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ORIGINAL

Analysis of Forefoot Bending Angle in Sprint Spikes According to Bobsleigh Start Lap Time for Development of Korean-Specific Bobsledding Shoes

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Objective: The aim of this study was to analyze effects of the toe-spring angle of bobsleigh shoes on start speed lap time to develop Korean-specific bobsled shoes suitable for winter environments and for domestic players on the basis of sports science and optimized biomechanical performance.

Method: Seven Korean bobsleigh athletes participated in this study, with three pairs of sprint spikes from three companies (Type A, Type B, Type C). To analyze sprint lap time and forefoot bending angle for each shoe, participants were instructed to drag a sled 15 meters from the start line at a maximum sprint. forefoot bending angle was collected by a high speed camera, and lap time speed was measured.

Results: Lap time for type B shoes was 3.52±0.17 sec, type A was 3.55±0.19 sec, and type C was 3.56±0.18 sec. Forefoot bending angles were: angle 1, 6.88±5.55°; angle 2, 9.23±6.38°; angle 3, 15.56±5.39°; angle 4, 9.54±3.85°; angle 5, 9.22±5.08°; angle 6, 7.66±6.44°; and angle 7, 4.30±6.24° ($p<.001$). Forefoot bending in angle 3 was as follows: type A, 16.47±6.01°; type B, 14.30±4.96°; and type C, 15.90±5.17°.

Conclusion: Hard outsoles and midsoles are better than soft type for reduced start lap time when developing a prototype Korean bobsled shoe.

Keywords: Bobsleigh, Toe spring angle, High speed camera, Lap time, Shoes

INTRODUCTION

France won the gold medal in bobsleigh at the 1998 Nagano Winter Olympics. The finish times of this 6 km race varied within 0.1 second: France, in first place, had a time of 53.63 seconds, followed by Germany with 53.70 seconds, Great Britain with 53.71 seconds, and the United States with 53.73 seconds. At the 2014 Winter Olympics in Sochi, rankings were determined by combining the finish times from four runs, all of which varied within 0.1 seconds: Russia placed first, with a time of 3:40.60, followed by Latvia with 3:40.69, and the United States with 3:40.99. These results indicate that bobsleigh is one of the fastest winter sports, in which wins are determined by shortening the time spent on narrow ice tracks and achieved through extreme speeds and competition (Dabnichki, 2015). A bobsleigh run lasts approximately 60 seconds, and the sleigh should run along the ice track at a mean speed of 135 km/h for competitive speed and decreased completion time (Denny, 2011). This is closely associated with the postures, weights, and steering techniques of the players, as well as aerodynamic variables of the sleigh. Efforts have been made to improve these factors and ultimately shorten the time (Chowdhury, Loganathan, Alam & Moria, 2015; Ubbens, Dwight, Sciacchitano & Timmer, 2016).

Recent studies focused on improving bobsleigh times found that shortening the start by 0.01 seconds could shorten overall lap time by 0.03 seconds, suggesting importance of the start (Dabnichki & Avital, 2006; Park, Kim & Park, 2015, Sabbioni, Melzi, Cheli & Braghin, 2016). In bobsleigh, starting involves teams sprinting approximately 30 m while pushing the 390 kg sleigh on a slippery surface. A strong propulsive force should be produced between the players' shoes and the ice surface in the starting area to decrease lap time and improve performance. Improvements in sports times have been associated with technological advancements in equipment. Bobsleigh shoes, along with the sleigh, helmets, and gloves, distribute the power of players onto the ice surface. Selection of appropriate shoes could act as a variable in improving the players' performance and times. In consideration of the various mechanical variables of each sport, forefoot bending angle has been modified in the general selection and development of athletic shoes. Forefoot bending angle in shoes is associated with ground reaction force and advancing force acceleration in terminal stance and pre-swing in running and jumping; ultimately, the angle has a close association with the athlete's performance (Goldmann, Sanno, Willwacher, Heinrich & Brüggemann, 2011). Forefoot bending occurs in the metatarsophalangeal joint, which is regulated by intrinsic foot and calf muscles (Goldmann, Sanno, Willwacher, Heinrich & Brüggemann, 2013). Forefoot bending angle in shoes can be modified by changes in the last design, which serves as the reference in shoe production, hardness and thickness of the outsole and midsole, and upper leather pattern. Forefoot bending angle should increase with running speed. However, excessive angle increases can lead to damage and increased fatigue or plantar fasciitis, whereas excessive bending limitation decreases efficiency in ground reaction force use, and acts as performance obstacle by limiting joint ranges of motion. Outsole and midsole thickness can influence shoe comfort and weight; these are modified in each track sport (Kwak, Mok & Kown, 2005; Kim, Cho, Lee & Park, 2009).

Bobsledding shoes with the following characteristics would improve bobsleigh performance and start times: light weight to maximize the force that kicks the ice surface, and a hard but elastic sole made by considering the sport's characteristic start movement and ground reaction force. Since research and development of bobsledding shoes have been almost nonexistent in Korea, Korean bobsleigh players have been sponsored by an overseas shoe brand since 2012 and worn the brand's shoes in games. In training, however, the players wear sprint spikes instead of bobsledding shoes. The internal bobsledding shoe structure is confidential information to the overseas shoe companies. Research is required to develop bobsledding shoes appropriate for Korean players by optimizing outsole and midsole thickness and hardness and sole structure. In this study, we aimed to provide necessary basic data by elucidating the relationship between toe spring angle and start sprint lap time in sprint spikes, which are used by Korean players when they practice starting, in order to develop Korean-specific bobsledding shoes.

METHOD

1. Participants

This study was conducted with seven players registered at the Gangwon Bobsleigh Skeleton Federation. The participants had no signs of musculoskeletal diseases in their lumbar vertebrae or lower limbs, and no morphological foot deformations. The participants were chosen from outstanding players who either participate annually in bobsleigh com-

Table 1. Participant information (N=7)

Item	Mean ± SD
Age (yrs)	22.71±4.61
Weight (kg)	86.57±13.62
Height (cm)	179.14±5.08
Foot length (mm)	268.57±6.27


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Figure 1. Sprint spike.

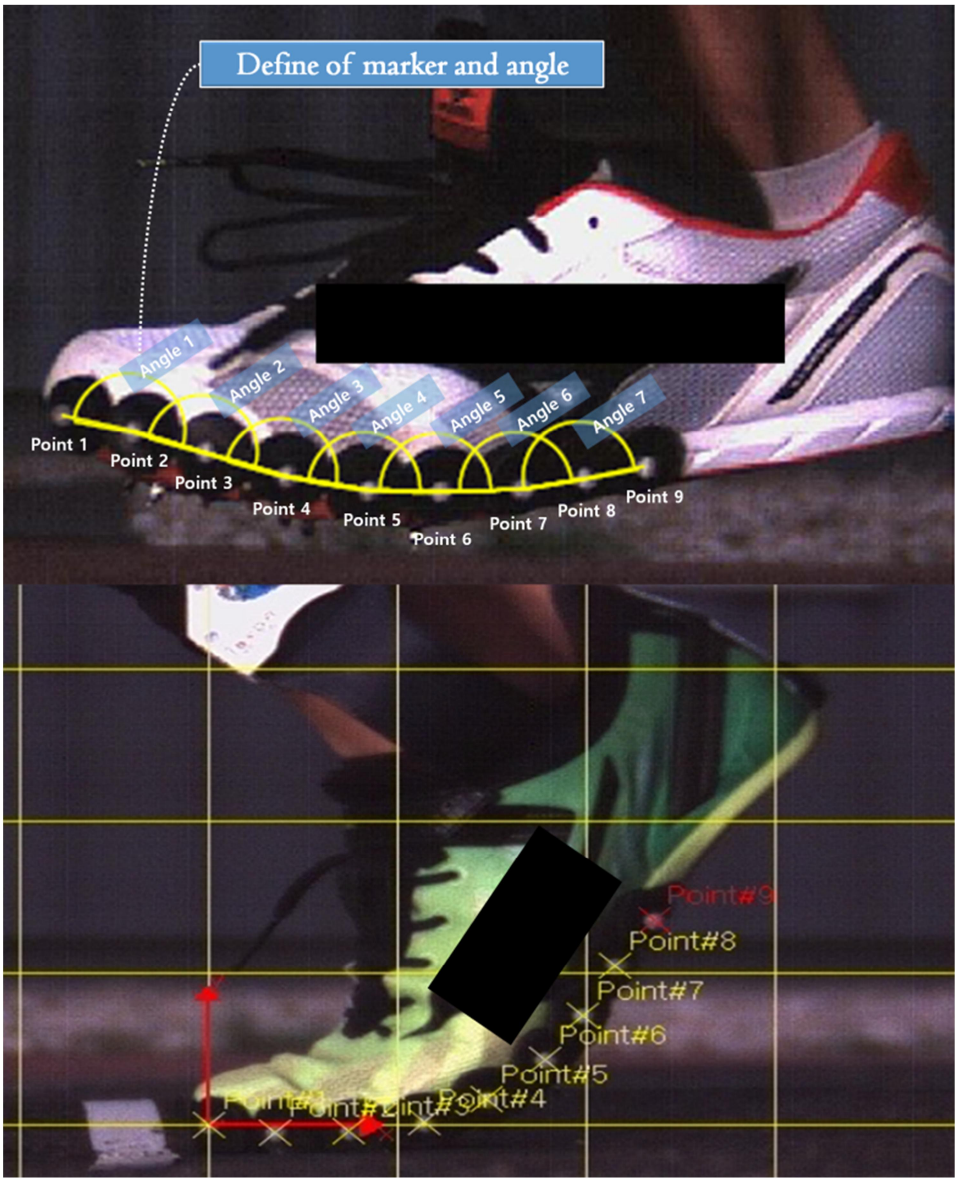

Figure 2. Definition of marker and angle for analyze toe spring angle.

petitions or have Olympics experience. We explained the purpose and methods of our study beforehand, and those who voluntarily consented to participate in the study were chosen. The general characteristics of the subjects are shown in (Table 1).

2. Instruments used for measurement

1) Shoes tested

Since shoes have yet to be optimized for Korean players practicing bobsleigh starting, players wear sprint spikes for practice rather than bobsledding shoes. We selected a total of three sprint spikes (type A from brand N, type B from brand M, and type C from brand M) with different toe spring angles and outsole hardness. Identical 8 mm two-layer parallel cast spike cleats were attached to all three sprint spikes to remove variability (Figure 1).

2) High-speed camera

(1) Filming with high-speed camera

In order to measure forefoot bending angle in participants while sprinting to start a bobsleigh race, a high-speed camera (S-pri, AOS, Switzerland) filmed the participants at 1000 frames per second. The high-speed camera was placed approximately 5 m from the start line, outside the bobsleigh start track to avoid disturbing participants while sprinting, and the focus was adjusted accordingly. We practiced moving the high-speed camera within a distance of 20 cm back and forth to match the participants' different strides. This enabled us to have the shoes in the angle of view and accurately film forefoot bending angle in sprinting players on the sagittal plane (Figure 3).

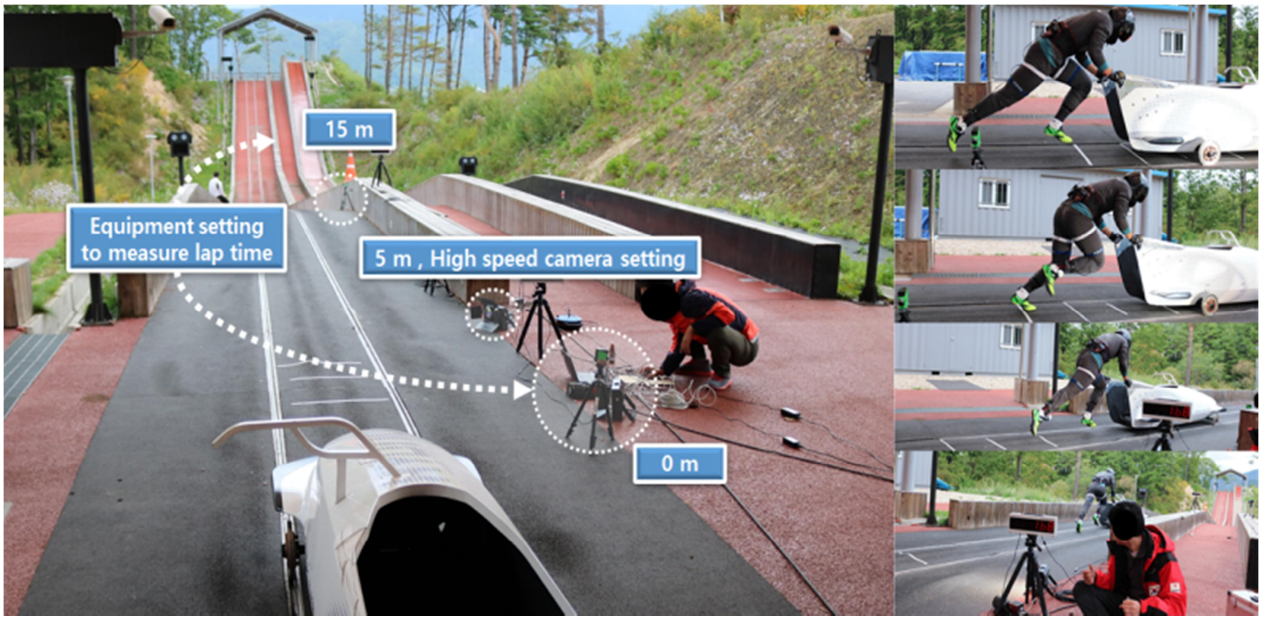

Figure 3. Bobsled start track and experimental scene.

(2) Definition of variables measured with the high-speed camera

We attached nine reflective markers (points 1-9) on the side of the forefoot and midfoot outsole, and defined the inner angles that form when lines are drawn to connect three points. For instance, if points 1 and 2 are connected with a line, and points 2 and 3 with another line, the inner angle between these two lines becomes angle 1. Similarly, the angle between the line connecting points 3 and 4 and the line connecting points 4 and 5 becomes angle 3. We analyzed a total of seven inner angles (angles 1-7) (Figure 2).

3) Lap timer

A digital lap timer (SR-500SP, Seed Tech, Korea), which can measure the time spent moving between two points by sensing objects with a beam sensor, was used to measure lap time. The free start mode was used, and the time required for players to leave the start line and sprint 15 m while pushing the bobsleigh was measured and analyzed (Figure 3).

3. Procedure

This study was conducted at a bobsleigh start track in resort A, located in Pyeongchang, Gangwon Province. The experiment was conducted during the participants' usual practice hours in consideration of their physical conditions. The participants were allowed sufficient time and practice before the actual experiment to get used to the measuring instruments installed in the bobsleigh start track. The outer sides of shoes were covered as much as possible so that the participants could not recognize different shoe types, and the shoes were distributed randomly. Following official Olympics rules, participants were asked to wait at the brakeman's start line position in flying start posture while holding a two-man bobsleigh. After we gave the signal to start, participants started to sprint while pushing the sleigh within 30 seconds. The start track was approximately 100 m long. After participants left the start line, forefoot bending angle was measured with a high-speed camera at 5 m, and the time spent to sprint 15 m was measured. Measurements were repeated three times for each sprint spike, and the mean of the three measurements was used for analysis. Participants rested for at least 10 minutes between each session to prevent fatigue, and the digital lap timer and high-speed camera were used simultaneously to collect respective data from each session to tune the measuring equipment (Figure 3).

4. Data analysis

Collected data were statistically analyzed with PASW for Windows (ver. 19), and all data were comparatively analyzed through one-way repeated analysis of variance (ANOVA). The lap time was compared among the three types of sprint spikes (type A, type B, and type C). To compare changes in the toe spring angle, means of forefoot bending angle measured as angles 1-7 were compared, and the three types of spikes were compared by greatest bending angle. The level of statistical significance was set as $\alpha = .05$.

RESULTS

1. Bobsleigh start lap time

We analyzed the time spent to sprint 15 m from the bobsleigh race start line in each shoe type, and observed no statistically significant difference between types (type A, 3.55±0.19 seconds; type B, 3.52±0.17 seconds; and type C, 3. 56±0.18 seconds) (Table 2) (Figure 4).

2. Toe spring angle

1) Forefoot bending angle measured as angles 1-7

Forefoot bending angle at start was measured as angles 1-7, and we observed statistically significant differences between the angles (angle 1, 6.88±5.55°; angle 2, 9.23±6.38°; angle 3, 15.56±5.39°; angle 4, 9.54 ±3.85°; angle 5, 9.22±5.08°; angle 6, 7.66±6.44°; and angle 7, 4.30±6.24°) ($p<.001$). As shown in (Figure 5), significant differences were observed in the following comparisons: {angle 1< angle 2, angle 1 < angle 4, angle 1 < angle 5, angle 1 > angle 7}, {angle 2 > angle 7}, {angle 3 > angle 1, angle 3 > angle 2, angle 3 > angle 4, angle 3 > angle 5, angle

Table 2. Results of lap time each shoes (Unit : sec)

Section	Shoe types			*F*	*p*
	Type A	Type B	Type C		
Lap time	3.55±0.19	3.52±0.17	3.56±0.18	3.195	0.064

Mean ± SD

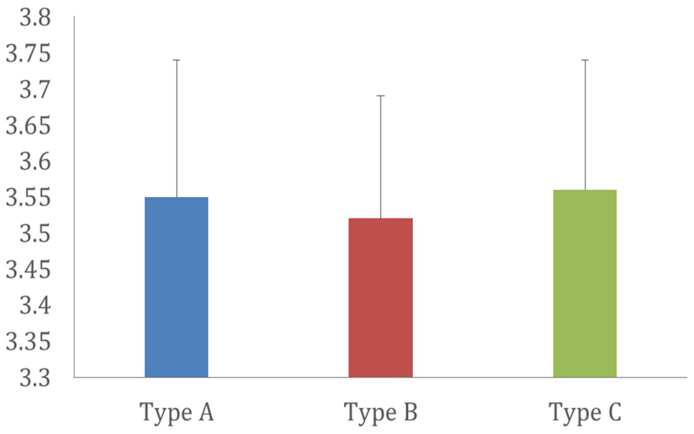

Figure 4. Comparison of lap time from start line to 15 meters in each shoe.

Table 3. Results of forefoot bending angle in Angle 1 to Angle 7 (Unit : °)

Angle 1	Angle 2	Angle 3	Angle 4	Angle 5	Angle 6	Angle 7	*F*	*p*
6.88±5.55^{a}	9.23±6.38^{b}	15.56±5.39^{c}	9.54±3.85^{d}	9.22±5.08^{e}	7.66±6.44^{f}	4.30±6.24	25.966	.000***

Mean ± SD, significant at ***$p<.001$

^{a}: Significant between Angle 1 and Angle 2, 4, 5, 7

^{b}: Significant between Angle 2 and Angle 7

^{c}: Significant between Angle 3 and Angle 1,2, 4, 5, 6, 7

^{d}: Significant between Angle 4 and Angle 7

^{e}: Significant between Angle 5 and Angle 6, 7

^{f}: Significant between Angle 6 and Angle 7

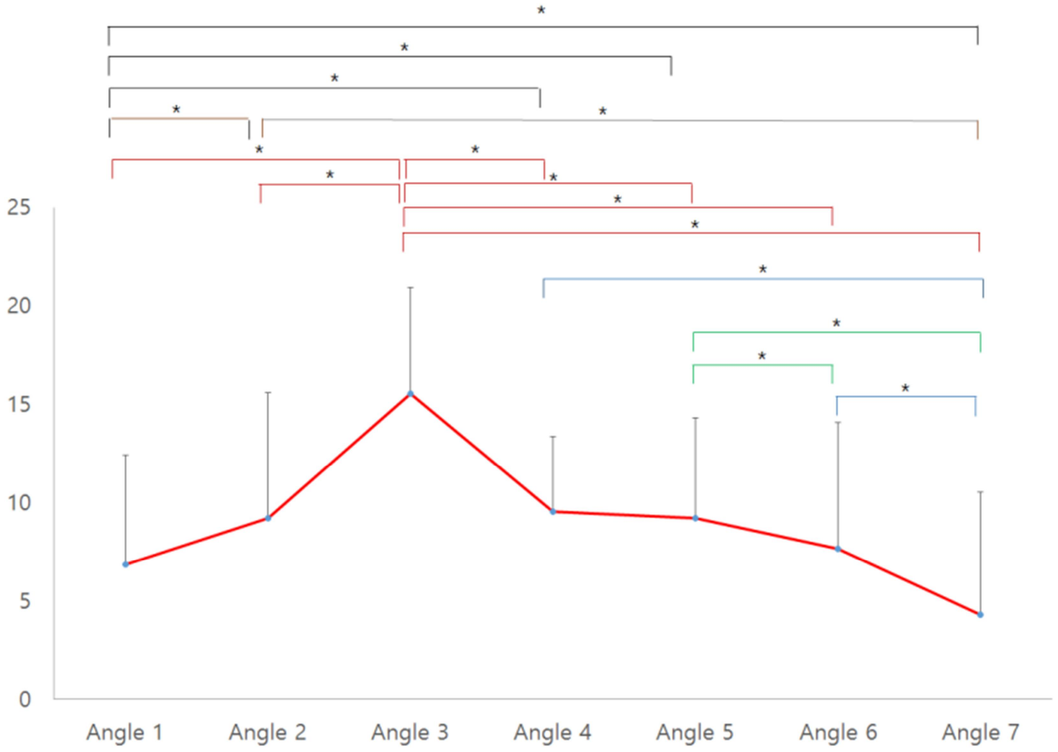

Figure 5. Comparison of forefoot bending angles in the spike shoes.

3 > angle 6, angle 3 > angle 7}, {angle 4 > angle 7}, {angle 5 > angle 6, angle 5 > angle 7}, {angle 6 > angle 7} (Table 3) (Figure 5).

2) Changes in bending angle (angle 3) in each shoe type

Bending angle at start (angle 3) was compared between the three shoe types, and no statistically significant difference was observed (type A, 16.47±6.01°; type B, 14.30±4.96°; and type C, 15.90±5.17°) (Table 4) (Figure 6).

Table 4. Results of each shoes bending angle of Angle 3 (Unit : °)

	Shoe types			*F*	*p*
	Type A	Type B	Type C		
Angle 3	16.47±6.01	14.30±4.96	15.90±5.17	1.122	0.347

Mean ± SD

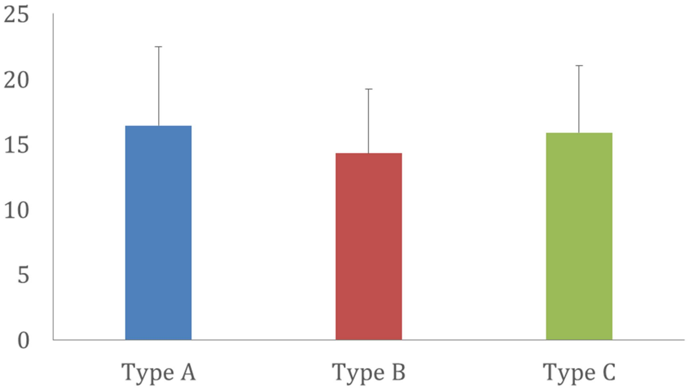

Figure 6. Comparison of bending angle results in angle 3.

DISCUSSION

Because a difference of 0.01 seconds determines the winner in bobsleigh, shortening the time spent to start the race has recently received attention. Considering that players have to sprint on short bobsleigh tracks, bobsleigh bears similarities to short-distance track running (Park, Kim & Park, 2015). In bobsleigh, however, players should reach maximum speed within a starting area that is shorter than most short-distance running tracks, while also pushing the sleigh. Center of mass moves further forward for upper extremities to hold and push the sleigh, which is also different from running.

In normal walking, the entire foot is in contact with the floor during the stance phase. To move the body forward, only the forefoot comes in contact with the floor, and the hindfoot lifts to increase the propulsive force. In 100 or 200 m short-distance running, runners gain propulsive force by using forefoot strike gait pattern, which decreases contact time with the floor while increasing stride rate (De Wit, De Clercq & Aerts , 2000; Squadrone & Gallozzi, 2009; Bonacci et al., 2013). Bobsleigh players push the sleigh in forefoot gait pattern to reach maximum speed within the short starting area. To increase running performance, bobsleigh players also conduct training programs including vertical jumping and 30 m sprint testing, which were originally designed to improve starting performance in short-distance runners (Sanno, Goldmann, Braunstein, Heinrich & Brüggemann, 2013).

In this study, we attached nine reflective markers to the side of the forefoot and midfoot outsole, and measured a total of seven angles. As a result, we found that angle 3, located in the forefoot, had greater bending when compared to other angles. When forefoot bending angle was compared between each shoe type at angle 3, no statistically significant difference was observed. Type B had the least bending compared to types A and C, and the start time was shorter when participants wore type B. The shoe sole absorbs the impact between the floor and the body, and is an important factor that determines propulsive force in walking and running. Soles with various forms and hardness have been developed for these reasons. The hardness and thickness of the shoe sole have particularly been consistently modified to improve propulsive force, which is a main shoe function. Previous studies that investigated the outsole and midsole hardness of running shoes reported that soles with high forefoot hardness can increase the propulsive force during running, even at low muscle activation, by improving gastrocnemius and soleus efficiency while walking, jumping, or jogging (Stefanyshyn & Nigg, 1998, 2000; Chen, Hsieh, Shih & Shiang, 2012; Lin et al., 2013). Willwacher, Knig, Potthast, and Brüggemann (2013, 2014) also reported that limiting metatarsophalangeal joint movement with shoe outsoles and midsoles during terminal stance and pre-swing in running is effective in energy return for obtaining propulsive force.

Type B shoes in this study were sprint spikes developed for short-distance running, with harder soles than type C, which was developed for mid- to long-distance running. Although type A was also developed for short-distance running, it had greater forefoot bending at angle 3 than type B, and the start sprint lap time was also slower than type B. This seems to be because type B shoes provide a bending moment appropriate for improving bobsleigh times in terms of the bending angle at the front of the shoes during forefoot strike and toe off. Using the structure and physical properties of materials used in type B shoes, as a reference for developing Korean-specific bobsledding shoes, would favor improvement of bobsleigh start times. Future studies would be needed to develop samples appropriate for use on ice tracks based on our type B shoes, and to investigate their functionalities in detail.

CONCLUSION

To provide basic data required for developing Korean-specific bobsledding shoes, this study analyzed start sprint lap time and toe spring angles with normal running shoes worn by bobsleigh players during practice, and obtained the following results:

1. Type B shoes showed the least bending at angle 3, which shortened the times.

2. Optimal materials for shortening start sprint times have hard structures and physical properties rather than soft, and can be used to manufacture the midsole and outsole of a proto sample of Korean-specific bobsledding shoes.

Future studies are needed to develop appropriate samples for use on ice tracks based on the type B shoes, and to thoroughly investigate their functionalities.

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