EFFECT OF ALPINE SKI BOOTS ON LOWER LIMB MOVEMENT DURING JUMPING

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This study aimed to investigate the effects of alpine ski boots (ASB) on lower-limb power generation for movements such as jumps. Seven male alpine ski racers participated in this study and performed counter movement jumps and squat jumps. All trials were recorded using a motion capture system and two force plates. The jump height in the ASB condition was significantly lower than that in the training shoe (TS) condition for both jumps. The range of motion of both the ankle and knee joints in the ASB condition significantly decreased for both jumps. The angular velocity at hip joint extension in the ASB condition was significantly higher than that in the TS condition for both jumps. Our findings revealed that lower-limb movement and power are restricted when wearing ASB, and suggested the importance of power transfer training using the hip joint while wearing an ASB.

KEYWORDS: jump height, counter movement jump, squat jump, hip joint, range of motion, training shoes

INTRODUCTION: Alpine skiers require specially designed ski boots. Alpine ski boots are made of stiff materials that transfer large forces from the skier to the ski. The alpine ski boot consists of two parts: upper and lower shells. In contrast to normal training shoes, the upper shell covers the skier's tibia. Therefore, alpine ski boots affect human movement. Lace and Błażkiewicz reported the effect of wearing alpine ski boots on human gait and observed that the ski boots decreased the range of motion (ROM) of the ankle and knee joints and increased the ROM of the hip joint (Lace and Błażkiewicz, 2021). In addition, joint torques during walking differ from those in barefoot (Lace and Błażkiewicz, 2021).
In alpine skiing, the skier uses the lower limbs to generate enough force and power to bend the skis and adjust to the snow surface (Turnbull et al., 2009). The lower-limb power generation is an important aspect of fitness for alpine ski racers. Therefore, they train to enhance the power generated by their lower limbs (Patterson et al., 2014). Alpine ski racers normally use training shoes during their training; however, they use alpine ski boots during alpine skiing. Unlike training shoes, the joint movement limitation caused by alpine ski boots may affect not only human gait but also lower-limb power generation (Lace and Błażkiewicz, 2021).
To estimate lower-limb power generation for alpine ski races, counter-movement jump or squat jump tests were previously used (Bosco et al., 1994; Ferland and Comtois, 2018; Raschner et al., 2013). However, scientific research that has clarified the differences in movement with or without the use of alpine ski boots, particularly for generating lower-limb power, has been limited (Lace and Błażkiewicz, 2021). Therefore, this study aimed to investigate the effects of alpine ski boots on lower-limb power generation for movements such as jump movements.

METHODS: Seven male collegiate alpine ski racers participated in this study (age: 19.9 ± 1.3 years, height: 170.8 ± 5.2 cm, weight: 67.7 ± 7.5 kg). Prior to the measurement, all participants were informed about the risks of this study, signed a document of agreement, and performed a satisfactory self-warm-up. The participants performed both the counter-movement jump without arm swing (CMJ) and the squat jump (SJ) with and without the use of alpine ski boots (ASB) with maximum effort. In the CMJ, each subject was asked to keep their hands on their hips throughout the entire jump. They started in the standing position, dropped into the squat position, and then immediately jumped with maximum effort. For maximum lower limb power output, countermovement depth was not controlled. In the SJ, each subject was asked to keep their hands on their hips throughout the entire jump. They first set into the squat position and then immediately jumped with maximum effort. In the SJ, the knee angle at the squat

position was controlled by investigators. In the ASB condition, the participants wore their own ASB and buckled them as they would during alpine skiing. In without ASB condition, participants wore their own training shoes (TS) which they used for usual strength or conditioning training such as running shoes or tennis shoes.
All jump tasks were recorded using a motion capture system (Vicon MX-460, Oxford, USA) and two force plates (KYOWA ELECTRONIC INSTRUMENTS Co., LTD, Tokyo, Japan) at a sampling rate of 120 Hz. Prior to the measurement, both systems were calibrated according to the manufacturer's recommendations. The kinematic and kinetic data were electrically synchronized. Reflective markers were placed on the glenohumeral joint, greater trochanter, femoral condyles, lateral malleolus, and head metatarsal II on the right side of each participant. In the ABS condition, reflective markers were placed at the hinge joint of the upper and lower shell where the lateral malleolus was located, and the lower shell where the head metatarsal II was located. Two investigators checked all trails, either with clear miss jump movements, such as unbalanced landing, or using counter movements during the squat jump. If there was a clear mistake in the jump, the trial was eliminated and the participant was asked to retry.
The joint angles and angular velocities at the hip, knee, and ankle joints were calculated using the kinematic data. Jump height was calculated to evaluate lower-limb power using kinetic data based on flight time. The flight time was defined as the time during the first intersection when the vertical force component was less than 0 N at take-off and above 0 N at landing. The jump height was calculated from the flight time using the following equation (Yamashita et al., 2020):

$$Jump\ height\ = \frac{1}{8} g t_{flight^2}$$

All parameters are presented as mean and standard deviation (SD). For statistical analysis, a repeated-measures t-test was performed to clarify the influence of wearing or not wearing an ASB. The significance level was set at $p < 0.05$. All calculations were performed using the IBM SPSS Statistics version 27 (IBM Co., Chicago, IL, USA).

RESULTS: The results are presented in Table 1. The jump height in the ASB condition was significantly lower than that in the TS condition during both the CMJ and SJ (Table 1).

Table 1: Results of CMJ and SJ tests.
The ROMs of both the ankle and knee joints in the ASB condition significantly decreased during both CMJ and SJ (Table 1). The angular velocities of ankle plantar flexion and knee extension

	Counter movement jump					Squat jump				
	Training shoes		Alpine ski boots			Training shoes		Alpine ski boots		
Parameters	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Jump height (m)	0.42	0.05	0.24	0.04	**	0.34	0.05	0.22	0.04	**
Ankle ROM (deg)	57.0	5.9	7.5	2.4	**	54.1	6.7	4.6	2.3	**
Knee ROM (deg)	95.6	8.1	60.7	6.2	**	78.0	8.1	57.0	4.6	**
Hip ROM (deg)	126.2	10.5	125.5	16.3		89.6	5.4	91.0	5.0	
Ankle angular velocity (deg/s)	413.5	53.5	63.1	19.7	**	404.2	42.2	43.4	22.1	**
Ankle angular velocity (deg/s)	-73.9	13.3	-46.1	37.0						
Knee angular velocity (deg/s)	544.7	32.7	428.0	34.2	**	481.3	32.0	394.5	34.6	**
Knee angular velocity (deg/s)	-227.4	48.1	-123.5	26.5	**					
Hip angular velocity (deg/s)	529.8	45.1	564.7	32.0	**	476.6	43.1	546.0	40.0	**
Hip angular velocity (deg/s)	-308.5	64.5	-290.2	79.4						

** demonstrates significant difference between training shoe and alpine ski boots ($p < 0.01$). Positive values of angular velocity indicate extension or plantarflexion, negative flexion and dorsiflexion. For the squat jump, negative values of angular velocity were not calculated. ROM means range of motion.

in the ASB condition were significantly lower than those in the TS condition during both CMJ and SJ (Table 1). The angular velocity of knee flexion was significantly lower in the ASB condition during CMJ (Table 1). The angular velocity at hip joint extension in the ASB condition was significantly higher than that in the TS condition during both the CMJ and SJ (Table 1).

DISCUSSION: This study investigated the effects of wearing an ASB on jump movement. The jump height in the ASB condition was significantly lower than that in the TS condition. This result indicated that the power produced by the lower limbs significantly decreased when the ASB was worn.

Wearing an ASB restricts ankle joint movements caused by the stiffness of the ski boot material and shape. The decreasing of ROM of the ankle joint during jumps in the ASB was consistent with that reported in a previous study on human gait (Lace and Błażkiewicz, 2021). The ROM values (7.5° ± 2.4°) in this study were smaller than those during gait while wearing ski boots (SB) (17° ± 3°, Lace and Błażkiewicz, 2021). This could be attributed to the difference in stiffness of the SB and ASB used in both studies. Lace and Błażkiewicz used SB with a flex value of 115; however, alpine ski racers in this study preferred a much stiffer SB with a flex value of 150. Stiffer ASB restricts ankle joint movement.

Restriction of the ankle joint may also affect the knee joint movement. Lace and Błażkiewicz (2021) reported that SB has the greatest effect on the knee joint. The decrease in the ROM of the knee joint seen with ASB use in the present study was consistent with previous studies (Lace and Błażkiewicz, 2021). Lace and Błażkiewicz (2021) reported that the ROM of the hip joint when walking with an SB was greater than that during barefoot walking. Unlike the previous study (Lace and Błażkiewicz, 2021), there was no significant difference in the ROM of the hip joint in the present study. This discrepancy may be due to the different stiffnesses of the SB and ASB, or the differences in performed tasks such as walking and jumping. However, no clear conclusion was reached regarding this in the present study. Our results suggest that the limited joint movement affects power production.

The ASB also influences the angular velocity of the lower limbs. Lace and Błażkiewicz (2021) reported that walking in SB produces greater muscle torque for the knee and hip joints. In the present study, muscle torque was not calculated. However, a decrease in angular velocity for ankle plantar flexion and knee extension and an increase in hip joint flexion were observed. This result may indicate that wearing an ASB requires more hip joint torque to produce lower-limb power. It also suggests the importance of the hip joint increases while wearing ASB. Joint torque measured during jumping while wearing an ASB may differ from that measured during walking while wearing an SB. Further studies on joint torque calculation during CMJ and SJ while wearing an ASB are required.

To the best of our knowledge, this is the first study to clarify the effects of ASB on lower-limb power production. These results may be useful to coaches and trainers. There is no doubt that strength and/or power training to produce lower-limb power is important for alpine ski racers. However, alpine skiers are required to produce adequate lower-limb power wearing ASB which is restricted joint movements. To generate enough lower-limb power while wearing ASB, the hip joint plays an important role. Therefore, our results highlight the importance of power transfer training using the hip joint while wearing an ASB.

This study had some limitations. First, only 7 male participants were analyzed. Female and/or a greater number of participants should be analyzed. Second, this study only computed kinematic parameters, such as the angle and angular velocity. In further studies, the joint torques of the lower limb should be calculated for comparison with previous studies. In the present study, the CMJ and SJ were used as indicators of lower-limb power generation. Both CMJ and SJ were widely used to evaluate lower limb power generation for alpine ski racers. However, a relationship between the movement of alpine skiing and that of jump has not been reported.

CONCLUSION: The ASB restricts jump movements and lower-limb power. The ROM of the ankle and knee joints decreased with CMJ and SJ. The angular velocity of the ankle and knee joints decreased while wearing the ASB during both CMJ and SJ. In contrast, the angular velocity of the hip joint increased when the ASB was worn during both CMJ and SJ. Our results highlight the importance of power transfer training in an ASB.

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ACKNOWLEDGEMENTS: The authors would like to express their gratitude to all participants.