ANALYSIS OF RUNNING MOTION IN THE STARTING PHASE OF MALE SKELETON ATHLETES AT INTERNATIONAL COMPETITIONS

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The purpose of this research was to assess which kinematic factors were related to running speed in the starting phase for international-level skeleton athletes during races. The starting motion of 22 male athletes was recorded with four video cameras during competitions and their starting motion was analysed by a three-dimensional direct linear transformation method. The maximum angular velocity of the thigh increased from the 2nd to the 3rd step. The maximum hip extension angular velocity of the support leg gradually increased up until the 6th step while the maximum knee extension angular velocity remained constant throughout. It would appear that international-level male skeleton athletes employed an increase in thigh motion and quick hip and knee extension for the support leg to obtain a large running speed.

KEYWORDS: skeleton start, videography, joint angle, joint angular velocity.

INTRODUCTION: Skeleton is a winter sliding sport that requires athletes to use a sled to descend an ice track. During the start phase, the athlete pushes their sled for approximately 20 m from the starting block to help accelerate the sled. They then lie down on the sled in prone position descending head-first. The start time is measured within a 50 m section between the 15 m and 65 m marks from the starting block by official timing system. The official finish time of the race is measured between the 15 m mark and the finish line (International Bobsleigh & Skeleton Federation, 2018). The race results are determined by the total time of finish times of two to four runs.

Zanoletti et al. (2006) found a significant relationship between the start time and the finish time in men's ($r = 0.48$, $p < 0.05$) and women's ($r = 0.63$, $p < 0.05$) races for 24 international competitions. Oguchi et al. (2021) reported that the start time significantly related to the finish time ($\rho = 0.87$, $p < 0.001$) in international races held in Innsbruck, Austria, 2018. The start time is likely to be one of the most important factors in determining performance during skeleton competition. Bullock et al. (2008) found a significant relationship between the start time and the sled speed at the 15 m ($r = -0.93$, $p < 0.001$) and 45 m ($r = -0.77$, $p < 0.001$) marks from the starting block in the women's skeleton races held at the St. Moritz ice track in Switzerland. Oguchi et al. (2021) reported that the sled speed at the 4 m mark from the starting block was significantly related to the start time ($\rho = -0.43$, $p < 0.05$). A large sled acceleration after leaving the starting block is important to shorten the start time. Although many investigations for running motion have been reported in athletics, there is very limited information reported for skeleton. Kivi et al. (2004) reported that the two-foot starting motion had a much larger knee flexion angle than the one-foot starting motion at the starting block release. However, the running motion for each step has not been analysed and it is unclear what strategies skeleton athletes implement to gain large running speeds before reaching the 15 m mark on ice tracks. The purpose of this research was to investigate the running motion and assess which kinematic factors which are related to the running speed in the starting phase for international-level skeleton athletes during races.

METHODS: The target races were the Intercontinental cups and Europe cups (round 1 and 2) held in Innsbruck, Austria (15-17, Nov., 2018), which were organised by the International Bobsleigh & Skeleton Federation. The participants were 22 male athletes (height, 1.79 ± 0.05 m; body mass, 79.0 ± 8.3 kg) who all started on the same side as the sled for the 1st step. Informed consents were obtained before the races with the cooperation of national coaches.
The calibrated volume was 1.6 m in height, 2.5 m in width and 12.0 m in length from the starting block, with running motion collected by four video cameras (120Hz, AX-700, Sony Co., Tokyo, Japan). A three-dimensional direct linear transformation (DLT) method was used to measure joint kinematics. Twenty-three points on the body were manually digitized without any markers due to the limitation of the international official competitions by an experienced digitizer with Frame-DIAS V (Q'sfix Co., Tokyo, Japan).
The angles and angular velocities of the hip, knee and ankle joints and thigh segment (Figure 1) were calculated. The 1st step began from the toe-off from the starting block to the toe-off of for the opposite foot. For the 2nd and subsequent steps, the step started from the toe-off to the toe-off for the contralateral foot. The inverse of the time elapsed for each step was defined as step frequency, and the horizontal distance between toes of the consecutive steps in the Y-axis direction was defined as step length. The running speed was calculated as a product of step frequency and step length.
Spearman's rank correlation coefficients were calculated to examine relationships between the running speed and parameters of joints and segment. Differences in parameters of joints and the thigh segment were tested using repeated-measures analysis of variance (ANOVA) and post hoc test ($p < 0.05$) was conducted using Bonferroni analysis. The significance level was set at 5%. SPSS version 25 (IBM Co., Armonk, NY, USA) was used for statistical analysis.

Figure 1: Definition of the joint and segment angles for the right leg.

RESULTS: Figure 2 shows changes in the maximum thigh angle and angular velocity of the swing leg. The asterisks indicate a significant correlation with running speed. The thigh angle (Figure 2a) significantly increased from the 2nd to 3rd step ($p < 0.05$) but did not change for other steps. A significant positive correlation between running speed and the thigh angle was observed in the 3rd ($\rho = 0.45$, $p < 0.05$) and 5th ($\rho = 0.45$, $p < 0.05$) steps. The maximum thigh angular velocity (Figure 2b) significantly increased from the 2nd to 3rd step ($p < 0.05$), and had significant positive correlations between running speed at the 2nd ($\rho = 0.62$, $p < 0.01$), 3rd ($\rho = 0.51$, $p < 0.05$) and 4th ($\rho = 0.44$, $p < 0.05$) steps.

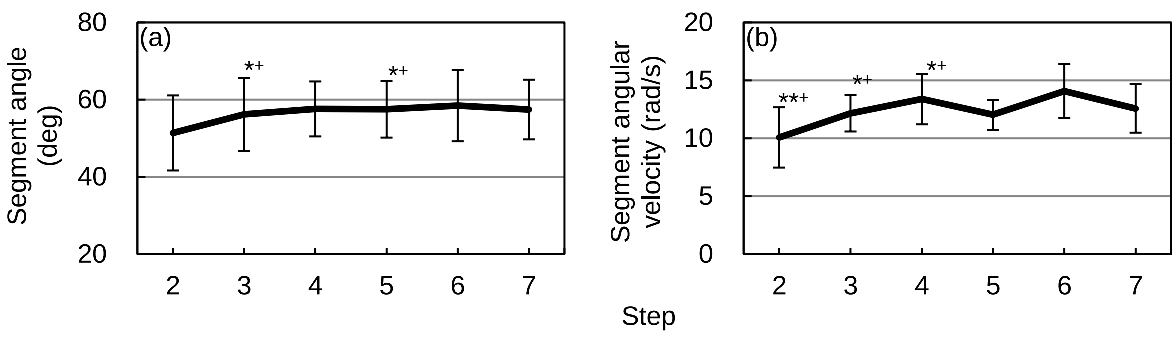

Figure 2: Step-to-step changes in the maximum thigh segment angle (a) and angular velocity (b) of the swing leg, and correlations with the running speed. *p < 0.05, **p < 0.01, ***p < 0.001. + and – indicate positive and negative correlations, respectively.

Figure 3 shows changes in joint angle and maximum joint angular velocity for the hip, knee and ankle joints at critical instants for the support leg. The asterisks indicate a significant correlation with running speed. The maximum angular velocity of hip extension at the 6th step (Figure 3b) was significantly increased from the 2nd and 3rd steps ($p < 0.05$), and the 6th ($\rho = 0.45$, $p < 0.05$) and 7th ($\rho = 0.53$, $p < 0.05$) steps showed significant positive relationship to running speed. The knee joint angle at the toe-on for the 2nd step (Figure 3c) was smaller than other steps ($p < 0.05$) and negatively related to running speed ($\rho = -0.44$, $p < 0.05$). The range of the knee motion for the 2nd step was larger than other steps ($p < 0.05$) with a

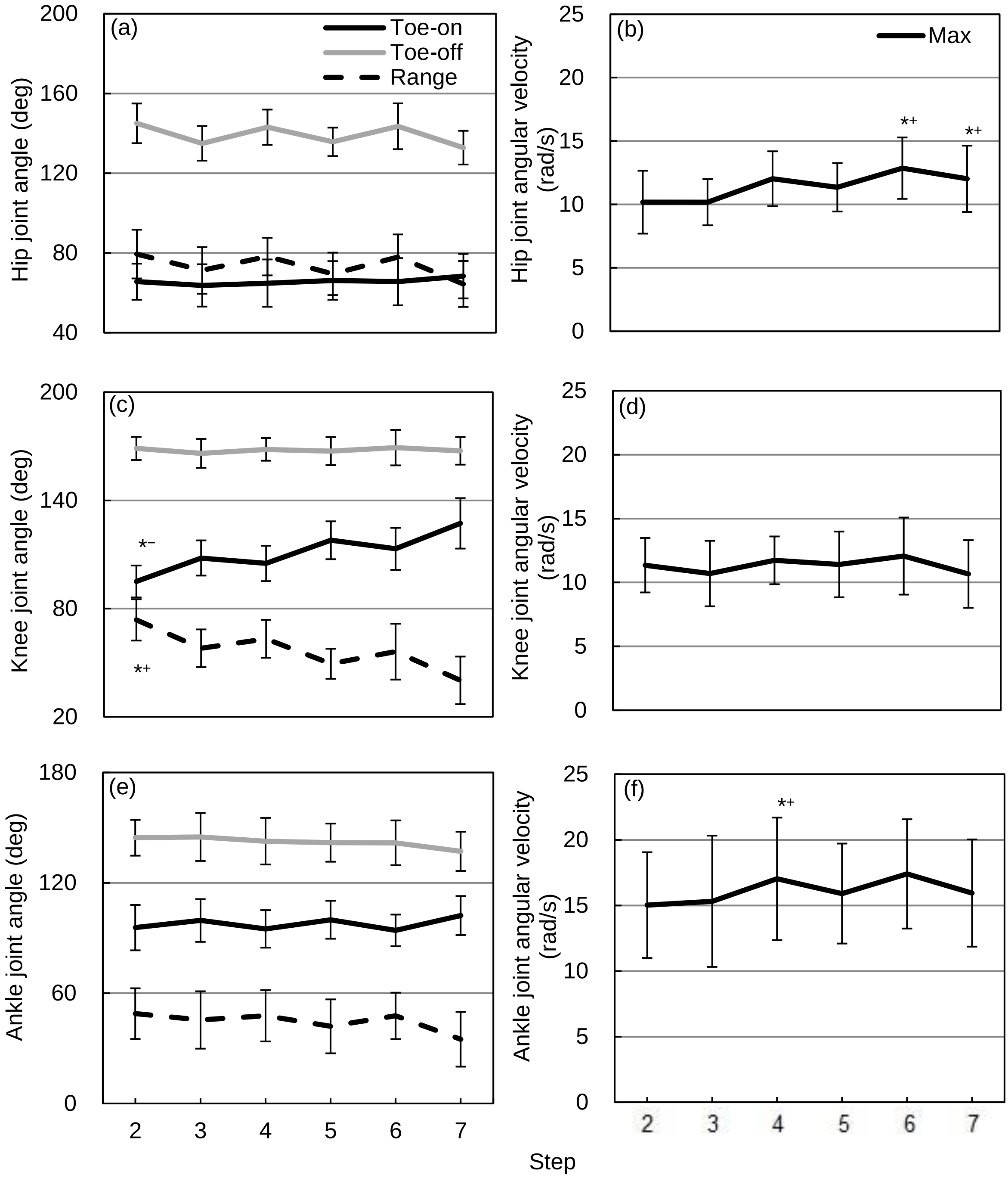

Figure 3: Step-to-step changes in the joint angles and angular velocities of the support leg, and correlation with the running speed. *p < 0.05, **p < 0.01, ***p < 0.001. + and – indicate positive and negative correlations, respectively.

significant positive correlation with running speed ($\rho = 0.43$, $p < 0.05$). The maximum angular velocity of knee extension (Figure 3d) was almost constant between the 2nd and 7th steps. The range of ankle motion (Figure 3e) and the maximum angular velocity of ankle plantar flexion (Figure 3f) appeared just before the toe-off and showed no significant changes between the 2nd and 7th steps.

DISCUSSION: The thigh angle of the swing leg for the world's top sprinters in the 100 m sprint has been measured between 60 to 70 degrees, increasing significantly from the 1st to 6th step ($r = 0.41$, $p < 0.01$, Kijima et al., 2010). In the present study, a smaller thigh angle for skeleton athletes was observed. This may be caused by the skeleton starting motion having a more flexed hip position, a requirement to push the sled forward. The international-revel skeleton athletes would gain running speed by swinging the thigh quickly without focusing on lifting the high thigh for the support leg.

For the support leg, the maximum hip extension angular velocity gradually increased toward the 6th step and showed significant correlations with running speed. In the 100 m sprint, it has been shown that hip extension was important for increasing running speed during the start phase (Kijima et al., 2010). In skeleton, the fast hip extension of the support leg would also contribute to an increase in running speed. The skeleton athletes showed no change in the maximum knee extension angular velocity, in contrast to 100 m sprinters who exhibited a decrease during the acceleration phase (Kijima et al., 2010). In addition, the knee joint angle at the toe-on and the range of knee motion at the 2nd step significantly correlated with running speed. A large extension of the knee joint in the first few steps and a quick knee extension during the support phase in subsequent steps were likely to contribute to obtaining increased running speed. These results may suggest that for a summer training period, a specific running motion in a deeply flexed hip position maybe helpful in improving the starts for skeleton athletes.

CONCLUSION: The international-level male skeleton athletes a quick swing of the thigh of the swing leg, and fast hip and knee extension of the support leg during the starting phase. The running motion of the skeleton athletes differed from that of 100 m sprinters who had a higher height of the thigh of the swing leg and the lower knee extension angular velocity of the support leg with increasing running speed. Therefore, it would be helpful for skeleton athletes to practice a specific running motion in a deeply flexed hip position during a summer training period.

REFERENCES

Bullock, N., Martin, D. T., Ross, A., Rosemond, D., Holland, T., & Marino, F. E. (2008). Characteristics of the start in women’s World Cup skeleton. *Sports Biomechanics*, 7(3), 351-360. https://doi.org/10.1080/02640410802613425

International Bobsleigh & Skeleton Federation. (2018). International skeleton rules 2018. *International Bobsleigh & Skeleton Federation*.

Kijima, K., Fukuda, K., Ito, A., Hori, H., Kawabata, K., Suematsu, D., Omiya, S., Yamada, A., Muraki, Y., Fuchimoto, T., & Tanabe, S. (2010). Starting dash movement of male and female sprinters. *The techniques of the world top athletes: Research report of the 11th World Championships. pp.24-38 (in Japanese).*

Kivi, D., Smith, S., Duckham, R., & Holmgren, B. (2004) Kinematic analysis of the skeleton start. *ISBS Proceedings Archive*, 22: 450-452.

Oguchi, T., Ae, M., & Schwameder, H. (2021). Step characteristics of international-level skeleton athletes in the starting phase of official races. *Sports Biomechanics*, in press. https://doi.org/10.1080/14763141.2021.1893375

Zanoletti, C., Torre, A, L.,Merati, G., Rampinini, E., & Impellizzeri, F. M. (2006). Relationship between push phase and final race time in skeleton performance. *Journal of Strength and Conditioning Reseach*, 20(3), 579-583. https://doi.org/10.1519/r-17865.1

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