HOW FEMALE COLLAGIATE GYMNASTS GENERATE A DOUBLE TWIST IN THE BACKWARD STRETCHED SOMERSAULT

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The purposes of this study were to describe how female gymnasts generate a double twist in the backward stretched somersault and to draw suggestions to improve twist techniques of female gymnasts by analysing female gymnasts twist motion three-dimensionally. Three varsity female gymnasts performed the backward stretched somersault with a double twist several times and were motion-captured with a Vicon system (250 Hz). The angular velocities and angular momenta of the body segments and whole body were calculated, based on the Tang's method. The female gymnasts of the contact-type twisted the trunk, especially the upper torso largely before the aerial-type one laterally flexed her trunk after the toe-off with her right arm swinging down.

KEYWORDS: angular momentum, angular velocity, backward somersault

INTRODUCTION: Recently, in the gymnastics floor exercise, very sophisticated maneuvers such as "Shirai / Nguyen", backward stretched somersault with 4 twists, "Shirai 2" forward stretched somersault with 3 twists have been seen. The backward stretched somersault with a double twist has been carried out by a number of gymnasts, and its technique has been widely used (Miki and Yamada, 1980) and has no much value as a single technique (Nagano, 1982). Some coaching methods for the twist technique have been studied from a morphological viewpoint (Yoshimoto and Watanabe, 2005), and some analyzed twist techniques biomechanically (Kamon and Yoshida, 2003). However, effective coaching methods for twisting techniques have not been established yet, and in many cases, they have been developed by technical confirmation based solely on the experience of gymnasts and coaches (Miki and Yamada 1980).
Some sport biomechanists (Tang et al. ,1990; Kamon and Yoshida, 2003; Yeadon, 2017) have investigated and reviewed how male gymnasts, generate twist, and proposed two theories for the generation of twist, for example, contact twist and aerial twist types (Yeadon, 2017). To complete a multi twist in somersault a gymnast has to gain flight time enough to generate twists, which would require the gymnast a great power output during the take-off phase and the control of the body segments, resisting the centrifugal force caused by a large angular velocity of the twist. These requirements would be severer for female gymnasts than male gymnasts. However, there is little information enough to understand how excellent female gymnasts maneuver body segments to perform superior twisting techniques and to design effective coaching methods. The purposes of this study were to describe how female gymnasts generate a double twist in the backward stretched somersault and to draw suggestions to improve twist techniques of female gymnasts by analyzing female gymnasts twist motion three-dimensionally.

METHODS: Three varsity female gymnasts (age, 20 ± 0.81 yrs; height, 1.51 ± 0.03 m; body mass, 44.43 ± 0.61 kg; career, 13 ± 1.63 yrs) of Nippon Sport Science University, Japan performed the backward stretched with a double twist on the floor several times. The participants rated their own performance on a scale of 1 to 5 (1 = poor, 2 = below average, 3 = average, 4 = good, 5 = excellent). The trials rated 4 or 5 were chosen for analysis.
Three - dimensional coordinate data of 47 reflective markers on the body were collected by using 20 cameras of the optical three - dimensional motion capture system (VICON MX+, Vicon Motion System) operating at 250 Hz. The three - dimensional coordinates data of body landmarks were smoothed by a Butterworth digital filter at cutoff frequencies ranging from 10 to 18 Hz, as determined by the residual method (Winter, 2009). A fifteen - segment model was used to obtain angular velocities and angular momenta of the body segments and whole body, which were calculated after the Tang's method (1995), as the following equation.

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

where $\boldsymbol{H_i}$ is the angular momentum of segment i, $\boldsymbol{r_{i/G}}$ is the relative vector of segment center of gravity (CG) i to the whole body CG, m is mass, $\boldsymbol{V_{i/G}}$ is relative velocity vector of segment i to CG, I is moment of inertia, and ω is angular velocity.
In the present study, the primary variable was the twist angular momentum of the whole body and segments which was defined as the angular momentum about the longitudinal axis of the trunk coordinate system i.e. quasi-twist axis. This study was approved by the Research Ethics Committee of Nippon Sport Science University (No. 018-H35).

RESULTS AND DICUSSION: Both actions for the generation of the twist angular momentum were considered to be : 1) a body inclination with asymmetrical arm swing (Tang et al ,1990), and 2) a large side bending of the trunk immediately after the take-off (Nagano, 1982). As pointed out by Yeadon (2017), there were two types for generating twist, “contact twist” in which a twist angular momentum was generated during the take-off phase and “aerial twist” where a twist angular momentum was generated after leaving the floor. In this study subjects A and C will be classified as the “contact twist” type, and subject B would be the “aerial twist” type, as described below.

1. Subject A (left twist, Figure 1 and 2)

As shown in Figure 1, the angular velocity of the whole body about the quasi-twist axis rapidly increased during the take-off phase (Figure 1, ②). In addition, it increased in the airborne phase (③), reached a large twist angular velocity, and in the second twist and landing phase, it decreased sharply for the preparation of landing.

As for the angular momentum of the whole body seen in the trunk coordinate system (Figure 2), the large angular momentum was observed about the x axis (perpendicular to the direction of the progression) in the round-off phase (Figure 2, ①). During the take-off phase (②), the angular momentum about the x axis sharply decreased but the positive angular momentum (left twist) about the z axis was generated. Furthermore, by moving the upper torso toward the twist direction (left), the angular momentum of the twist was generated. During the twist in the airborne phase, the lateral and the backward sagittal rotations were performed alternately, and the angular momenta about the x axis (somersault) and the y axis (lateral rotation) of the trunk coordinate system changed in a phase-shift manner but the angular momentum of the whole body was maintained during the second twist and landing phase (④). And preparing for landing, by swinging the arm of the twist side (in the case of the right twist, the right arm) in the outward direction (abduction), the angular momentum was transmitted from the upper torso to the arm.

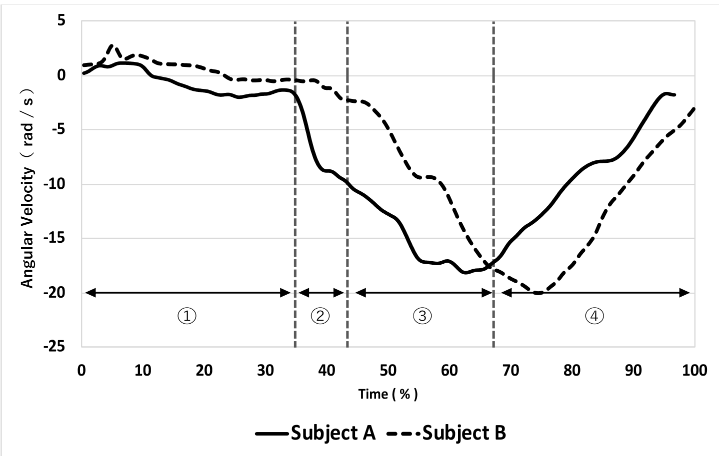

Figure 1. The angular velocities about a quasi-twist axis for subjects A and B. ① the round-off to the backward phase ② the take-off phase ③ the backward stretched somersault with the first twist ④ the backward stretched somersault with the second twist to landing

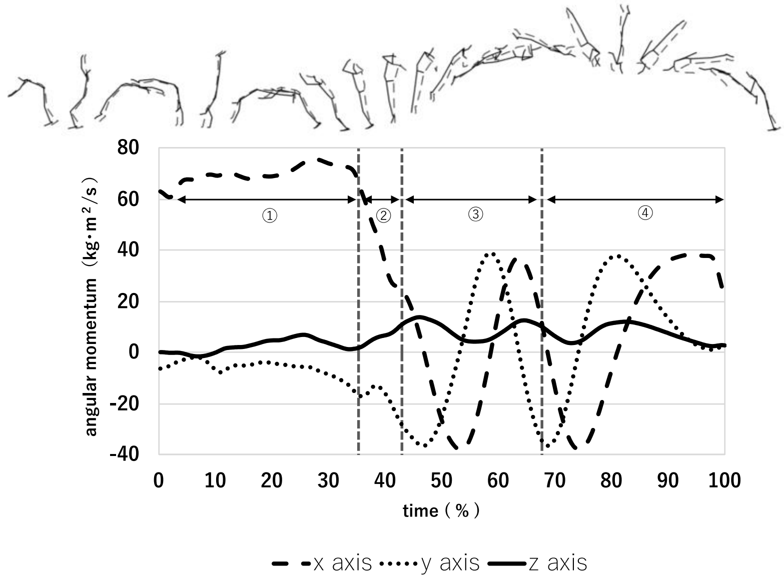

Figure 2. The angular momentum of the whole body in the trunk coordinate system for Subject A. ① the round-off to the backward phase ② the take-off phase ③ the backward stretched somersault with the first twist ④ the backward stretched somersault with the second twist to landing

Subject B (right twist, Figures 1 and 2)
Compared to the subjects A and C, changes in the angular velocity (Figure 1) and angular momentum of the twist for the whole body about the quasi-twist axis were small during the take-off phase (②). At the instant of the take-off, the left arm was extended obliquely upward and extended outside (abducted), and it had angular momentum in the opposite direction to the twist of the upper torso. This movement was thought to suppress the twist of the whole body. It would be hypothesized that the twist for subject B could be produced more easily if she had held the arms in slightly lower position than the chest. Her timing to start the twist was later than two other gymnasts. By holding the left arm in front of her chest during the first twist phase after leaving the floor, she could reduce the moment of inertia about the z axis and increase the twist angular velocity. The change in the angular velocity after leaving the floor was large, and in the twist phase the angular velocity about the quasi-twist axis was the largest among three gymnasts (about -20 rad／s).
In coaching of the twist technique, it is necessary to consider which type of twist generation, the contact or aerial twist, would be suitable for the gymnast to be coached.

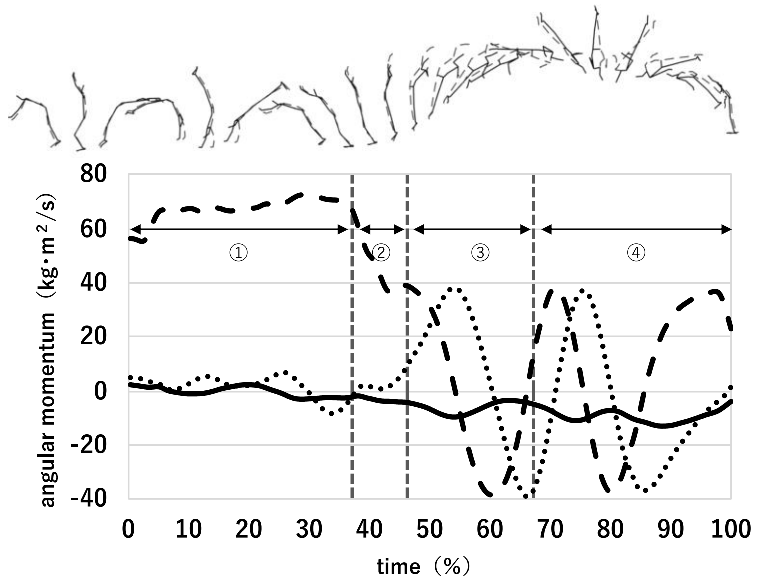

Figure 3. The angular momentum of the whole body in the trunk coordinate system for Subject B. ① the round-off to the backward phase ② the take-off phase ③ the backward stretched somersault with the first twist ④ the backward stretched somersault with the second twist to landing

CONCLUSION：Three excellent female gymnasts employed one of two types of the technique to generate a double twist in the backward stretched somersault ; two of them mainly used the contact-type technique in which most of the twist angular momentum was generated during the take-off phase, and one gymnast used the aerial-type one in which more than half of the twist angular momentum was generated in the airborne phase.
The female gymnasts of the contact-type twisted the trunk, especially the upper torso largely before the aerial-type one laterally flexed her trunk after the toe-off with her right arm swinging down.
For female gymnasts who intend to gain larger twist angular momentum or increase it, it is recommended to quickly move the opposite arm and twist the upper torso toward the twist direction during the take-off phase.

REFERENCES

Kamon, M., & Yoshida, K. (2003). Mechanical analysis of twist somersault. *Transactions of the Japan Society of Mechanical Engineers*, 69 (680), 236-243
Miki, S., & Yamada, M. (1980). Exercise morphological study on backward somersault twist technique on the floor.: The backward stretched somersault with a double twist. *Memories of Osaka Kyoiku University*. 29 (2・3), 113-122
Nagano, J. (1982). Exercise morphological study on backward stretched somersault with a double twist on the floor. *Bulletin of Tenri University*, 33,31-62
Tang, Hai-Peng., Michiyoshi, A., Takashi, Y., & Kanji, S. (1990). Biomechanical analysis of production of an aerial twist during a somersault with the use of an asymmetrical arm swing. *Biomechanism*, 10, 107-118
Tang, Hai-Peng., (1990). A method to determine the angular momentum of a human body. *Research journal of physical education. 40, 161-169*
Winter, D.A. (2009). *Biomechanics and control of human movement* (4th ed.) “pp. 70-73” New Jersey; John Wiley & Sons.
Yeadon M.R. (2017) Airborne Movements: Somersaults and Twists. *Handbook of Human Motion*, “pp. 1-19”

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