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Push-Off Mechanics in Actual Speed Skating and Slide Board Training: A Pilot Study for Designing Skating Simulator

Jong-Hyun Yang[1*], Do-Hoon Koo[2] and Insik Shin[2]

[1]Korea Institute for Curriculum and Evaluation, Seoul, South Korea; yakus13@snu.ac.kr
[2]Department of Physical Education, Seoul National University, Seoul, South Korea;
dhkoo4155@snu.ac.kr, ccdartha@gmail.com

Abstract

Objectives: The purpose of this study was to analyze the differences in posture during push-off phase between an actual speed skating condition and on slide-board, and provide the basis for improvement of slide-boards. **Methods/Statistical Analysis:** Nine speed skaters participated in the experiment. To obtain kinematic data in these two conditions, two methods were taken under consideration for the recording motion. The push-off phase was defined as the time period from the left toe contact on the ice surface to the right toe off which was normalized to 100 data points. Univariate analysis of variance was used to test if the differences between two groups with changing time frame in the whole push-off phase are significant. **Findings:** The results show that the distance between the two feet on the slide board was much longer, while the angle of rotation of both feet was much smaller in the entire push-off phase. Also, there was no significant difference in hip angle between two situations. The knee angle was significantly higher at the early stage of push - off, and the ankle angle was higher at the end of the push - off phase during the slide board training than the actual skate situation. In conclusion, design constraints limits the space on the slideboard which effects the kinematic parameters and made the distance between the left and right foot more distant, as well as smaller rotations of the push off foot. Current slideboards prefer hip-bending exercises, but they do not help with stretching exercises on the knees and ankles. **Application/Improvements:** Therefore, the structural design of the slide board can be improved by allowing the skater to perform forward propulsion, but not propel the knee or ankle explosively in the medial-lateral direction at the end of the push-off phase.

Keywords: Posture, Push-Off, Skating, Slide-Board

1. Introduction

Similar to any other winter sports, speed skaters perform dry land training during the offseason i.e., slide board training, anaerobic training, weight training etc. Among them, the slide board training is considered by the coach for training athletes for the improvement of technical skill as well as management of the basic skills. Although, it does not actually represent realities such as when to perform on ice but implements a situation similar to ice-skating. Thus, most off-season technical training is performed on the slide-board, as the skater can reproduce the sense of movement needed to skate in a restricted environment and space[1-3].

However, it is almost inevitable to avoid the difference between sliding board training and actual performance. Previous literatures have reported that the joint angle at the push-off stage is an important factor for obtaining higher power and maintaining stable performance. One of the differences between slide board and actual performance is the posture at the push off stage. In kinematic analysis, it has been confirmed that speed skating the angle of the joint at the push-off stage is important for high power generation and superior performance[4]. Thus,

**Author for correspondence*

an irrelevant posture can have an adverse effect on the muscle physiology resulting in localized muscle fatigue and may even affect the skating performance[5-7]. Previous studies have compared the klapskate and conventional skates where they studies reported the importance of foot rotation and a delay in onset of foot rotation was related to the increase in angular displacement and the peak angular velocity of knee and hip joint. Also, increased flexion of the knee joint moment at the end of the push-off phase and a reduction of work at the knee joint was also observed[8-11]. Therefore, it is necessary to investigate the differences in posture between two conditions, in order to maximize the benefits from this off season training method. Furthermore, by quantifying these differences could facilitate to redesign the slideboard more similar to an actual skating condition.

2. Method

2.1 Subjects

A total of nine participants were recruited (gender: 5 males, 4 females, age: 18±1.67 years, weight: 60±6.88 kg, height: 168±3.75 cm). None of the subjects had a previous history of physical problems to upper and lower extremities. Experimental procedures and possible risks were communicated verbally and in writing to all study participants, who then signed Institutional Review Board (IRB) approved informed consent (IRB NO.1501/001-003) to comply with the ethical principles of the Declaration of Helsinki (1975, revised 1983).

2.2 Apparatus

There are two sets of apparatus applied in two conditions: 1. Actual Speed Skating (ASS) on ice rink and 2. Slide Board Skating (SBS).

For the ASS condition, 86 control objects (8 m×1 m×2 m in size) were constructed to define the space coordinates (Width 8 m, Length 50 m, Height 2 m). 8 video cameras (HDR-PJ380, Sony, Japan) firmly mounted in the stands with a camera clamp (Manfrotto 035 Super clamp, Italy) and ball head (Manfrotto 488 RC4 MIDI ball head, Italy) to capture the movement.

For the SBS condition, the slide board was laid flatten and adjusted 1.6 m to match the height of the player. A total of sixty-one spherical passive reflective markers (12.7 mm) were attached at anatomical bony landmarks. A total of 8 infrared motion capture cameras (Oqus 500, Qualisys AB, Sweden) were used to record the participant's performance. A L frame and a T wand were used to calibrate.

2.3 Experimental Procedures

The ASS test took place at Taereung indoor ice rink at Seoul, Korea. The constructed control object was moved every 5 m and aligned precisely to cover the experimental course of 50 m length. To analyze the skating movement in actual condition, video cameras were set up at the height of approximately 15 meters which was placed on the railings of the stands, at an angle of 45°. The frame rate was set to full HD, 60 frames/sec and shutter speed was 1/350 sec.

Prior to the SBS test, a Non-Linear Transformation (NLT) method was used to establish three-dimensional spatial coordinates. Motion capture data was sampled at 100 Hz. The L frame was installed at the origin point of the global coordinate system and the T wand was moved and calibrated to include the entire experimental space for 30 sec.

The subjects wore specially designed tight motion analysis suit to reduce any discomfort and errors while collecting data. Passive reflective markers were attached at Upper body: Head (vertex, forehead, left ear, right ear), arm (shoulder, lateral/medial elbow, lateral/medial wrist, hand); lower body: Pelvis (left/right ASIS (Anterior Superior Iliac Spine), left/right PSIS (Posterior Superior Iliac Spine), each leg (GT (Great Trochanter), lateral/medial knee, lateral/medial ankle), and each foot (heel, toe, proximal first/fifth metatarsal, distal first/fifth metatarsal) and four more tracking markers on the trunk, upper arm, fore arm, thigh and shank segment.

Then, the subjects performed warm-up for 10 minutes and executed the task. There was no restriction applied on the number of lateral movement but the subject was informed to match tempos with actual speed skating. Each trial lasted for 1 minute followed by 1 minute for rest and recovery.

2.4 Analysis

The push-off phase was defined as the time period from the left toe contact on the ice surface to the right toe off. In other words, the left leg was a support-leg and the right leg was a swing-leg during the push-off phase in the experiment.

For the ASS condition, the motion videos were analyzed using video editing (Sony Vegas pro 9.0, Japan), video analysis software (Kwon 3D 3.01, Korea). And manual digitization of thirteen joint centers (Head, Right/Left (shoulder, hip, knee, ankle, heel, toe) was performed. Furthermore, 3D coordinates were calculated via the Direct Linear Transformation (DLT) method. When calculating the 3D coordinates, Butterworth 2nd Order low-pass filter was used which eliminated any noise occurring from various sources, such as digitizing errors and skin movement, while smoothing was performed with a cut-off frequency of 6 Hz.

The foot position was computed as the intermediate point between heel and toe projected to the horizontal plane:

$$P_{foot} = ((\mathrm{x}_{heel} + \mathrm{x}_{toe})/2, (\mathrm{y}_{heel} + \mathrm{y}_{toe})/2, 0) \quad (1)$$

The foot rotation angles were computed via anti-trigonometric function:

$$\theta_x = \arcsin\left(\frac{x_{toe} - x_{heel}}{((x_{toe} - x_{heel})^2 + (\mathrm{y}_{toe} - y_{heel})^2)^{1/2}}\right) \quad (2)$$

$$\theta_x = \arcsin\left(\frac{y_{toe} - y_{heel}}{((x_{toe} - x_{heel})^2 + (\mathrm{y}_{toe} - y_{heel})^2)^{1/2}}\right)$$

Where, $\mathrm{x}_{heel}, \mathrm{x}_{toe}, \mathrm{y}_{heel}, \mathrm{y}_{toe}$ are coordinates of heel and toe calculated via the DLT method.

The position data of shoulder, hip, knee, ankle, and toe were used to compute the absolute left hip, knee and ankle joint angle via anti-trigonometric function:

$$\theta_{hip} = \arccos\left(\frac{\overrightarrow{HipShould} \bullet \overrightarrow{KneeHip}}{|\overrightarrow{HipShould}| \cdot |\overrightarrow{KneeHip}|}\right)$$

$$\theta_{knee} = \arccos\left(\frac{\overrightarrow{KneeHip} \bullet \overrightarrow{AnkleKnee}}{|\overrightarrow{KneeHip}| \cdot |\overrightarrow{AnkleKnee}|}\right) \quad (3)$$

$$\theta_{ankle} = \arccos\left(\frac{\overrightarrow{AnkleKnee} \bullet \overrightarrow{ToeAnkle}}{|\overrightarrow{AnkleKnee}| \cdot |\overrightarrow{ToeAnkle}|}\right)$$

Where, $\overrightarrow{HipShould}$ is the vector between hip and should, $\overrightarrow{KneeHip}$ is the vector between knee and hip, $\overrightarrow{AnkleKnee}$ is the vector between ankle and knee, $\overrightarrow{ToeAnkle}$ is the vector between toe and knee. While standing in static position, hip angle and knee angle was 180 degrees while ankle angle was 90 degrees.

For the SBS condition, the Qualisys Track Manager was used to capture the movement, and the kinematic data obtained from the three-dimensional coordinate values were processed using Visual 3D V5 Professional (C-Motion, Inc., Germantown, Maryland, USA) and Excel 2013 (Microsoft Inc., USA). The 3D coordinates of the reflective markers attached to the body were smoothed using a Butterworth 4th order low pass filter to remove noise and the cut-off frequency was set at 6 Hz.

Also the foot position and foot rotation angles were computed using the position data of heel and metatarsal 2. The equation of these computations was similar with Equation (1) and (2). And via anti-trigonometric function, the position data of knee, ankle and metatarsal 2 was used to compute left ankle angle. The left knee angle was computed using the position data of knee, ankle and pelvis. The position data of top marker of head, pelvis and knee was used to compute left hip angle. The equation of these computations was similar with Equation (3).

The whole push off phase was normalized to 100 data points. The average angles of 6 speed skating trials and 3 slide board trials were analyzed. Then the whole push off phase was divided into five parts with 20 data points on each part.

2.5 Statistics

The univariate analysis of variance was used to test if the differences between two groups with changing time frame in the whole push-off phase are significant. Group 1 is ASS condition while group two is SBS condition. Independent t-test was performed to determine significant differences between the values obtained from the sliding board situation and the actual skating situation for each part of the push-off phase. Statistical analyses was performed SPSS (IBM Corporation, Somers, NY, USA) and significant level was set at $p < 0.05$.

3. Results

3.1 Position of Foot

In the SBS test, the center of the push-off foot (right foot) with respect to the stable foot (left foot) displaced from 0.66 m to 1.06 m from Medial-Lateral (ML)direction and moved from -0.01 m to 0.05 in Anterior Posterior (AP) direction. The center position of the push-off foot (right foot) with respect to stabilizing foot (left foot) in the ASS test moved from 0.21 m to 0.54 m in ML direction and 0.09 m -0.35 m in AP direction is shown in Figure 1.

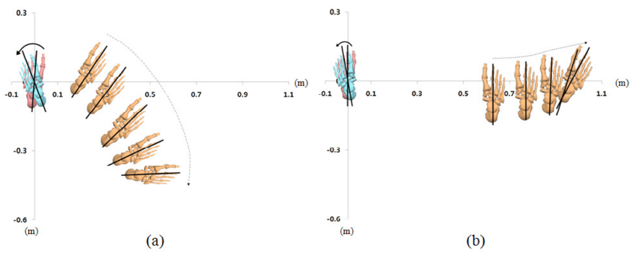

Figure 1. Position and rotation of feet with respect to the stable foot (left foot) during right foot push-off phase. (a) On slide-board. (b) In actual skating condition.

Therefore, a univariate variance analysis was performed on the entire data set of distance between the left and right foot positions for SBS and ASS conditions. This indicated that the two data sets were significantly different from each other at $p < 0.01$. Therefore, in order to correctly understand the fact that the two data sets differ greatly from each other, the push-off phase was divided into five parts. Before dividing the data sets, it was normalized to 100 data points with 20 data points on each part. The distance moved by the push-off foot (right foot) in its central position with respect to the stable foot (left foot) in both ML and AP direction for each part can be seen in Table 1. Henceforth, independent T-test was done for each of the 5 parts separately which concluded that the data sets were significantly different on each part with $p<0.01$.

3.2 Foot Rotation Angle

In the SBS test, the rotation angle of push-off foot changed from -1 to 30 degrees. Whereas for ASS condition, the rotation angle of push-off foot changed from 14 to 28 degrees Figure 1. In order determine the relation between the rotation angle for these two situations, an univariate analysis of variance was done for the whole data set and found that there was a significant difference between these two situations with $p<0.01$. Similar to the case of foot position, the push-off phase was divided into five parts and normalized to get 100 data points with 20 data points in each part is shown in Table 2. Furthermore, independent T-test was performed on each of the five parts of the push-off phase and found that the end two parts of the push-off phase for left foot were significantly different with $p<0.01$. Whereas for the right foot, the initial three parts were significantly different with $p<0.01$.

3.3 Joint Angles for Lower Limbs

For SBS condition the angle of lower limb ranged from, $\theta_{hip} = 70 - 73\,^{o}$, $\theta_{knee} = 113 - 118\,^{o}$, $\theta_{ankle} = 82 - 85\,^{o}$ whereas, angle of lower limb during ASS condition ranged at $\theta_{hip} = 72 - 73\,^{o}$, $\theta_{knee} = 95 - 111\,^{o}$, $\theta_{ankle} = 73 - 81\,^{o}$ in Figure 2. Univariate analysis was performed to determine the relationship of the lower limb joints to the entire data set under these two conditions. The data set turned out to be significantly different at $p<0.01$. Similarly, for comparing the two conditions the SBS condition and the ASS conditions, an independent T test was performed on the normalized 100 data points of the data set divided into five parts at the lower limb joint angle is shown in Table 3. No significant difference in each part of hip joint angle $p> 0.01$ was observed. Regarding the knee angle, it was found that only the initial part of the push-off phase was significantly different at $p <0.01$. Finally, with regard to the ankle angle, it was found that there was a significant difference between the two ends of the push-off phase with $p <0.01$.

Figure 2. Postural of stable leg during the push-off phase divided into 5 symmetrical parts. (a) On slide-board training. (b) In actual skat.

Table 1. Central position of push-off foot related to stable foot in 5 phases

	Actual skating		Slide board	
	FDx	**FDy**	**FDx**	**FDy**
P1	0.05	0.24	0.05	0.72
P2	-0.06	0.31	0.04	0.83
P3	-0.16	0.39	0.02	0.92
P4	-0.25	0.47	0.01	1.01
P5	-0.32	0.52	-0.02	1.05

Note: "FD": foot distance; "P": Phase

Table 2. Feet rotation angles in 5 phases

	Actual skating		Slide board	
	$\theta_{Left\ foot}$	$\theta_{Right\ foot}$	$\theta_{Left\ foot}$	$\theta_{Right\ foot}$
P1	6.25	15.16	8.81	-0.71
P2	4.17	16.27	7.62	0.64
P3	1.81	18.14	6.15	3.36
P4	-0.87	21.18	5.01	11.28
P5	-3.22	25.67	3.73	24.80

Note: "θ": angle; "P": Phase

4. Discussion

During ASS condition, subjects needed to push backward in order to advance their body and glide in the forward direction. However, on the slide-board training, subjects glided only on lateral directions which could be the direct reason why the distance in a fore-and-aft direction between the central position of the push-off and stable foot was further on slide-board than in actual situation. However, the difference of distance in left-and-right direction was also distinct. One was less than 0.6 m while another was larger than 0.6 m. The results suggest that subjects were anxious to contact the board when performing slide-board in order to reduce the risk of fall. As stable foot was restrained by the edge of the board, it is dangerous to increase the hover time of another foot, as well as the time of push-off phase which leads higher instantaneous velocity at the moment contacting the edge. Therefore, enlarging the space may facilitate to decrease the effect of edge.

In addition, the rotations of both feet were much smaller on slide-board than in actual situation. In fact, the push-off foot rotated clockwise on the slide-board at the end of the push-off phase while it rotated counter-clockwise in an actual situation during the whole phase. It suggests that subjects tried to restrain the trend of moving forward. Moreover, a great deal of scientific research proved that skaters use gravity for smooth propulsion in the first part of push-off phase while producing explosive force at the end of the push-off phase. However, on slide-board subjects must produce large force at first at the beginning of the motion which in fact leads to distortion of skating technique. Considering this fact, it is considered that finding a way to free the forward movement may make slide-board training more efficient.

Appropriate lower limb joint angles of stable leg facilitate in decreasing the air resistance and producing stable push condition. In the actual skating situation, it was difficult to maintain appropriate angles because of fatigue. In the first part of the push-off phase, i.e., the gliding part, the hip, and ankle angle were quite high. At the end of the push-off phase, explosive part, all angles were adjusted. However, on the slide-board, the hip angle was appropriate though the knee and the ankle angle kept high. Knee and ankle produced force later than hip and are considered as a key factor for explosive propulsion during later end of the push-off phase. Hence, the later parts for the ankle angle of the push-off phase shows significant difference for the sliding board when compared to actual situation. This is due to the fact that the subjects were anxious to contact the board when performing slide-board in order to reduce the risk of fall. This anxiousness of the skater prevents him/her to reduce the amount of explosive propulsion compared to the actual skating situation. Furthermore, result suggests that there is almost no explosive push-off phase when performing on slide-board, and present slide-board training is adverse for postural adjustment training of knee and ankle joints. It may also be due to the need of controlling the instantaneous velocity while contacting the edge. Therefore, present slide-board can only be used to train the posture of hip joint for gliding part of the push-off phase.

Therefore, in order to improve the effectiveness of the sliding board, structural limitations imposed by the sliding board must be removed so as to allow the skaters to

Table 3. Lower limb joint angles in 5 phases

	Actual Speed skating			Slide board		
	θ_{Hip}	θ_{Knee}	θ_{Ankle}	θ_{Hip}	θ_{Knee}	θ_{Ankle}
P1	72.14	98.05	80.23	73.04	113.90	81.71
P2	72.43	103.66	80.01	72.68	114.66	81.75
P3	72.64	108.12	79.36	71.37	114.12	82.36
P 4	72.69	110.20	76.94	71.10	114.44	83.75
P 5	72.64	110.85	74.35	72.12	116.70	85.03

Note: "θ": angle; "P": Phase

move freely across the sliding board. Henceforth, training to better simulate the actual skating situation, design of the slide board needs to be modified.

5. Conclusion

The study shows some differences in the posture during the push-off phase of speed skating and slide-board motion. The limitation of space on slide-board leads to restriction of movement, velocity, and joint stretch which changed skaters' kinematics parameters. Comparing to actual condition, on slide-board the amplitude of foot rotation decreased, and the trend of stretching backward was limited. Present slide-board is in favor of hip bending practice but is not conducive to the knee and ankle's stretch training. Thus, it is considered that the present slide-board needs a structural redesign for making slide-board training more similar to an actual skating condition.

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