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ORIGINAL

Biomechanical Analysis at the Start of Bobsleigh Run in Preparation for the 2018 Pyeongchang Winter Olympics

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Objective: The bobsleigh shoes used in the start section are one of the most important equipment for improving the competition. Despite the importance of the start section, there are no shoes that are specific for bobsleigh athletes in Korea and Korean athletes have to wear sprint spike shoes and practice the start instead of wearing bobsleigh shoes. The objective of the present study was to provide data for improving the performance of Korean bobsleigh athletes by investigating the differences in their split time, plantar pressure, and forefoot bending angle based on skill levels at the start of a run under the same conditions as training conditions.

Method: Six Korean bobsleigh athletes were divided into two groups, superior (n=3) and non-superior (n=3). A digital speedometer measured the split time at the start; the Pedar-X system (Novel, Germany) measured plantar pressure. Plantar pressures and split times were measured as the athletes pushed a bobsleigh and sprinted at full speed from the start line to the 10-m mark on the bobsleigh track. An ultra-high-speed camera was used to measure the forefoot bending angle during the start phase.

Results: Significant between-group differences were found in split times ($p<.000$; superior = 2.38 s, non-superior = 2.52 s). The superior group had a larger rearfoot ($p<.05$) contact area, maximum rearfoot force ($p<.01$), and a larger change in angles 3 and 4 ($p<.05$).

Conclusion: At the start of a bobsleigh run, proper use of the rearfoot for achieving effective driving force and increasing frictional resistance through a wider frictional force can shorten start time.

Keywords: Bobsleigh, Plantar pressure, Forefoot bending angle, Sprint, Biomechanics

INTRODUCTION

Korean winter sports are still not given sufficient attention in comparison to summer sports, with attention focused on merely a few ice events. The 53 medals that Korea has won throughout all Winter Olympics up to the 2014 Sochi Winter Olympics in Russia have been from just 3 events (short track, speed skating, and figure skating). This means that Korean winter sports have advanced based almost solely on ice events. However, there is a growing interest in ice and sliding events. This is likely due to participation in tournaments, as athletes in these events are achieving outstanding results in world championship events. Among winter sports, bobsleigh was introduced for the first time in Korea in 2003, and, despite its short history, Korean athletes entered the men's 4-man bobsleigh event in the 2010 Vancouver Winter Olympics in Canada and competed in the finals, while in the 2014 Sochi Winter Olympics in Russia, Korean athletes competed in all bobsleigh events; men's 2-man and 4-man events and women's 2-man events. During the 2015~2016 season, the Korean team was ranked number 1 in the world by the International Bobsleigh & Skeleton Federation (IBSF), which further elevated Korean public interest.

A bobsleigh event is divided into 3 phases: the start run phase, drive phase, and finish phase. The start run phase is the phase where the athletes assume a ready position; once the starting horn sounds, they have 60 sec to run forward while pushing the sled. Depending on the start phase conditions for tracks in each country, the athletes must sprint at full speed for up to 55 m while pushing a very heavy sled (Sabbioni et al., 2016). During the 1998 Nagano Winter Olympics, the run times of each country were 53.63 sec for France (1st place finish), 53.70 sec for Germany (2nd), 53.71 sec for England (3rd), and 53.73 sec for USA (4th), showing that a 0.1 sec difference in the split time over a course of 6 km decided the final order of finish. In the latest 2014 Sochi Winter Olympics in Russia, the combined time from 4 runs in the 4-man bobsleigh event was 3:40.60 sec for Russia (1st place), 3:40.69 sec for Latvia (2nd), 3:40.99 sec for USA (3rd), and 3:41.02 sec for Russia (4th), demonstrating that just 0.1 sec in the combined time from 4 runs determined the color of the medal.

As shown, bobsleigh is one of the fastest winter sports, with a win or a loss being decided by just 0.1 sec; thus, reducing the time in the start phase by just 0.01 sec can have a critical effect on the overall run time and the final outcome (Wacker et al., 2006; Dabnichki & Avital

2006). Costanza et al. (2006) 4 reported that in a bobsleigh competition, a fast-starting split time is an essential element of success. Since shortening the time in the start phase has such an important influence on the overall outcome, the importance of the start phase in bobsleigh runs continues to be emphasized (Dabnichki & Avital, 2006; Sabbioni et al., 2016). The start of a bobsleigh run involves pushing the sled using a forefoot gait pattern that is similar to that used in short-distance track events. However, the bobsleigh event does not have a starting block to ease take-off, as seen in short-distance track events. Bobsleighing also presents the limitations of having to creating maximum driving force on a slippery surface, while movement is restricted by the sled in front of them. Owing to recent advances in sports science technologies, various studies have been conducted on performance improvement in numerous sports events; however, earlier performance improvement studies in bobsleigh have mostly examined bobsleigh equipment and overall run time (Brüggemann, Morloc & Zatsiorsky, 1997; Dabnichki, Motallebim & Avital, 2004; Dabnichki & Avital, 2006; Lewis, 2006; Roche, Turnock & Wright, 2008). However, studies on biomechanical analysis for enabling athletes to use maximum power are still lacking. Accordingly, the objective of the present study was to provide data for improving the skill levels of Korean bobsleigh athletes by conducting a comparative analysis on the split time based on differences in skill levels and associated plantar pressure and forefoot bending angles.

METHODS

1. Subjects

Six athletes who were members of the Gangwon Bobsleigh and Skeleton Federation participated in this study. The subjects were informed of the study objectives and volunteered to participate. The experiment was conducted on the subjects that gave written informed consents. Approval for the study was obtained from Kyungsung University Human Ethics Committee (approval number: KSU-13-12-002-0528). Among these athletes, 3 athletes, who were reserves on the national team, were allocated to the superior group, while the other 3, who were back-up reserves, were allocated to the non-superior group. The subjects were healthy athletes with no musculoskeletal disorders or symptoms in the lower back and lower limbs, as well as no morphological deformities in the foot. The general characteristics of the superior and non-superior groups are summarized in Table 1.

Table 1. Subject information

Item	Superior group (N=3) Mean ± SD	Non-Superior group (N=3) Mean ± SD
Age (yrs)	23.33±2.38	1 9.33±1.52
Weight (kg)	94.66±11.71	91.66±4.93
Height (cm)	182.33±5.85	178.33±6.42
Foot length (mm)	270.00±8.66	273.33±7.63

2. Measurement equipment

1) Split time measurement equipment

Split time records were measured using a digital universal speed timer (SR-500SP, Seed Tech, Korea). The digital universal speed timer measured the time travelled between phases using beam sensors for recognition and detection of the moving object. Accordingly, the starting mode was set to a free starting mode. The time it took the athlete to take off from the start line and sprint at full speed up to the 10 m point, while pushing the bobsleigh sled, was measured and analyzed. From each subject, repeated measurements were taken for 3 runs and the mean values from those runs were derived and analyzed (Figure 1). Figure 1. Start split time measurement equipment and settings.

Figure 1. Start split time measurement equipment and settings

2) Plantar pressure measurement equipment

Plantar pressure was measured using Pedar-X system (Novel, Germany) with the sampling frequency set to 100 Hz. Plantar pressure data were collected from the plantar pressure that appeared from the time the athlete took off and sprinted, while pushing the sled, to the 10 m point. Collected data were divided into forefoot, midfoot, and rearfoot regions, and the contact area and maximum force within each region were analyzed (Figure 2).

3) Ultra high-speed camera measurement equipment

An ultra-high-speed camera (S-pri, AOS, Switzerland) was set up outside the track at about 5 m from the starting line to acquire data on the forefoot bending angle during the bobsleigh starting motion at 1,000 fps. Because each athlete has a different stride length, the ultra-high-speed camera was moved forward or backward, based on trial and error, by up to 20 cm from the 5 m point for each athlete, so the outer side of the right foot that was being measured during full

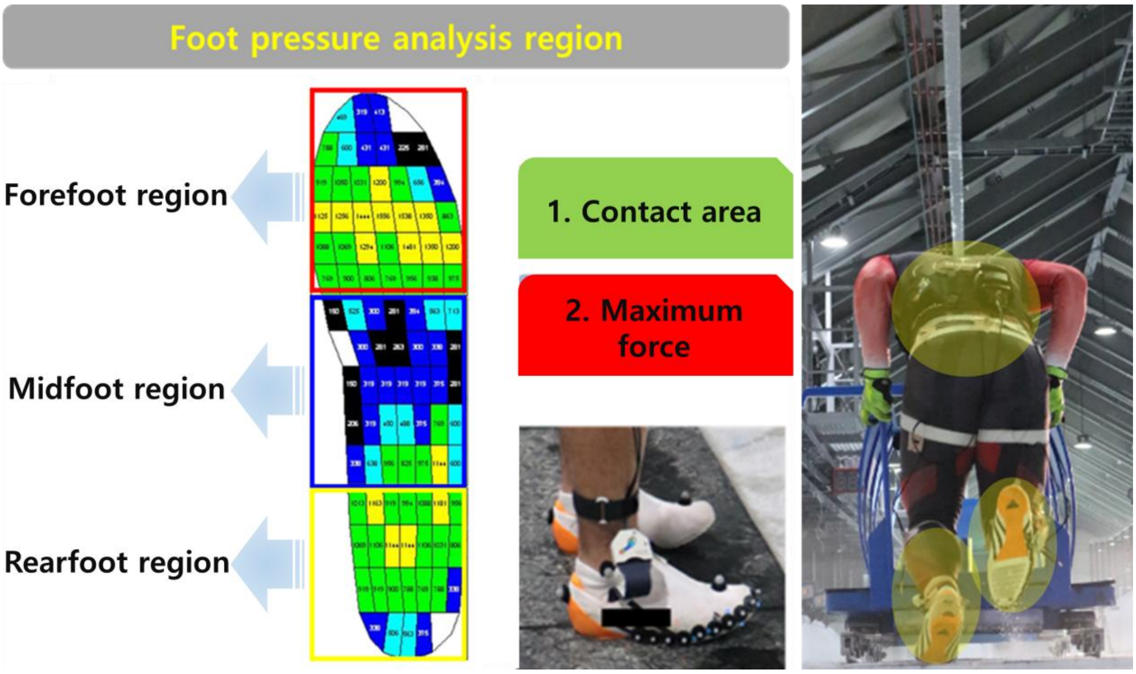

Figure 2. Plantar pressure measurement equipment and definition of plantar pressure regions

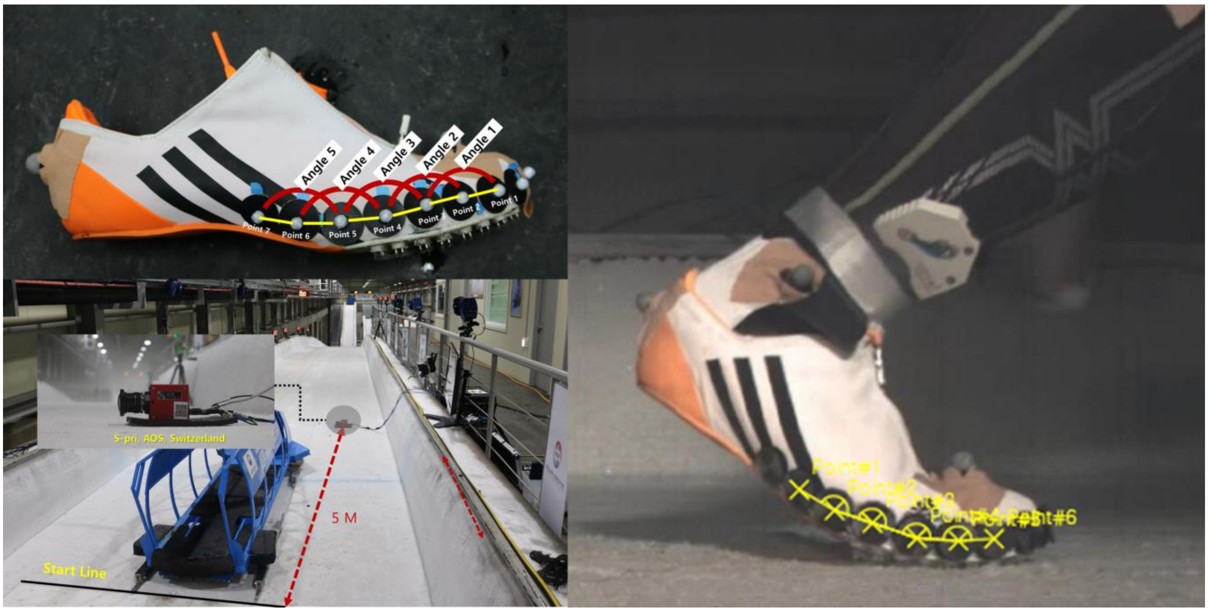

Figure 3. Ultra high-speed camera settings and definition of markers for analysis using ultra high-speed camera

sprint would be within the angle of view of the camera to allow accurate image acquisition. For the analysis of forefoot bending angles, 9 markers were attached to the experimental shoe, starting from the center of the forefoot and moving along the outer side in 2.2 mm increments, up to the midfoot outsole. To minimize distortion from lateral imaging, the marker in the center and the neighboring marker were excluded from analysis, meaning the third marker was designated as Point 1 and the subsequent markers were assigned numbers until reaching Point 7 for the last marker. During the analysis, the internal angle created by connecting the center of each marker (point) was defined as a single angle and the maximum amount of change in a total of 5 internal angles were analyzed. For example, the internal angle created from Point 1 to Point 2 and from Point 2 to Point 3 formed Angle 1, while the internal angle created from Point 3 to Point 4 and from Point 4 to Point 5 formed Angle 3 (Figure 3).

3. Experimental procedures

The present study was conducted on the Bobsleigh Start Course at "A" Sliding Center located in Pyeongchang-gun, Gangwon-do, South Korea. The experiment was conducted under the same conditions as actual start training conditions, with all the subjects wearing the same bobsleigh shoes. The subjects were given verbal guidelines about the measurement process and safety requirements, and the measurements were done according to the guidelines. Prior to the actual measurements, the subjects were given sufficient time for warm up and repeated practice time to become acclimated to the plantar pressure measurement equipment attached to the body and split time measurement equipment and ultra-high-speed camera set up on the track. To ensure the start phase was the same as that set according to Olympic standards, the subjects were instructed to stand in the brakeman's position, holding on to the practice-use 2-men bobsleigh sled and waiting in the flying start position at the track starting line. Then, the subjects were instructed to take off and sprint at full speed while pushing the sled, within 30 sec from when the start signal was given by the researcher. To synchronize the data between the different equipment, split time, plantar pressure, and ultra-high-speed camera data were collected simultaneously. The experiment was repeated 3 times for each subject, and at least 10 min of rest was given in between trials to prevent fatigue accumulation.

4. Data processing

PASW for Windows (Ver. 19) was used for data processing. All measured variables were tested for normality using the Shapiro-Wilk test, while independent *t*-tests were performed to compare start time, split time, plantar pressure, and forefoot bending angle between the two groups. The statistical significance level was set to α=.05.

RESULTS

1. Start phase split time analysis

The bobsleigh start time in the superior and non-superior groups was 2.38±0.05 sec and 2.52±0.05 sec, respectively ($p<0.001$) (Table 2).

Table 2. Results of start phase split time analysis (Unit: sec)

Split time	Superior group	Non-superior group	t	p
0~10 m	2.38±0.05	2.52±0.05	-8.048	0.00^{***}

Mean ± SD, $^{***}p<.001$

Table 3. Comparative analysis on contact area and maximum force between the groups (Mean ± SD)

Foot pressure	Region	Superior group	Non-superior group	t	p
Contact area (cm^2)	Forefoot	59.40±0.00	59.40±0.00	0.000	1.00
	Midfoot	39.67±3.86	43.37±1.99	-3.613	0.00^{**}
	Rearfoot	24.33±7.44	20.23±2.69	2.199	0.03^{*}
Maximum force (N)	Forefoot	1540.03±57.96	1518.03±76.89	0.970	0.33
	Mid foot	354.98±152.69	390.12±107.34	-0.799	0.43
	Rear foot	64.06±23.21	46.41±12.71	2.828	0.00^{**}

$^{*}p<.05$, $^{**}p<.01$

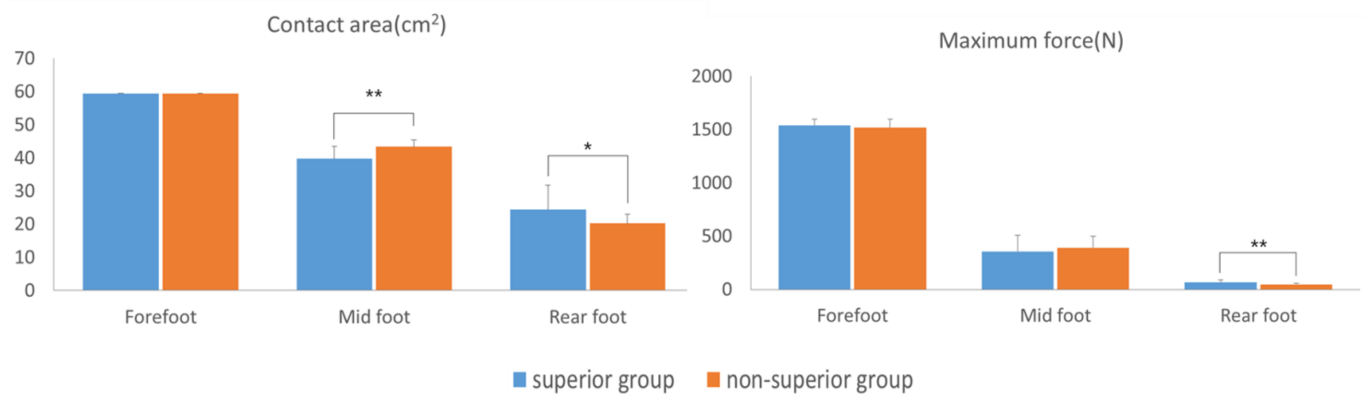

Figure 4. Comparative analysis of plantar pressure between the groups

2. Plantar pressure analysis

The midfoot surface area in the superior and non-superior groups was 39.67±3.86 cm^2 and 43.37±1.99 cm^2, respectively ($p<0.01$). With respect to the rearfoot, the surface area in the superior and non-superior groups was 24.33±7.65 cm^2 and 20.23±2.77 cm^2 ($p<0.03$). With respect to maximum force, a statistically significant difference was found only in the rearfoot, with the superior and non-superior groups showing 64.06±23.21 N and 46.41±12.71 N, respectively ($p<0.01$) (Table 3) (Figure 4).

3. Forefoot bending angle analysis

In the analysis of forefoot bending angle at the start of a bobsleigh run, the forefoot bending angle for Angle 3 in the superior and non-superior groups was 16.68±3.68° and 13.72±6.62° ($p<.05$). The results for Angle 4 in the superior and non-superior groups were 12.14±5.04° and 9.04±5.27° ($p<.05$) (Table 4) (Figure 5).

Table 4. Analysis of forefoot bending angle

(Unit: °)

Angle	Superior group	Non-superior group	*t*	*p*
Angle 1	12.61±4.66	10.73±3.54	1.636	.10
Angle 2	12.32±4.60	14.79±4.26	-1.989	.05
Angle 3	16.68±3.68	13.72±6.62	2.081	.04
Angle 4	12.14±5.04	9.04±5.27	2.135	.03*
Angle 5	16.28±9.21	15.76±7.97	0.216	.83

*$p<.05$

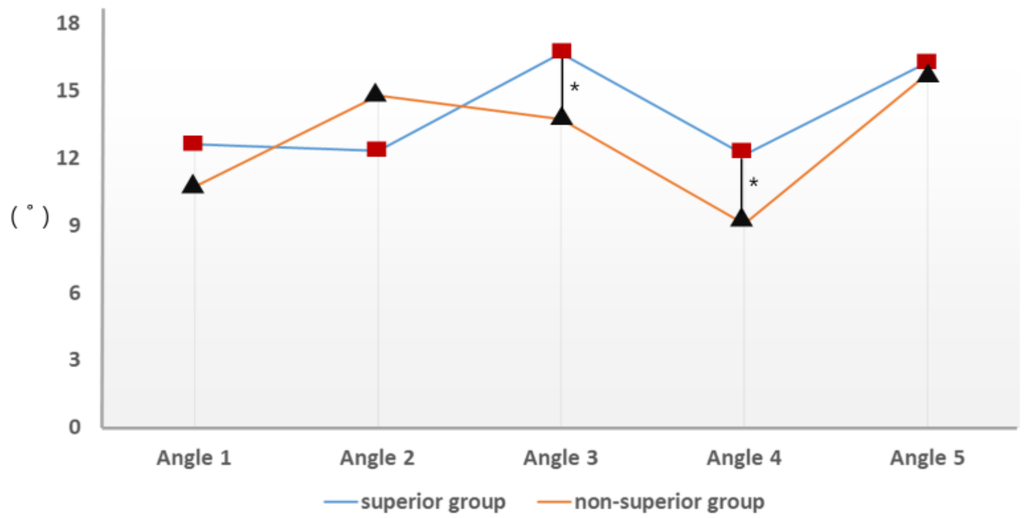

Figure 5. Comparative analysis of forefoot bending angle between the groups

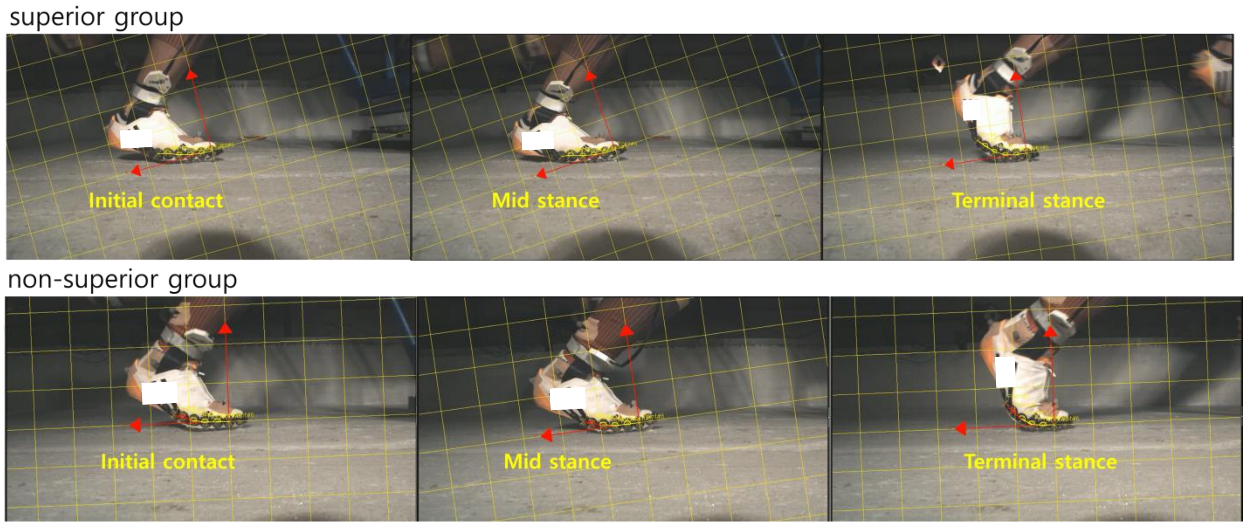

Figure 6. Captured image of forefoot angle during phases of gait between the groups

DISCUSSION

The present study examined the differences in split time, plantar pressure, and forefoot bending angle of bobsleigh athletes based on their skill level under the same conditions as actual training conditions, with the athletes wearing the same bobsleigh shoes for the objective of providing data for improving Korean bobsleigh athletes' performance.

A normal gait pattern comprises stages in which the rearfoot touches down on the ground first, followed by the midfoot and forefoot. During gait, maximum contact force is generated when the foot contacts the ground, and in particular, contact force appears higher in the heel in the rearfoot region than in other regions (Olney & Richards, 1996). However, track athletes who compete in short-distance events, such as the 100 m and 200 m, show a gait pattern of forefoot strike, in which only the forefoot contacts the ground and the rearfoot lifting off the ground, to maximize their driving force. This forefoot gait pattern is known to reduce contact time with the ground and increase gait speed (De Wit, De Clercq & Aerts, 2000; Squadrone & Gallozzi, 2009; Bonacci et al., 2013). Bobsleigh athletes also need to sprint at full speed with explosive power within the short distance in the bobsleigh start phase, which means that as they push the bobsleigh sled, they also use a forefoot gait pattern similar to that of short distance track athletes (Park, Kim & Park, 2015; Park et al., 2016; Park et al., 2017). However, bobsleigh is different from track in that the entire bobsleigh track is covered by man-made ice and the athletes need to push a high-weight sled in front of them. Therefore, competitive efficiency must be increased by preventing the shoes from slipping and by improving quickness.

In the present study, analysis of start phase split time of superior and non-superior athletes showed that the split time was faster by about 0.14 sec in the superior group. However, biomechanical comparisons for analysing the cause of such time difference showed that, with respect to plantar pressure, the superior group had higher maximum force and contact area in the rearfoot than the non-superior group, whereas the non-superior group had higher maximum force and contact area in the midfoot than the superior group. These results may be due to two reasons. First, from initial contact to mid stance, the superior group may have employed a rearfoot strategy by creating a bigger axial drop of the metatarsophalangeal joint than the non-superior group, which activated a greater stretch reflex of the calf muscles (Stefanyshyn & Nigg, 1998, 2000; Chen, Hsieh, Shih & Shiang, 2012; Lin et al., 2013). Moreover, just as seen by the superior athletes having greater change in Angles 3 and 4 in the forefoot bending angles, the superior athletes maximized the use of the elasticity in the shoe structure generated in the toe spring angle of the bobsleigh shoes (Figure 6). Second, bobsleigh requires the generation of optimal driving force by sprinting at full speed on a slippery surface. Consequently, bobsleigh shoes have over 250 spiked cleats throughout the forefoot region to prevent slipping on the ice surface during landing and to maximize frictional resistance. In other words, superior athletes exert greater kicking force on the rearfoot with the forefoot as the axis, for leverage during forefoot landing, to maximize frictional resistance and achieve wider frictional force on the ice surface; thus, they use their midfoot and rearfoot to allow greater cleats distribution throughout the forefoot region to dig deeper into the ice surface. More in-depth studies are needed in the future to examine biomechanical factors that can have a positive impact on bobsleigh start, including 3D motion analysis on lower extremities segments during bobsleigh start.

CONCLUSION

The present study examined the differences in split time, plantar pressure, and forefoot bending angle of bobsleigh athletes based on their skill level for the objective of providing the basic data for improving the performance of Korean bobsleigh athletes. Based on the findings in the present study, following conclusions were derived.

The superior bobsleigh athletes showed higher rearfoot contact area and maximal force than the non-superior athletes, while also showing greater amount of change in Angles 3 and 4 in the forefoot bending angle. Therefore, it is believed that proper use of the rearfoot for achieving maximum driving force and increasing frictional resistance through wide frictional force during landing on the slippery ice surface can have a positive impact on shortening the split time in the start phase.

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