Kinematic Characteristics of Curve Skating in a 300 m Time Trial Race Among Top Roller Speed Skaters

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The purpose of this study was to investigate the kinematic characteristics associated with curve skating among a group of top skaters in a 300 m time trial (TT) race (300 m TT) at the World Roller Speed Skating Championships that were held in China in 2016. The twelve finalists were classified as constituting the top group. A further nine skaters, ranked between 25th and 45th place, were classified as the subgroup. Data from the three-dimensional coordinates were calculated using the direct linear transformation technique. Recorded parameters included the 300 m TT finishing time, stroke frequency, skating speed, distance of center of body mass (COM) from support leg ($D_{\text{com}}$), and the segment and shank tilt angle of the support leg. The results confirmed that the Top roller skaters glided at a higher skating speed on the right stroke and operated at a higher stroke frequency for both strokes. The $D_{\text{com}}$ was similar in both groups for both strokes. The top roller skaters demonstrated less forward thigh rotation and more forward shank rotation. These results suggested that the top roller skaters:

1) glided at a higher skating speed on the right stroke by obtaining a higher stroke frequency to move their COM inward.
2) moved their COM forward by increasing their shank forward rotation.
3) generated a higher stroke frequency by rotating their shank forward for both left and right strokes.

Keywords: roller speed skating, 300 m time trial race, curve skating, kinematics

1. Introduction

A roller speed skating 300 m time trial (TT) race (300 m TT) is a timed competition held on a banked 200 m track (a full circuit is designated one lap). Roller skaters maintain a low skating position and extend their supporting leg (an action called the push-off movement) sideways to propel themselves. This sideways push-off movement is uncommon among other sports except ice skating and cross-country skiing, and effective investigation of the technical factors required the application of biomechanical methods. Roller speed skating involves both straight skating and curve skating. While straight skating, skaters move their center of body mass (COM) from side to side. While curve skating, skaters move their COM inwards toward the center of the curve. While curve skating, roller skaters perform a push-off movement while the right leg passes in front of the left leg. This is called the ‘leg over’ movement (de Boer at al., 1987). In ice speed skating, it was reported that elite ice skaters glided at a high skating speed in curves (Yuki et al., 1999; Yuda et al., 2002). This suggested that the curve technique necessary to achieve a high skating speed were important for a good result in a race. Furthermore, the curves in ice speed skating are flat, whereas those in roller speed skating are banked. It can be inferred that curve skating on a banked track is a more difficult action to perform than that required on a flat track. It is therefore important to understand the technical factors associated with curve skating on a banked track. However, there are no existing studies that have evaluated these technical factors. An investigation into banked track curve skating biomechanical
characteristics could thus lead to enhanced skater performance.

Roller speed curve skating on a flat track involves performing the push-off movement with the body and shank tilting inward, which is similar to characteristics associated with ice speed skating (Okabe et al., 2017). This suggests that an effective approach to investigating the characteristics of roller speed skating on a curved, banked track would include reviewing studies on ice speed skating. For curve skating on ice, ice skaters worked to increase horizontal blade reaction force by tilting the shank inward toward the center of the curve (Yuda et al., 2003, 2004). Furthermore, elite ice skaters in sprint races moved their COM forward by increasing the forward rotation of their thigh and shank in the sagittal plane (Yuda and Ae, 2002).

Studies on ice speed skating suggested that a good curve skating technique was related to the movement of the thigh and shank in the sagittal plane and to the inward tilt of the shank. Therefore, the technical factors associated with roller speed skating on curved, banked track can also be clarified by focusing on ice speed skating parameters. The purpose of this study was to investigate the kinematic characteristics of the push-off movement among the top roller speed skaters on a curved, banked track.

2. Methods

2.1. Subjects

Data were collected from the senior men’s 300 m TT at the World Roller Speed Skating Championships held in China on September 10, 2016. Of the 52 skaters competing in this race, 21 skaters agreed to participate in the study. Twelve were finalists in the 300 m TT and were classified as the top group (age, 24.0 ± 2.7 years; height, 177.0 ± 6.0 cm; weight, 73.0 ± 5.2 kg), and 9 skaters, ranked between 25th and 45th place, were classified as the subgroup (age, 24.9 ± 4.1 years, height, 178.0 ± 4.0 cm, weight, 75.2 ± 5.7 kg).

2.2. Data collection

Curve skating data were collected within the length of track between the midpoint to the exit of the second curve using two high-speed cameras (EX-100Pro, CASIO, Japan) that were placed near the entry and exit of the curve on the outside of the track (frame rate, 240 fps, exposure time, 1/2000 s). Three-dimensional coordinates were measured on the area of track between 129.08 and 143.13 m from the start line (Figure 1). The coordinates of the inclined plane were calculated using the trigonometric ratio along with distances and angles measured using a spirit slant-level measuring device (SLANT100YE, TAJIMA, Japan) between the calibration points. The three-dimensional measurement range was 4.89 m wide (X-axis), 12.40 m long (Y-axis), and 2.89 m high (Z-axis). The angle of inclination of the banked track was 8 degrees at the midpoint of the curve and reduced to 4 degrees at the exit of the curve. Two high-speed cameras were synchronized to capture images at the time when the participant’s right wheel took off from the runway.

2.3. Analysis and parameters

Twenty-one points on the subject’s bodies were digitized using a three-dimensional movement analysis software package (Frame-DIAS V, DKH, Japan). The digitized body points included the left
and right hands, wrists, elbows, shoulders, toes, heels, outside ankles, knees, trochanters, and head, tragus, and upper margin of the sternum. The body points were mainly digitized by judging them by sight; however, the body points hidden by other body points were estimated from the other adjacent body points, or by using cubic spline interpolation. The digitized coordinate values were converted to actual lengths using the three-dimensional direct linear transformation technique. The optimal cutoff frequency (11.5-25.9 Hz) was determined using the residual analysis method (Wells and Winter, 1980), and smoothing was performed using a fourth-order Butterworth low-pass digital filter. The coordinates of COM were calculated by using the body segment inertia coefficients provided by Ae et al. (1992). Skating velocity was calculated by differentiating the displacement of the COM over time. Furthermore, the relative coordinates of the body segments for COM were calculated and normalized by the height of subject (Ae et al., 2007).

To analyze the curve skating, the Y’-axis was defined as skating velocity in the horizontal plane, and the X’-axis as the perpendicular direction for the Y’-axis in the horizontal plane, and the Z’-axis as the vertical direction associated with the X’-Y’ plane. In this study, the skating cycle was divided into left and right strokes.

Parameters in this study consisted of the finishing time for the 300 m TT, skating speed, stroke frequency, distance of COM from the support leg (D_com), shank tilt angle on the X’-Z’ plane, and segment angle on the Y’-Z’ plane (thigh, and shank angle). Skating speed was calculated as the mean value of the skating velocity achieved for each stroke. Stroke frequency was calculated as the reciprocal of the time spent performing each stroke. D_com was calculated as the displacement of the COM from the ankle of the support leg. Figure 2 shows the definition of the shank tilt and segment angle. The shank tilt angle was defined as the angle between the shank segment and the Z’-axis on X’-Z’ plane. The change in the shank tilt angle from the Z’-axis in the clockwise direction was a positive value, defined as inward tilt. On the Y’-Z’ plane, the thigh angle was defined as the angle between the thigh segment and the Y’-axis and the shank angle was defined as the angle between the shank segment and the Y’-axis. The time for these variables was normalized by the time spent performing each stroke.

### 2.4. Statistics

Data are expressed as mean ± standard deviation. Significant differences in the finishing time of the 300 m TT, skating speed, and stroke frequency were determined between the top group and the subgroup using a non-paired Student’s t-test. Significant differences in D_com, shank tilt angle, and segment angle of the support leg between the top group and the subgroup were determined by using a two-way analysis of variance (ANOVA) [2 groups × 11 stroke times (0, 10, 20, ..., 100%)]. When significant differences were detected using ANOVA, a post hoc analysis was performed using the Bonferroni correction. When a significant effect was found in a group using ANOVA, the non-paired Student’s t-test was used. The level of significance was set to p < 0.05.

### 3. Results

The top group (24.28 ± 0.24 s) achieved a significantly shorter finishing time in the 300 m TT than did the subgroup (25.80 ± 0.54 s, p < 0.05). The
Table 1  Mean value of measurements.

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Left stroke</th>
<th>Right stroke</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top group</td>
<td>Subgroup</td>
</tr>
<tr>
<td>Skating speed [m/s]</td>
<td>11.1 ± 0.3</td>
<td>10.7 ± 0.3</td>
</tr>
<tr>
<td>Stroke length [m]</td>
<td>1.72 ± 0.18</td>
<td>1.85 ± 0.21</td>
</tr>
<tr>
<td>Stroke frequency [Hz]</td>
<td>3.6 ± 0.5</td>
<td>3.2 ± 0.3</td>
</tr>
<tr>
<td>Distance between COM and support leg on X'-axis [m]</td>
<td>0.16 ± 0.04</td>
<td>0.15 ± 0.05</td>
</tr>
<tr>
<td>Distance between COM and support leg on Y'-axis [m]</td>
<td>0.27 ± 0.04</td>
<td>0.29 ± 0.04</td>
</tr>
<tr>
<td>Angular parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thigh angle [deg.]</td>
<td>49.6 ± 1.8</td>
<td>53.5 ± 2.1</td>
</tr>
<tr>
<td>Shank angle [deg.]</td>
<td>62.9 ± 1.6</td>
<td>68.7 ± 1.9</td>
</tr>
<tr>
<td>Shank tilt angle [deg.]</td>
<td>47.4 ± 1.4</td>
<td>46.7 ± 1.6</td>
</tr>
</tbody>
</table>

† Mean value of measurements for each stroke. Top and Sub indicate top group and subgroup. Significant difference: *, p < 0.05, ***, p < 0.01

Figure 3  Distance between the COM and the support leg of all subject in three-dimensional space
†The figures above show the plots of distance between the COM and support leg of the end of stroke in three-dimensional space. These figures show movement distance of COM by push-off movement in real stroke time.

top group achieved a significantly higher skating speed on the right stroke than the subgroup (Table 1). The top group generated a significantly higher stroke frequency than the subgroup for both strokes (Table 1). Figure 3 shows the $D_{COM}$ of all subject in three-dimensional space, and Figure 4 shows the $D_{COM}$ in the X'-Y' plane for each stroke. No interactions or significant differences in $D_{COM}$ were noted on the X- or Y-axis for either stroke. Figure 5 shows the shank tilt angle for each stroke. No significant interactions or effects on the shank tilt angle were noted. Figure 6 shows the segment angle for each stroke. A significant interaction in the thigh angle was noted on the left stroke. The thigh angle was significantly lower in the top group than in the subgroup in 90-100% of the left stroke (p < 0.05). No significant interaction in the thigh angle was noted, although a significant effect was noted in the right stroke of the top group. The top group had a significantly smaller thigh angle than the subgroup with respect on the right stroke (Table 1). No significant interactions for the shank angle were noted, although significant effects were noted for the group in both strokes (p < 0.05). The top group had a significantly lower shank angle than the subgroup for both strokes (Table 1).

4. Discussion

4.1. Characteristics of moving the COM inward, skating speed, stroke frequency, and shank tilt angle

In the curve, it was reported that when ice skaters moved to the outer part of the curve under the influence of centrifugal force, their skating speed decreased (Yuda et al., 2006). On a banked track, roller skaters climb the bank by moving toward the
Figure 4  Distance between the COM and the support leg in X’-Y’ plane.
The figures above show the plots of distance between the COM and support leg in X-Y plane. Circles marking data points are plotted at increment of 10% normalized stroke time. The origin represents the ankle of the support leg.

Figure 5  Shank tilt angle for each stroke
The figures show the shank tilt angle for each stroke. The change to a positive value represents inward tilt, and that to a negative value represents outward tilt.

outside of curve. This causes even more of a decrease in skating speed than occur in a curve on a flat track. To resist the centrifugal force, ice skaters must glide at a high stroke frequency (Yuki et al., 1999; Yuda and Ae, 2002; Yuda et al., 2003), and move their COM inward by tilting their shank inward during the push-off movement (van Ingen Schenau et al., 1985, 1987; Yuda et al., 2003, 2004). In this study, D_com in both groups were similar, however, the top group moved their COM inward as long as the subgroup in shorter real stroke time in both strokes (Table 1, Figure 3, Figure 4). On the curve skating, roller skaters move their COM toward the inside of curve constantly, therefore, they can resist the centrifugal force by gliding at a higher stroke frequency. In the case that D_com in both groups are similar, it is considered the skaters gliding at a higher stroke frequency can restrict moving the outside of curve than skaters gliding at a lower stroke frequency. Therefore, it was indicated that the top group glided at a high skating speed on the right stroke by restricting moving their COM toward the outside of curve by higher stroke frequency of moving their COM inward (Table 1).

Shank tilt angle for both groups were similar for both strokes (Figure 4, Table 1). These results differed from the previous studies performed on ice speed skaters. It was considered that the reason for this difference was the magnitude of the radius of the curve. The radius of the curve used on roller speed skating tracks is smaller than that used on ice speed skating tracks. It was also reported that the centrifugal force in roller speed skating was higher than that in ice speed skating (Okabe et al., 2017).
The radius of the curve on the flat track used in the previous study was 16.8 m (Okabe et al., 2017), and in this present study, that of the banked track was 13.42 m. If two roller skaters possessing the same body weight were to glide at the same skating speed on both roller speed skating tracks, the centrifugal force on the banked track would be higher than that on the flat track. In the flat, curved section of the roller speed skating track, roller skaters increased their inward shank tilt for both strokes (Okabe et al., 2017). According to this present study, roller skaters had to increase the inward tilt of their shank. However, in this study, there were no significant differences noted in the shank tilt angle for both groups, nor were there any significant differences noted for both strokes (Figure 5). On the banked track, it was inferred that the horizontal ground reaction force was higher than on a flat track, because the runway in the banked track was inclined. This meant that on the banked track, roller skaters could move their COM inward more easily than on flat tracks. It was proposed that roller skaters could glide along the curve more easily on a banked track. However, increasing the inward tilt of the shank was the factor of sideslip. Sideslip in turn was a factor that played a part in falls. Therefore, it could be inferred that the top group prevented movement to the outside of curve by gliding at a higher stroke frequency, instead of increasing the inward tilt of their shank, which would have increased the likelihood of sideslip.

4.2. Characteristics of moving the COM forward, skating speed, stroke frequency, and segment angle

The push-off movement was evaluated using the movement of the thigh and shank in the sagittal plane in ice speed skating (Yuda and Ae, 2002; Yuda et al., 2003), and the elite ice skaters demonstrated an increased forward thigh and shank rotation in sprint races (Yuki et al., 1992; Yuda and Ae, 2002). Furthermore, in long-distance ice speed skating races, the elite ice skaters glided at a higher skating speed by increasing their forward thigh rotation and COM movement (Yuda et al., 2003, 2007). These studies suggest that increasing the forward COM movement through increasing the forward thigh rotation is important in generating a higher skating speed. In this study, the forward movement of the COM was similar in both the top group and the subgroup (Table 1). However, the top group did not rotate their thigh forward as much in both strokes (Table 1, Figure 6). The top group glided at similar skating speed on the left stroke, and at a higher skating speed in the right stroke (Table 1).
These results suggested that the top group glided at a higher skating speed on the right stroke without increasing the forward rotation of their thigh. Skating speed was calculated using $D_{\text{com}}$ multiplied the stroke frequency. The top group glided at a higher stroke frequency, and it could be inferred that the stroke frequency affected the skating speed in this study. In ice speed skating, the ice skaters who glided at a higher stroke frequency in the curve increased their forward shank rotation (Yuda and Ae, 2002). It was reported that elite ice skaters who increased the forward rotation of their shank were able to generate push-off force in the early part of the stroke (Yuda and Ae, 2002). Ice skaters need to move their COM forward by using the push-off movement. These ice speed skating studies indicated that the push-off force was used to quickly move the COM forward. In this study, the top group increased the forward shank rotation. However, they glided at a similar skating speed to the subgroup on the left stroke. This result suggested that the top group obtained a higher skating speed without increasing the forward rotation of their shank. Increasing the forward shank rotation generates a force that raises the heel of the support leg which decreases the time for the wheel to take off from the ground. This leads a shortening of the stroke time and increase in stroke frequency. Therefore, the top group rotated their shank more forward to generate a higher stroke frequency for both strokes. In curve skating, skaters move their COM inward constantly. Roller skaters glide at a higher stroke frequency to move their COM more inward. The top group thus maintained a high skating speed by preventing themselves from moving to the outer part of the curved track by gliding at a higher stroke frequency. Therefore, it could be inferred that the top group glided at a higher stroke frequency by increasing their forward shank rotation and also maintained a higher skating speed by moving their COM inward towards the center of the curve.

5. Conclusion

The study investigated the kinematical characteristics of curve skating among top roller skaters in a 300 m TT. The kinematical characteristics of curve skating as identified by this study were as follows:

1) Top roller skaters glided at a higher skating speed than subgroup on the right stroke.

2) Top roller skaters glided at a higher stroke frequency than subgroup in both strokes.

3) The distance between COM and support leg in both groups was similar for both strokes.

4) Top roller skaters used less forward thigh rotation, and more forward shank rotation than subgroup when performing both strokes.

This study suggested that top roller skaters 1) glided at a higher skating speed on the right stroke because they prevented movement to the outside of the curve by generating a higher stroke frequency, 2) moved their COM forward not by rotating their shank, but by gliding at a higher stroke frequency, and 3) generated a higher stroke frequency by increasing their shank forward rotation.

References


Yuda, J., Yuki, M., Fujii, N., and Ae, M. (2002). [Analysis of the race pace for elite long distance speed skaters in 5000 m