Bobsleigh start interval times and three-dimensional motion analysis of the lower limb joints in preparation for the 2018 Pyeongchang Winter Olympics

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This study aimed to provide data to improve the technique of Korean bobsledders. To this end, we measured the start interval times of bobsledders with different performance levels and performed a motion analysis of the lower limb joints during the start interval. We divided 12 Korean bobsledders into a superior group and an inferior group before measuring the interval times and performing the motion analysis of the lower limb joints at the start of the bobsleigh. The start interval times showed a statistically significant difference between the superior and inferior groups ($p < .05$). The motion analysis of the lower limb joints revealed significant differences in hip flexion and extension, and in ankle dorsiflexion, plantar flexion, and supination ($p < .05$). Based on these differences, we deduced that the superior bobsledders achieved superior start times by using movements that focus more on horizontal changes in the center of gravity than on vertical changes, and movements that facilitate a longer stride.

KEY WORDS: Lower extremity, 3D motion analysis, Winter sports, Bobsleigh, Start

INTRODUCTION: Together with luge and skeleton, bobsleigh is one of the fastest winter sp-orts, with medals decided based on differences of as little as 1/1000th of a second. Recently, the start interval has been recognized as crucial for improving bobsleigh race times (Dabnic hki & Avital, 2006). This is because although the start only constitutes 6 seconds of the appr-oximately 60s race, reducing the time in this interval by 0.01 s can lead to a 0.03-s reduction in the total race time. Although bobsleigh starts can be considered similar to sprint starts in at hletics, important differences exist in that bobsleigh starts have no starting blocks, are perf-or med on slippery ice rather than on a running track, and require athletes to sprint at full speed while pushing a heavy bobsled. Based on previous studies that aimed to reduce bobsleigh ra ce times, most athletes focus on piloting the bobsled during the descent phase, or on the aer odynamic design and materials used in the sled (Brüggemann, Morloc, & Zatsiorsky, 1997; D abnichki, Motallebim, & Avital, 2004; Dabnichki & Avital, 2006; Lewis, 2006). Research is la cking on the importance of the start in bobsleigh races and the biomechanics required to g enerate explosive power in spite of the unique conditions of the bobsleigh track. Therefore, th is study compared the start interval times and lower limb joint movements of athletes with dif ferent performance levels to provide data for improving the technique of Korean bobsledders.

METHODS: The subjects of this study consisted of 12 Korean bobsledders who participated willfully after hearing a thorough explanation of the research objectives. Six of the 12 bobsle-dders (the superior group) were from the Korean national team, and the other 6 bobsledders (the inferior group) were reserve members of the Korean national team. The study was cond-ucted at the bobsleigh training track in Gangwon-do, where the Winter Olympics will be held in 2018. Considering the condition of the subjects, the experiment was conducted during th-eir usual training time. A three-dimensional (3-D) motion analysis system (Motion Analysis, U SA) consisting of 22 Raptor-E infrared cameras, a data station, a control PC. Reflective mar-kers was used to analyze the ranges of motion (ROMs) of the hip, knee, and ankle joints during bobsleigh starts(Table 2). A digital lap timer (SR-500SP, Seed Tech, Korea) was used to me-asure start interval times. Before taking measurements, the subjects were given ample time to practice, repeatedly, until they were comfortable with the equipment installed at the start track. To comply with the Olympic rules for bobsleigh starts, the subjects adopted a flying start position, holding a 2-man bobsled at the start line at the brakeman's end. Once they received the start sign from the researcher, they had 30 s to push the sled while running at full speed. For measurement of start interval times and lower limb joint ROMs, data were collected up to 10 m from the starting position. The mean of three measurements was used for all data, and the subjects were given at least 10 min of rest between measurements to eliminate the effects of cumulative fatigue. To ensure the agreement of data from different devices, data were collected from the digital lap timer and the 3-D motion analysis system, simultaneously. Independent t tests (PASW for Windows Ver. 19) were used to compare the start interval times and lower limb joint ROMs between the superior and inferior groups, and p values of <0.05 were considered statistically significant.

Table 2
Detailed placement of marker sets

Description	Marker name	Placement
Left ASIS	L. ASIS	Anterior superior iliac spine
Right ASIS	R. ASIS	
Sacrum	V. Sacrum	Superior aspect the L-5-sacral interface
Left Thigh Wand	L. Thigh	One lower thigh below the midpoint
Right Thigh Wand	R. Thigh	
Left lateral knee	L. knee	Along the flexion/extension axis of rotation at lateral femoral condyle
Right lateral knee	R. knee	
Left shank wand	L. shank	On lower shank below the midpoint
Right shank wand	R. shank	
Left lateral ankle	L. ankle	Along the flexion/extension axis of ration at lateral malleolus
Right lateral ankle	R. lateral	
Left heel	L. heel	Posterior calcaneus at same height from floor as toe marker
Right heel	R. heel	
Left toe	L. toe	Center of the foot between the 2nd and 3rd metatarsals
Right toe	R. toe	
Left medial knee	L. medial knee	Along the flexion/extension axis of rotation at medial femoral condyle
Right medial knee	R. medial knee	
Left medial ankle	L. medial ankle	Along the flexion/extension axis of ration at medial malleolus`
Right medial ankle	R. medial ankle	
Left PSIS	L. PSIS	Posterior superior iliac spine
Right PSIS	R. PSIS	

RESULTS: When we compared the start interval times between the superior and inferior gro -ups, the start time of 2.38 s of the superior group was significantly faster than the 2.52 s of th e inferior group ($p < 0.001$***)(Table 2).

Table 2
Results of start interval times in each groups(Unit : sec)

Distance	superior group	inferior groups	p
0 ~ 10 m	2.38±0.05	2.52±0.05	.00***

When we compared lower limb joint ROMs between the two groups, the superior group showed reduced extension ($p < 0.05$*) and increased flexion ($p < 0.05$*) in both hips. The superior group also showed increased lateral rotation of both knees ($p < 0.05$*). Moreover, the superior group showed decreased dorsiflexion ($p < 0.05$*) and increased plantar flexion ($p < 0.05$*) of the ankles(Table 3).

Table 3
Comparison of range of lower extremity motion in each groups(Unit : ˚)

Joint	Movement	Right Side			Left Side		
		superior group	inferior groups	p	superior group	inferior groups	p
Hip	Extension	-0.49±10.05	18.20±7.21	.00***	12.07±8.99	-26.86±5.68	.00**
	Flexion	100.57±12.71	83.56±9.31	.00**	110.95±12.89	95.26±14.81	.02*
	Adduction	15.85±3.72	6.33±4.04	.00***	4.06±3.16	4.21±3.65	.92
	Abduction	10.93±2.48	16.12±4.17	.00**	21.07±4.42	22.84±6.16	.49
	External rotation	21.49±7.84	22.09±12.46	.94	27.18±5.75	15.29±8.32	.00**
	Internal rotation	24.06±8.82	14.78±3.93	.01*	21.60±7.77	20.30±8.08	.73
Knee	Extension	-20.39±4.29	16.47±5.70	.11	-9.94±8.94	-9.59±5.71	.92
	Flexion	120.40±5.11	125.99±7.89	.09	121.92±8.64	121.64±6.10	.73
	Varus	18.43±4.44	14.10±2.72	.02*	20.11±3.67	20.89±7.44	.78
	Valgus	11.00±18.71	6.25±7.28	.48	8.15±4.96	4.07±4.49	.08
	External rotation	29.95±6.55	20.15±6.51	.00**	26.12±6.87	18.97±4.44	.01*
	Internal rotation	6.08±6.91	5.76±4.21	.96	3.76±3.46	6.70±3.48	.09
Ankle	Dorsiflexion	21.49±3.53	27.18±5.85	.02*	20.52±-27.60	27.60±3.67	.00***
	Plantar flexion	52.05±2.90	43.41±6.52	.00**	55.40±7.94	45.47±5.32	.00**
	Pronation	-11.03±3.58	-11.81±3.56	.64	15.73±8.91	16.19±4.90	.84
	Supination	12.16±5.32	3.24±4.31	.00**	8.93±4.88	3.16±6.05	.04*
	Inversion	18.83±4.92	17.98±2.87	.66	22.19±9.71	16.98±1.93	.13
	Eversion	0.81±3.38	-4.40±5.86	.13	-1.87±3.98	-0.35±8.19	.62

DISCUSSION: One factor that can affect gait patterns is gait speed, and increasing gait spee d requires increases in stride length and/or frequency (Mercer et al., 2005; Schwartz et al., 2 008). Increases in stride length and frequency are achieved by changing joint ROMs. According to a study by Novacheck (1998), when sprinting was compared with typical walking and jog-ging, hip and knee flexion angles increased mid swing with increasing gait speed, as a strat-egy to increase stride length. Likewise, the present study also found an increased hip flexion angle in the superior group and an increased range of ankle plantar flexion and supination to produce more thrust in the late stance phase. However, no significant difference was found between the two groups at the knee joint. This is thought to be because the bobsledders had to sprint with the bobsled in front of them. The crouching start used for sprinting in athletics is a means of using a larger reaction force by shifting the center of mass anteriorly, maximizing instability, and kicking forcefully against the starting blocks. Oh (2015) compared crouching starts between proficient and non-proficient subjects, and found that the proficient subjects' center of mass moved further horizontally during the first 3 strides and stayed lower vertically . The bobsleigh start shows similarities to the crouching start. Specifically, during a bobsleigh start, bobsledders must focus on exerting a horizontal rather than a vertical force to effectivel y push the heavy sled. Thus, bobsledders must direct their center of mass forward and conve y that force to the sled to gain an advantage. The athletes in the superior group in this study ar e thought to have shown a significant decrease in hip extension and ankle dorsiflexion becau se they shifted their center of mass anteriorly.

CONCLUSION: The superior and inferior groups showed significant differences in lower limb joint motions during bobsleigh starts. The superior athletes showed motions focused on horizontal, rather than vertical movements to transfer the force from sprinting effectively, and they effectively used movements of the hip and ankle joints to increase their stride length. As a result, it was found that bobsleigh start requires body movements, that help players put centroid to the forwarding direction rather than vertical direction, so that thrust can be delivered to the bobsled up until the moment players ride on the bobsled sled. Future studies will need to analyze the lower limb joint movements during bobsleigh starts for each position in the team and to investigate coordination between the upper and lower limbs in more detail.

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Acknowledgement

This study was supported by National Sports Promotion Fund of Korea Sports Promotion Foundation in accordance with the Sports Industry and Technology Development Project of Korean Ministry of Culture, Sports and Tourism (Assignment number: 2014-Sports-5).