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ORIGINAL

Kinematic Analysis for Improving the Starting Technique in 500-m Speed Skating

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Objective: In this study, we analyzed kinematic changes in the start phase of speed skating before and after physical training.

Method: We introduced a new strength training program (2017) that was improved in terms of exercise type and intensity [%, one repetition maximum (1RM)] compared with the previous strength training program (2016). The new program was applied to elite speed skating athletes (four males and four females). To determine the improvement in starting technique, we recorded race images during the start phase of the 500-m race held in 2016 and 2017. The race images were collected using five high-speed cameras and kinematic characteristics of the start phase were analyzed by three-dimensional image analysis.

Results: The 1RMs were improved by 11% on an average after the strength training. In 2017, records of four out of the eight athletes were shortened in terms of the initial lap time (100 m), and 500-m records were shortened in six athletes. The time to nine strokes was shortened in five athletes, and the ratio of correct kinetic chain was increased or maintained at a high level in six athletes.

Conclusion: In this study, the new strength training program (2017), applied to elite speed skating athletes, showed a positive effect on starting technique and reduced the record times.

Keywords: Speed skating, Start phase, Kinetic chain, Physical training, Kinematic analysis

INTRODUCTION

The race course for speed skating can be divided into the starting, straight-away, and cornering phases, and in most cases, the skater who crosses the 100-m mark quickly and maintains a high speed will reach the 500-m mark in good time (Jeon, Choi, Lee & Jegal, 2016). The basic motions in skating consist of push-off and gliding, but in short-distance skating events, complete push-off and gliding cannot be achieved in the starting phase. Unlike gliding in the latter part of the race or the second half, during the first 30 m, acceleration is generated by very short gliding after every five to six strokes (Back, 1996; Maw, Proctor, Vredenbur & Ehlers, 2006).

Because the starting motion in a short-distance speed skating event involves overcoming inertia from a stationary position and propelling the center of mass (CoM), a quick reaction to the starting signal and the ability to generate acceleration by explosive force are of utmost importance (Jun, 2010; Jeon et al., 2016; Lee & Back, 2005; Ryu, Kim & Hong, 2016). According to studies that conducted kinematic analysis on the technique used during the starting phase, the main technical factors that affected the starting motion were time and frequency of strokes in the starting phase, horizontal velocity of the CoM, and blade angle at push-off (Shin, Yoon & Back, 1998). Moreover, reducing the time required for taking the first stride, having a consistent pattern of stroke length and stroke rate in the starting phase, and having a large blade angle were factors that allowed the CoM to be propelled effectively (Jun, 2010; de Boer, Schermerhorn, Gademan, de Groot & van Ingen Schenau, 1986; Shin & Back, 1996).

For Korean short-distance speed skaters, the starting technique tends to be their area of weakness. Although they execute fast stroke motions by moving the CoM within a narrow range in the starting phase, they show the characteristics of spreading their feet too far apart, and such a stroke motion with the feet wide apart makes it difficult to quickly move the CoM, while also making it difficult to generate effective acceleration of the body from the movement of the CoM (Jun, 2010).

Accordingly, Song, Lee & Moon (2017) conducted a three-dimensional (3D) technical analysis on the starting technique of Korean and other international elite skaters and identified the CoM position at 2.5 s after starting, average power, time to nine strokes, resistance, and knee and trunk angles as the major factors that impact the net time taken in 100 m. A comparative analysis between Korean and top world-class skaters indicated that a lower proportion of Korean skaters execute proper kinetic chain that appears from the harmonious cooperation between the joints in the lower extremities, and their reaction time to the starting signal was also longer. Moreover, compared with the top world-class skaters, Korean skaters generated less acceleration and showed starting motions with smaller knee, trunk, and push-off angles, preventing them from executing a dynamic starting motion. Such findings suggested the need for technical training that can increase their kinetic chain rate, along with training for increasing power.

Short-distance speed skating races characteristically require the skaters to instantaneously generate explosive power, and thus, anaerobic power capable of recruiting energy needed for generating and maintaining strong muscle strength is known to be an important fitness factor (Holum, 1984; de Koning, Foster, Bobbert, Hettinga & Lampen, 2003; de Koning, Hettinga, Foster, Lampen & Bobbert, 2004; de Koning, 2002). Moreover, the development of muscle functions around the spine, ankle, and knee joints is also needed for maintaining posture and increasing speed (Kim, Jeon & Kim, 2006; Ji, 2013; Jeon & Kim, 2011).

Based on these characteristics, the present study aimed to achieve improvement in the speed skating starting technique through training for muscle strengthening and overall fitness enhancement in the upper and lower extremities. In addition, the study also aimed to identify the pattern of changes in the starting technique from before to after training in elite skaters through a kinematic comparative analysis.

METHODS

1. Participants

The participants in the study consisted of elite Korean male and female short-distance speed skaters: four males (M1-M4, mean age: 23.8 ± 3.1 years, height: 178.0 ± 0.8 cm, and weight: 69.5 ± 10.5 kg) and four females (W1-W4, mean age: 23.3 ± 4.3 years, height: 166.5 ± 1.3 cm, and weight: 54.3 ± 2.2 kg).

Table 1. Strength training program

<table>
<tr><th></th><th colspan="2">Phase</th><th>Adaptation</th><th>Hypertrophy</th><th>Maximal strength</th><th>Power</th></tr>
<tr><th></th><th colspan="2">Period</th><th>2 weeks</th><th>4 weeks</th><th>6 weeks</th><th>4 weeks</th></tr>
<tr><td rowspan="8">2016
&
2017</td><td rowspan="2">Items</td><td>Upper</td><td>Bench press, Military press, Chin-up, Biceps curl, Triceps extension, Lat pull-down, Dips</td><td>Bench press, Military press, Chin-up, Biceps curl, Triceps extension, Lat pull-down, Dips</td><td>Bench press, Shoulder press, Chin-up with load, Dips with load, Barbell row</td><td rowspan="2">Bench press, Squat to throw, High pull, Power clean, Front jump (band), Medicine ball throw, Plyometric push-up, Plyometric jump (single and both leg), Countermovement jump, Lunge jump</td></tr>
<tr><td>Lower
& core</td><td>Dead lift, Squat, Hip adduction, Hip abduction, Nordic hamstring curl, Calf raise, Knee extension, Knee flexion</td><td>Dead lift, Isometric squat, Squat, Nordic hamstring curl, Calf raise, Knee extension, Knee flexion</td><td>Dead lift, Single leg squat, Eccentric back extension, Cross lunge, Trunk rotation, Hip thrust, Eccentric leg raise, Decline eccentric abdominal twist</td></tr>
<tr><td colspan="2">No. of exercise/day</td><td>5~7</td><td>7~9</td><td>4~7</td><td>5~8</td></tr>
<tr><td colspan="2">Speed</td><td>Moderate</td><td>Low-moderate</td><td>Low</td><td>Moderate-high</td></tr>
<tr><td colspan="2">Reps</td><td>10~20</td><td>8~15</td><td>1~5</td><td>10~15</td></tr>
<tr><td colspan="2">Sets</td><td>3</td><td>3</td><td>3</td><td>3</td></tr>
<tr><td colspan="2">Frequency</td><td>2 days/week</td><td>3 days/week</td><td>3 days/week</td><td>3 days/week</td></tr>
<tr><td colspan="2">Resting time between sets</td><td>Free</td><td>60~90 s</td><td>>3 min</td><td>2~3 min</td></tr>
<tr><td rowspan="3">2016</td><td colspan="2" rowspan="2">Exercise type</td><td>Full body training</td><td>Full body training</td><td>Full body training</td><td>Full body training</td></tr>
<tr><td>Concentric</td><td>Isometric & concentric</td><td>Concentric</td><td>Concentric & plyometric</td></tr>
<tr><td colspan="2">% 1RM</td><td>40~60</td><td>65~80</td><td>90~100</td><td>50~80</td></tr>
<tr><td rowspan="3">2017</td><td colspan="2" rowspan="2">Exercise type</td><td>Full body training</td><td>Split training</td><td>Split training</td><td>Full body training</td></tr>
<tr><td>Isometric & concentric</td><td>Isometric & concentric</td><td>Concentric & eccentric</td><td>Concentric & plyometric</td></tr>
<tr><td colspan="2">% 1RM</td><td>40~60</td><td>65~80</td><td>90~110 (Eccentric exercise: 110%)</td><td>50~80</td></tr>
</table>

2. Training protocol

A strength training program was designed and implemented as shown in Table 1 for the goal of improving endurance and explosive power needed by skaters in short-distance speed skating races. The training program applied in the present study was developed by modifying and supplementing the training cycles and principles proposed by Kraemer & Ratamess (2004) and Kraemer & Fleck (2007). The strength training program was divided into adaptation, hypertrophy, maximal strength, and power phases. The program gradually transitioned from single-joint exercises to multi-joint exercises, and then to coordinated exercises. The training program from 2016 and 2017 comprised the same content, but the exercise type and intensity [%, one repetition maximum (1RM)] were set differently. In 2016, the entire training program comprised full body training, whereas in 2017, a split program was applied to reduce fatigue in the skater during the hypertrophy and maximal strength phases. Moreover, the program in 2016 focused on concentric contraction for up to 100% of 1RM during the maximal strength phase, whereas the program in 2017 applied an eccentric contraction during the maximal strength phase and the contraction was increased to 110% of 1RM, where training was performed with the assistance of a partner.

The degree of improvement in the strength of skaters was assessed by measuring 1RM from before to after the training program application. The items measured for 1RM included six types of exercises: power clean, bench press, sit-up, dead lift, squat, and seated row.

3. Procedure

The present study collected images from actual events during the 51st (October 2016) and 52nd (October 2017) Korea National All-Round Speed Skating Championships. The 2016 measurement results collected were used as the baseline values for the comparative analysis of the 2017 measurement results after the strength training program was applied. The present study followed the same procedures used in the studies by Song et al. (2017) and Song (2016). For 3D motion analysis concerning the starting technique of skaters who participated in the 500-m speed skating races, five high-speed video cameras (NEX-FS700, SONY, Tokyo, Japan) were used to acquire the images. For image acquisition in the 40-m interval being analyzed, two cameras were set up on both the right and left sides and one camera was set up in the back (Figure 1). Shooting began as soon as the skaters assumed their starting posture on the starting line and ended automatically after 16 s. The shooting speed was set to 120 frames/s, while the shutter speed was set to 1/500 s. To establish the spatial coordinates after the completion of the races, images acquired by two sets of control point frames, 8 × 1 × 2 m in size (Visol, Seoul, Korea), were moved around the track.

4. Data processing

Image data processing in the present study was performed using KWON3D 3.1 (Visol, Seoul, Korea; version 3.1) program. Data processing involved calculating the actual spatial coordinates using the control points and deriving the 3D coordinates of the body. Here, the left/

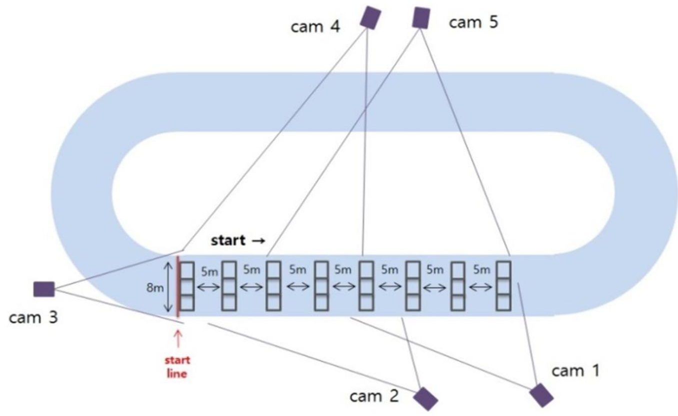

Figure 1. Layout of cameras and control point installation (Song, 2016)

right direction was defined as the X axis; forward/backward direction (the direction of motion) was defined as the Y axis; and the up/down direction was defined as the Z axis. The human body model was defined by a rigid body system connecting 16 body segments based on a total of 20 joint points (head, chin, right/left shoulder, right/left elbow, right/ left wrist, right/left hand, right/left hip, right/left knee, right/left ankle, right/left heel, and right/left toe). The two-dimensional coordinates obtained from each camera were synchronized using cubic spline interpolation, while the direct linear transformation (DLT) method developed by Abdel-Aziz & Karara (1971) was used to calculate the 3D coordinates. Moreover, the Butterworth second-order low-pass filter was used for data smoothing to eliminate errors introduced as a result of noise generated by various causes, including digitizing. The cut-off frequency was set to 10 Hz.

5. Variables

Based on the results from the studies by Song et al. (2017), Song (2016), Noordhof, Foster, Hoozemans, & de Koning. (2013), and Jun (2010), the present study analyzed the angular variables shown in Figure 2, along with time taken to reach 500 m and 100 m marks, reaction time, CoM position at 2.5 s after starting, time to nine strokes, and kinetic chain. The angular variables were presented as the average values of each stroke (push-off and trunk angles) and average values of the absolute values (knee joint angles) from stroke one to stroke five.

- Push-off angle: absolute angle formed by the blade and CoM relative to the X axis (θ_1)
- Upper extremity angle: absolute angle formed by the trunk relative to the Y axis (θ_2)
- Knee joint angle: relative angle formed by the thigh and lower leg (θ_3)
- Ankle joint angle: relative angle formed by the lower leg and foot (θ_4)
- Hip joint angle: relative angle formed by the thigh and trunk (θ_5)
- Kinetic chain: proper kinetic chain defined as when the moment of reaching the maximum extension angle as an organically connec-

ted body by the hip, knee, and ankle joints take place in the order of knee-hip-ankle joint (Song et al., 2017; Bunton, Pitney, Cappaert & Kane, 1993)

- Kinetic chain rate: number of proper kinetic chain strokes/total number of strokes (n=8) * 100

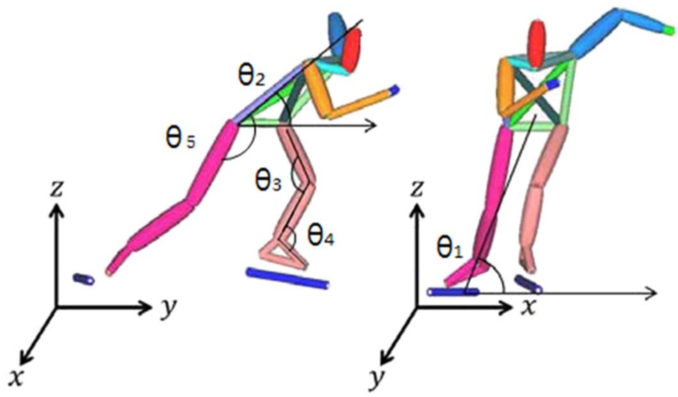

Figure 2. Definition of angles (Song et al., 2017)

RESULTS

1. Degree of improvement in strength

Table 2 shows the degree of improvement in 1RM of each measured exercise from before to after applying the 2017 strength training. Both male and female skaters showed an average of 11% improvement in strength from before to after the strength training.

2. Factors significantly correlating with the 100-m time

Table 3 shows the 500-m race times of elite skaters from 2016 and 2017 and the kinematic variables that affect the 100-m time.

Table 2. Improvement of 1RM (%)

	Power clean	Bench press	Sit-up	Dead lift	Squat	Seated row
Men	16.0	7.3	20.0	12.0	8.0	3.0
Women	13.9	13.3	17.0	6.7	5.6	7.5

The M1 skater showed higher values for 500-m and 100-m time and reaction time in 2017 than in 2016, indicating that the skater was slower by 0.27, 0.09, and 0.01 s, respectively. The distance traveled as indicated by the CoM position at 2.5 s after starting was longer by 0.93 m in 2017 than in 2016, while the time to nine strokes reduced by 0.08 s.

The M2 skater showed lower values for 500-m time and reaction time in 2017 than in 2016, indicating that the skater was faster by 0.27 and 0.05 s, respectively. However, the value for 100-m time in 2017 was higher by 0.1 s than that in 2016, while the CoM position at 2.5 s after starting was 0.45 m closer to the starting line than that in 2016 and the time to nine strokes reduced by 0.03 s.

The M3 skater showed a higher value for 500-m time in 2017 than in 2016, indicating that the skater was slower by 0.03 s, and a lower value for 100-m time and reaction time in 2017 than in 2016, indicating that the skater was faster by 0.01 and 0.1 s, respectively. Meanwhile, the CoM position at 2.5 s after starting was 1.14 m farther from the starting line and the time to nine strokes was reduced by 0.23 s.

The M4 skater showed a lower value for 500-m time and reaction time in 2017 than in 2016, indicating that the skater was faster by 0.05 and 0.06 s, respectively. However, 100-m time and time to nine strokes in 2017 showed higher values than those in 2016, indicating that the skater was slower by 0.09 and 0.15 s, respectively. The CoM position at 2.5 s after starting was 0.01 m closer to the starting line in 2017.

The W1 skater showed lower values for 500-m and 100-m time and

Table 3. Results of the 500-m lap time and variables affecting 100-m lap time

	500-m lap (s)		100-m lap (s)		Reaction time (s)		COM position after 2.5 s (m)		Time to nine strokes (s)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
M1	**35.39**	35.66	**9.62**	9.71	**0.22**	0.23	12.60	**13.53**	2.80	**2.72**
M2	35.61	**35.34**	**9.73**	9.83	0.22	**0.17**	**12.90**	12.45	**2.62**	2.65
M3	**35.50**	35.53	9.76	**9.75**	0.30	**0.20**	12.54	**13.68**	2.63	**2.40**
M4	35.49	**35.44**	**9.83**	9.92	0.28	**0.22**	**11.62**	11.61	**2.68**	2.83
W1	38.57	**38.23**	10.66	**10.53**	0.25	**0.20**	**12.63**	11.49	2.97	**2.83**
W2	39.50	**38.83**	**10.73**	10.79	**0.23**	0.24	**10.89**	10.87	2.98	**2.80**
W3	39.94	**38.91**	11.10	**10.80**	**0.28**	0.29	**11.40**	10.52	3.03	**2.98**
W4	40.04	**39.66**	11.10	**11.01**	0.28	**0.19**	**12.13**	10.29	**2.83**	2.88

*__Bold__: superior results

Table 4. Kinetic chain and angle variables

	Kinetic chain (%)		Maximum knee angle (°)		Average trunk angle (°)		Average push-off angle (°)	
	2016	2017	2016	2017	2016	2017	2016	2017
M1	**100**	**100**	**151.57 (11.42)**	148.03 (7.35)	34.46 (3.59)	**34.95 (2.53)**	55.45 (3.34)	**57.56 (3.89)**
M2	**75**	62.5	**145.40 (3.48)**	132.23 (10.00)	41.69 (3.65)	**41.82 (3.23)**	54.90 (1.91)	**58.54 (3.52)**
M3	**87.5**	**87.5**	**149.88 (3.76)**	108.39 (12.61)	**47.23 (5.10)**	46.52 (3.67)	**60.68 (1.98)**	57.66 (1.73)
M4	**100**	**100**	**140.33 (6.96)**	134.96 (7.32)	38.10 (4.22)	**44.13 (5.97)**	**60.00 (2.05)**	58.28 (0.79)
W1	**87.5**	**87.5**	**158.16 (2.41)**	134.60 (15.44)	33.22 (4.19)	**35.55 (2.68)**	**59.12 (2.54)**	56.34 (2.99)
W2	75	**100**	143.78 (21.76)	**146.09 (4.52)**	34.68 (4.90)	**40.92 (1.76)**	58.34 (3.24)	**58.72 (3.17)**
W3	87.5	**100**	**142.15 (6.70)**	136.68 (4.42)	39.01 (4.57)	**39.58 (4.66)**	**61.46 (2.60)**	59.80 (3.13)
W4	**87.5**	75	**146.82 (3.09)**	140.92 (16.88)	**35.71 (3.04)**	34.03 (3.54)	60.24 (2.34)	**63.46 (4.29)**

*__Bold__: superior results

reaction time in 2017 than in 2016, indicating that the skater was faster by 0.34, 0.13, and 0.05 s, respectively. The time to nine strokes showed that the skater was also faster by 0.14 s in 2017, whereas the distance traveled as indicated by the CoM position at 2.5 s after starting was reduced by 1.14 m.

The W2 showed higher values for 100-m time and reaction time in 2017 than in 2016, indicating that the skater was slower by 0.06 and 0.01 s, respectively, and the distance traveled as indicated by the CoM position at 2.5 s after starting was shorter by 0.02 m. Meanwhile, the 500-m time in 2017 was lesser by 0.67 s and the time to nine strokes was also lesser by 0.18 s.

The W3 skater showed lesser time to reach 500-m and 100-m marks in 2017 than in 2016, and was faster by 1.03 and 0.3 s, respectively, while the time to nine strokes was also faster by 0.05 s. However, reaction time in 2017 was more than that in 2016 by 0.01 s and the distance traveled as indicated by the CoM position at 2.5 s after starting was shorter by 0.88 m.

The W4 skater showed lesser time for 500 m and 100 laps and lesser reaction time in 2017 than in 2016, indicating that the skater was faster by 0.38, 0.09, and 0.09 s, respectively. Meanwhile, the time to nine strokes in 2017 was increased by 0.05 s and the distance traveled as indicated by the CoM position at 2.5 s after starting was shorter by 1.84 m.

3. Major joint angle factors

Table 4 shows the results of kinetic chain, maximum knee extension angle, average trunk angle, and average push-off angle.

The M1 skater showed a proper kinetic chain rate of 100% in both 2016 and 2017, while the maximum knee angle was larger by 3.54° in 2016 and the average trunk and push-off angles were larger by 0.49° and 2.11°, respectively, in 2017.

The M2 skater showed a decrease of 12.5% in the kinetic chain rate from 2016 to 2017, while showing an improper kinetic chain with the order of ankle-knee-hip joints during Strokes 1 and 3 and knee-ankle-hip joints during Stroke 5. The maximum knee angle was smaller by 13.17° in 2017, and the average trunk and push-off angles were also smaller by 0.13° and 3.64°, respectively, in 2017.

The M3 skater showed a kinetic chain rate of 87.5% in 2017, which was the same as that in 2016, and an improper kinetic chain with the order of knee-ankle-hip joints was shown during Stroke 3. The maxi- mum knee angle was smaller by 41.49° in 2017, and the average trunk and push-off angles were also smaller by 0.71° and 3.02°, respectively, in 2017.

The M4 skater showed a kinetic chain rate of 100% in both 2016 and 2017, while the average trunk angle was larger by 6.03° in 2017. However, the maximum knee and push-off angle were smaller by 5.37° and 1.72°, respectively, in 2017.

The W1 skater showed a kinetic chain rate of 87.5% in 2017, which was the same rate as that in 2016, and an improper kinetic chain with the order of knee-ankle-hip joints was shown during Stroke 2. The maximum knee and average push-off angles were smaller by 23.56° and 2.78°, respectively, and the average trunk angle was larger by 2.33° in 2017.

The W2 skater showed a proper kinetic chain rate of 100% in 2017, which was an increase of 25% from 2016. Meanwhile, the maximum knee, average trunk, and average push-off angles were larger by 2.31°, 6.24°, and 0.38°, respectively, in 2017.

The W3 skater showed a proper kinetic chain rate of 100% in 2017, which was an increase of 12.5% from 2016. Meanwhile, the maximum knee and average push-off angles were smaller by 5.47° and 1.66°, respectively, and the average trunk angle was larger by 0.57° in 2017.

The W4 skater showed a decrease of 12.5% in kinetic chain rate from 2016 to 2017, showing an improper kinetic chain with the order of knee-ankle-hip joints during Strokes 5 and 7. Meanwhile, the maximum knee and average trunk angles were smaller by 5.9° and 1.68°, respectively, and the average push-off angle was larger by 3.22° in 2017.

DISCUSSION

The present study analyzed kinematic differences in the starting techniques of elite speed skaters for 500-m races from 2016 (before strength training) to 2017 (after strength training). The characteristics of each skater were as follows.

The M1 skater showed 100-m time that was lesser by 0.09 s in 2016 than in 2017, and this result is believed to have been caused by the effects of pushing off with a larger knee extension angle by a proper kinetic chain rate of 100% and a slightly lesser reaction time (0.01 s) in 2016 than in 2017. Despite having a longer reaction time in 2017, the skater was able to skate through the starting phase quickly because the CoM position at 2.5 s after starting was farther and the time to nine strokes was lesser than those in 2016. This may be attributed to improvement in strength, allowing for greater power to be generated in the push-off motion and more effective thrust by creating a larger push-off angle (de Boer et al., 1986). However, the reason for the longer 100-m time may have been the problems in the interval between Stroke nine and the 100-m mark, where the stroke motion appeared to be different compared with that in the starting phase, and the analysis of the stroke motion in this interval is believed to be necessary. Moreover, since this skater had the longest reaction time among all male skaters, reducing the reaction time as much as possible would allow for the 100-m time to be reduced.

Despite the reaction time being lesser by 0.05 s in 2017 than in 2016, the M2 skater showed a shorter distance traveled from the starting point as indicated by the CoM at 2.5 s after starting and longer time to nine strokes. It is believed that this was a result of the dynamic push-off motion not being executed in the early part of the starting phase because of the kinetic chain rate being 12.5% lower than that in the previous year and the maximum knee angle being smaller by 13.17°. Moreover, the M2 skater showed a kinetic chain rate of 62.5%, indicating that he executed an improper kinetic chain with the order of ankle-knee-hip joints or knee-ankle-hip joints. This reduces the dynamic efficiency of the body causing the need for compensation by the lower extremity joints that are connected (Loudon & Reiman, 2012), and thus, the kinetic chain rate should be improved to a proper order of knee-hip-ankle joints.

Meanwhile, as the M2 skater completed the 500-m race in the lowest time, which was lesser by 0.27 s than the previous year, it is suspected that he was able to complete the 500-m race under optimal conditions without fatigue owing to improved strength, or it is possible that his strength may be in curved sections or sub-sections. It is believed that by training to execute proper kinetic chain and generating faster acceleration of the CoM by faster strokes in the starting phase (Jun, 2010), mastery of the starting technique can be improved to shorten the overall rate time.

The reaction time of the M3 skater was reduced significantly by 0.1 s and both the CoM position at 2.5 s after starting and time to nine strokes were improved, indicating that the starting technique was effectively executed. In particular, the M3 skater showed increase in 1RM values for power clean, bench press, sit-up, and squat after strength training, and it is suspected that increase in muscle strength and anaerobic power from strength training had the largest impact on the improved starting technique of the M3 skater (Holum, 1984; de Koning et al., 2003; de Koning et al., 2004; de Koning, 2002).

However, the M3 skater showed the smallest maximum knee angle among all skaters, while both the average trunk and push-off angles were smaller than those in the previous year. Moreover, as the 500-m time did not improve, technical analysis on curved sections or sub-sections may be necessary. It is believed that by continuing to undergo strength training and training for dynamic starting technique with larger knee, trunk, and push-off angles, while also improving the kinetic chain rate to achieve 100%, the M3 skater should be able to significantly reduce his 100-m time.

The M4 skater showed a shorter reaction time in 2017, but the results for CoM position after starting, time to nine strokes, and 100-m time were all worse than before, which is believed to result from the inability to generate enough thrust in the starting phase because of smaller maximum knee and push-off angles than those in 2016. However, because the M4 skater showed a proper kinetic chain rate of 100% in both 2016 and 2017, he showed efficient joint movement from the perspective of relaying the force generated in the muscles. Moreover, the M4 skater showed shorter 500-m time than the previous year, which is suspected to be the result of improved technique in the curved sections and sub-sections or the effect of improved strength.

As the M4 skater showed the longest time to nine strokes among all male skaters, acceleration should be increased by faster strokes to quickly skate through the starting phase and 100-m mark (Jun, 2010), while larger knee and push-off angles should be created to strengthen the thrust when starting (Kunz & Kaufman, 1981; de Boer et al., 1986).

The W1 skater showed the shortest 100-m time among all female skaters and her reaction time and time to nine strokes were shorter in 2017 than those in the previous year, indicating an overall improvement in the starting technique. Her 500-m time was also shorter by 0.34 s than the previous year. However, the kinetic chain rate was the same as that in 2016 (87.5%), and thus, by incorporating technical training to form a proper kinetic chain of 100%, she should be able to execute faster and more efficient starting motion with the same muscle strength.

The W2 skater showed a 25% increase in the kinetic chain rate from the previous year, which reached 100%, while her knee, trunk, and push-off angles also increased, indicating that she was able to execute the starting motion with a greater mastery. However, her 100-m time and reaction time in 2017 were longer than those in the previous year and the distance traveled as indicated by the CoM position at 2.5 s after starting was also shorter, and thus, reducing the reaction time can help shorten the time spent in the starting phase. Meanwhile, 500-m time of the W2 skater was shortened significantly by 0.67 s, and considering that the 1RM values for all times were improved, it is believed that it was not difficult for her to repeat the same motion under maximum power because of an increase in overall muscle strength.

The W3 skater showed a significant decrease of 0.3 and 1.03 s in 100-m and 500-m times, respectively. The W3 skater showed 12.5% improvement in kinetic chain rate, which reached 100%, indicating that she was able to execute a fast and efficient starting motion by repeating short strokes and forming a proper kinetic chain rate of 100%. One area of improvement was her reaction time, which was longest among all skaters at 0.29 s. Consequently, the distance traveled as indicated by the CoM position at 2.5 s after starting was also shorter. In a study by Harvey, Beauchamp, Saab & Beauchamp (2011), application of a reaction time training program in short-track skaters was able to reduce the reaction time by an average of 0.08 s, which led to medal-winning performances during the 2010 winter Olympics. Thus, if reaction time reduction training is applied additionally, race time can be improved even further.

The W4 skater showed that her 100-m time was shortened by 0.09 s in 2017 compared with that in 2016, while she also showed a push-off angle that was closest to the top world-class skaters. In addition, she showed significant improvement in 1RM values for power clean, bench press, dead lift, squat, and seated row. A dynamic starting motion was possible through the expression of strong muscle power resulting from improvement in overall muscle strength and fitness, which is suspected to have had an impact on the 500-m time as well. However, despite having the lowest reaction time among all female skaters (0.19 s), the distance traveled as indicated by the CoM position at 2.5 s after starting was shortest among all female skaters, which indicated that her fast reaction time was off set. It is believed that this result was caused by the effect of having a relatively low kinetic chain rate of 75%, and in particular, because of an improper kinetic chain with the order of knee-ankle-hip joints. Therefore, by undergoing technical training for push-off with the proper kinetic order to increase the efficiency of relaying force, the time spent in the starting phase could be reduced significantly.

CONCLUSION AND SUGGESTION

In the present study, strength training was applied to elite skaters who participated in 500-m speed skating races and a comparative analysis on the kinematic factors and factors that affect strength with respect to starting technique was conducted from before to after training.

The male and female skaters who participated in the strength training program of the study showed 11% improvement in strength, and among a total of eight skaters, four skaters showed a shorter 100-m time, while six skaters showed a shorter 500-m time. From a kinematic perspective, five skaters showed a shorter time to nine strokes, while six skaters maintained or improved their kinematic chain rate. Therefore, it was concluded that the strength training program provided in the present study had a positive impact on improving 500-m race performances of elite skaters.

It is believed that if the muscle power improvement training in the present study can be combined with additional reaction time reduction training program, the finish time of skaters could be shortened even further.

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