 rad/s at 90% time for the preparation of landing. The maximum twist angular velocity during the second twist phase about 21 rad/s (Figure 2, 65%).

2. The angular momentum and angular velocity of the whole body in the trunk coordinate system for a somersault backward stretched with 3/1 twist (Left twist, Figure3 and 4)
The maximum height of center of mass for gymnast A for 3/1 twists was 2.11m. The large angular momentum of the whole body about the x axis of the trunk coordinate system, was observed during the round-off to the backward phase (Figure 3, ①). However, it rapidly decreased to about 15 kg・m^2/s during the take-off phase (Figure 3, 40%). During the take-off phase, the angular momentum in the z axis direction was generated and the maximum of angular momentum appeared during the second twist phase. It was 17.62 kg・m^2/s (Figure 3, 62%), which was large than in 2/1 twist. During the airborne phase, the angular momentum was maintained with fluctuating. The angular momenta in the y and z axes decreased towards the landing phase (Figure 3, 90%), but that about the x axis increased.
The angular velocity of the whole body about the z axis of the trunk coordinate system (Figure 4), rapidly increased during the take-off phase (Figure 4, ②). During the two and three twist phases, the angular velocity was maintained virtually constant (Figure 4, 65-80%) and the maximum value was about 22.9 rad/s (Figure 4, 70 %), and rapidly decreased to about 12 rad/s at 90% time for the preparation of landing.

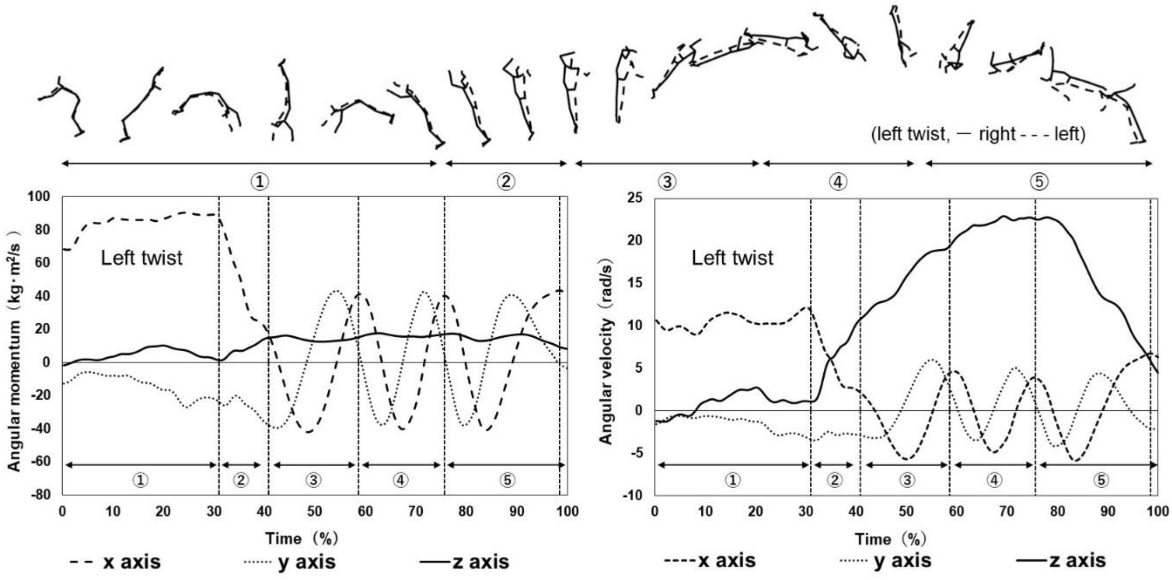


Figure 3. The angular momentum of the whole body in the trunk coordinate system for a somersault backward stretched with 3/1 twist (left twist). ① the round-off to the backward phase, ② the take-off phase, ③ the sault backward stretched with the first twist phase, ④ the sault backward stretched with the second twist phase, ⑤ the sault backward stretched somersault with the third twist to landing

Figure 4. The angular velocity of the whole body in the trunk coordinate system for a somersault backward stretched with 3/1 twist (left twist), movement phase, as shown in Figure 3.

DISCUSSION: We analyzed somersault backward stretched with 2/1 and 3/1 twist for the male gymnast A. More than half of the twist angular momentum of the whole body in both 2/1 twist and 3/1 twist was generated during the take-off phase, which implied that the gymnast A was classified as a contact twist type (Yeadon, 2017). The angular momentum of the trial of the 3/1 twist was generated slightly earlier, and the angular momentum of the twist around the z axis was also slightly larger than the 2/1 twist. This indicated that it was important to generate the angular momentum of the twist and to initiate the twist in earlier timing by moving the trunk and arms toward the twist direction. In addition, the gymnast A would seem to control the angular momentum of the twist by asymmetrical arms towards landing phase, as Yeadon (2014) pointed out. In the 3/1 twist, the body maneuver increased angular velocity by bringing the arm to the trunk to make moment of inertia smaller in the airborne phase. However, the twist angular momentum in the 3/1 twist at 90% before landing was about 17 $kg \cdot m^2/s$ and large than that of the 2/1 twist, about 7 $kg \cdot m^2/s$. This implied that the preparation for stable landing would be completed earlier in the 2/1 twist than 3/1 twist. Therefore, the gymnast would encounter the difficulty of the stable landing in the 3/1 twist.

CONCLUSION: The analysis of the 2/1 and 3/1 twist by a single male gymnast, focusing on the generation of angular momentum and angular velocity revealed the followings.
Much of the angular momentum of the whole body around the z axis in the trunk coordinate system for the 2/1 and 3/1 twist was generated in the take-off phase, which could be classified as a contact twist type. The 2/1 twist could be controlled in earlier stage by asymmetrical arms moved as a preparation before landing. Therefore, the preparation for stable landing was completed earlier in the 2/1 twist than 3/1 twist. During the airborne phase, the angular velocity varied with the body manipulation such as bringing the arms to the torso. The gymnast A of contact twist type produced angular momentum at an earlier phase and controlled the number of twists by the body maneuver before landing phase. However, it should be kept in mind that the findings were obtained from a single subject without statistical testing became of a case study. In the future, we would like to investigated various subjects and examine other twist types.

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