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Original Article

Effect of ski simulator training on kinematic and muscle activation of the lower extremities

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Abstract. [Purpose] This study aimed to verify the effectiveness of an augmented reality-based ski simulator through analyzing the changes in movement patterns as well as the engagement of major muscles of the lower body. [Subjects] Seven subjects participated in the study. All were national team-level athletes studying at "K" Sports University in Korea who exhibited comparable performance levels and had no record of injuries in the preceding 6 months (Age 23.4 ± 3.8 years; Height 172.6 ± 12.1 cm; Weight 72.3 ± 16.2 kg; Experience 12.3 ± 4.8 years). [Methods] A reality-based ski simulator developed by a Korean manufacturer was used for the study. Three digital video cameras and a wireless electromyography system were used to perform 3-dimensional motion analysis and measure muscle activation level. [Results] Left hip angulation was found to increase as the frequency of the turns increased. Electromyography data revealed that the activation level of the quadriceps group's extension muscles and the biceps femoris group's flexing muscles had a crossing pattern. [Conclusion] Sustained training using an augmented reality-based ski simulator resulted in movements that extended the lower body joints, which is thought to contribute to increasing muscle fatigue.

Key words: Ski simulator, Kinematic, EMG

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INTRODUCTION

Alpine skiing is a timed racing event in which skiers compete while descending down a steep course through a series of gates. The introduction of carving skis has brought remarkable progress during the last decade in terms of the turns that a skier can execute. Compared with conventional skis, carving skis have shorter plates and higher side cuts. Also, the increment in the height of the binding by 1–2 cm has helped skiers execute various turning techniques[1)]. However, some researchers have expressed concerns regarding the evolution's effects on the risk of injuries because technical movement patterns required to execute a turn have become larger and faster[2)].

Skiing is an activity that requires intricate coordination between the upper and lower body. The skier copes with increasing speed by engaging muscles required for rotation to successfully descend an ultra-steep slope all the way to the finish line while repeatedly making turns[3)]. Especially to execute smoother turns by applying appropriate edging techniques, muscles surrounding the knee and ankles must be strengthened[4)]. Additionally, to effectively improve the techniques, training that incorporates mechanical degrees of freedom is required[5)]. To integrate the above into training protocols and to provide skiers with an unrestricted training environment, studies using ski simulators have been conducted. However, the development of these simulators poses certain limitations in terms of effectively providing augmented reality that utilizes visual and other information. Furthermore, existing ski-simulator studies stop at merely verifying the training effect through observation of changes in the movement pattern[6–8)]. Thus, this study aimed to verify the effectiveness of an augmented reality-based ski simulator through analyzing the changes in movement patterns as well as the engagement of major muscles of the lower body.

SUBJECTS AND METHODS

Seven subjects participated in the study. All were national team-level athletes studying at "K" Sports University in Korea who exhibited comparable performance levels and had no record of injuries in the preceding 6 months (Age 23.4 ± 3.8 years; Height 172.6 ± 12.1 cm; Weight 72.3 ± 16.2 kg; Experience 12.3 ± 4.8 years). Before the test, participants were given a full explanation of the research purpose and experimental procedure and signed a consent form approved by the Institutional Review Board to comply with the ethical principles of the Declaration of Helsinki (1975, revised 1983).

An augmented reality-based ski simulator designed by

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Gridspace Inc. (Korea), and developed with funds supported by the research and development supporting policies for small and medium enterprises, was used in the study. Three digital video cameras (Sony, HXR-NX70N, Japan) and a wireless electromyography (EMG) system (Noraxon, TELEmyo DTS, USA) were used to perform 3-dimensional motion analysis and measure the muscle activation level. Gel-type, 20-mm diameter, Ag/AgCl alloy dual electrodes (Noraxon Dual EMG Electrode, product no. 272, USA) were attached to the rectus femoris (RF), vastus medialis obliquus (VMO), vastus lateralis obliquus (VLO), tibialis anterior (TA), semitendinosus (SM), biceps femoris (BF), medial gastrocnemius (MG), and lateral gastrocnemius (LG) muscles of each leg after cleaning the sites with alcohol to reduce skin impedance.

The experimental procedure was composed of a warm-up exercise session, measurement of each muscle's maximum voluntary contraction (MVC), a 2-minute training session for familiarization with the new equipment, and a main exercise session. During the main exercise session, participants were asked to perform carving turns for 2 minutes, repeated 5 times for measurement, with a 5-minute rest period between each trial. The carving turns were intermediate-level, to both left and right, and required maintaining the skis in a parallel position at all times.

Signals were filtered at a bandwidth of 10–500 Hz to eliminate noise recorded during the data collection process, and a root-mean-square window of 50 ms was used for signal smoothing. Subsequently, the data were standardized into the MVC by muscles and expressed as a ratio between the total EMG value and the EMG value of the muscle measured[9)]. Vegas 9.0b software (Sony, Japan) was used to trim the clips. To calculate the kinematical variables, motion data acquired from the simulator were digitized using Kwon3D 3.1 software (Visol, Korea) and smoothed with a Butterworth lowpass filter (10 Hz). Subsequently, the kinematical variables chosen were changes in distance between center of mass (CM) and feet, left and right inclinations of CM, and angle of hip and knee. In addition, skiing movements on the simulator were classified into 5 different events and 4 phases as follows: P1, from the center of the simulator to the right fall line; P2, from the right fall line to the center of the simulator; P3, from the center of the simulator to left fall line; and P4, from the left fall line to the center of the simulator[10)]. Statistical analysis was performed using SPSS ver. 21.0 (IBM, USA) for a one-way repeated analysis of variance as a means to verify the differences observed among the dependent variables during training. Least significant difference was selected for the post-hoc analysis, and the significance level was set at $p<0.05$.

RESULTS

Results of the kinematical analysis to examine the training effects of the ski simulator are presented in Table 1. No statistical significant differences were observed in the skiers' left and right inclinations of CM and right hip angulation over the course of the training ($p=0.022$). The left hip angulation was found to increase as the frequency of the turns (left and right) increased ($p=0.022$). The angle of the right knee was found to increase as the frequency of left turns increased (Set 1–Set 3: $p=0.026$, Set 1-Set 4: $p=0.016$, Set 1–Set 5: $p=0.003$).

The results of activation of the major muscles in the skiers obtained through the analysis are presented in Table 2. In P1, VLO, VMO, and TA were the major muscles engaged in the right leg; and SM, BF, and MG were the major muscles engaged in the left leg. In P2, muscle activation was the highest in RF, VLO, and VMO for both legs. In P3, VLO, TA, and SE were the major muscles engaged in the right leg; and RF, VLO, and VMO were the major muscles engaged in the left leg. In P4, VLO, VMO, TA, and RF exhibited the highest level of activation in the right leg; and RF, VLO, and VMO exhibited the highest level of activation in the left leg, which was a result similar to P2.

DISCUSSION

The aim of the present study was to verify the changes in movement patterns and the major muscles engaged when performing a series of turns in an environment created by a ski simulator. The results showed that the inclination, which was large during the 1st and 2nd sets, tended to decrease as the frequency of turns increased. In terms of hip angulation, a lower upper-body position was observed during the 1st set, whereas a higher upper-body position was observed during the 4th and 5th sets. Previous studies have reported that sustained exercise on a ski simulator leads to a reduced range of motion due to accumulating fatigue[7)]. A study that analyzed skiers' turns on a real slope reported that the skiers rapidly changed the inclination in order to execute the turns most suitable for the course and accordingly, hip angulation varied greatly. This finding is congruent with that of the present study[11, 12)]. As such, it is expected that ski-simulator training during the off-season, when access to real slopes is limited, would benefit skiers. Other studies have reported that in slalom racers and giant slalom racers, the muscle engagement patterns were observed to be similar: the muscles co-contract to put pressure on the skis[13)]. Co-contraction appears to be a mechanism that helps maintain the postural stiffness and stability required to execute turns[14)]. The results obtained through our study also indicate that the quadriceps group (RF, VLO, VMO) and biceps femoris group (SM, BF) co-contract, which is similar to the results of existing research.

The load on the outer ski, which performs the turn, was the heaviest, and a high level of extensor activity occurred in the outer extension muscles[2, 15)]. However, when performing a carving turn, a heavy co-load is placed on the inner leg. Therefore, to prevent race injuries and improve technique, strengthening of the biceps femoris is required[2, 7)]. Analysis of the present study's EMG data revealed that the activation level of the quadriceps group's extension muscles and the biceps femoris group's flexing muscles had a crossing pattern. This finding indicates that training on a simulator will help strengthen the muscles.

In summary, sustained training using an augmented reality-based ski simulator resulted in movements that extended the lower body joints, which is thought to contribute to increasing fatigue. EMG analysis verified the co-contraction of the quadriceps and biceps femoris groups,

Table 1. Change of CM tilt, hip, and knee joint angles (degrees)

Variables		Set 1	Set 2	Set 3	Set 4	Set 5	Post-hoc (LSD)
CM tilt angle	RT	26.0±4.6	26.3±4.7	25.4±2.9	25.4±3.4	24.8±4.2	
	LT	24.9±5.0	24.7±3.9	24.7±5.4	24.6±3.0	24.2±4.0	
R. hip angle	RT	127.8±5.5	126.3±2.7	128.0±2.8	127.4±3.0	129.3±2.0	
	LT	93.8±2.9	95.1±3.3	96.1±6.3	96.9±3.8	99.7±1.7	
L. hip angle	RT	93.2±3.4*	97.2±3.8	96.8±3.2	99.6±3.8	102.4±5.2*	Set 1<Set 5
	LT	124.9±1.2*	126.4±1.3	126.3±2.4	127.3±2.6*	128.7±2.2*	Set 1<Set 4, Set 5
R. Knee angle	RT	159.8±8.2	160.9±3.6	163.0±2.1	162.6±2.1	161.5±3.3	
	LT	120.1±2.6*	122.34±0.8	123.3±1.3*	123.5±1.7*	124.1±1.2*	Set 1<Set 3, Set 4, Set 5
L. Knee angle	RT	122.2±5.0	123.4±1.1	123.9±1.4	123.6±0.7	123.5±1.3	
	LT	166.1±1.8	166.1±1.6	166.5±2.6	166.5±2.0	167.1±2.2	

*p<0.05; CM: center of mass; LSD: least significant difference

Table 2. Result of muscle activation (%)

Phase	Muscles	Set 1		Set 2		Set 3		Set 4		Set 5		Mean±SD	
		right	left	right	left	right	left	right	left	right	left	right	left
P1	RF	12.11	10.65	11.83	10.49	11.38	8.37	12.92	11.94	12.94	14.77	12.24±0.68	11.24±2.35
	VLO	24.43	9.39	25.72	9.50	26.07	10.15	24.79	7.47	24.52	11.69	25.11±0.74	9.64±1.52
	VMO	22.52	4.69	22.92	5.46	22.37	4.38	24.83	4.65	23.62	6.86	23.25±1.01	5.21±1.00
	TA	14.60	22.30	14.85	19.18	18.03	25.96	16.70	17.96	13.96	11.27	15.63±1.69	19.33±5.47
	SM	5.53	21.52	5.03	23.06	5.22	22.25	5.51	22.81	5.71	19.14	5.40±0.27	21.76±1.58
	BF	5.95	12.70	5.66	11.50	4.07	9.91	4.43	13.32	4.57	14.19	4.94±0.82	12.32±1.67
	MG	8.19	9.55	7.30	11.96	6.76	9.93	6.30	11.21	8.32	11.73	7.37±0.88	10.88±1.08
	LG	6.67	9.19	6.69	8.85	6.09	9.05	4.52	10.64	6.36	10.36	6.07±0.90	9.62±0.82
P2	RF	13.47	13.58	13.32	12.07	13.88	13.84	14.15	17.24	14.42	14.02	13.85±0.46	14.15±1.89
	VLO	25.18	18.10	27.85	25.04	27.08	24.19	22.06	22.60	26.48	24.07	25.73±2.27	22.80±2.77
	VMO	25.45	16.09	24.27	19.41	25.13	15.90	24.96	16.15	28.79	19.38	25.72±1.77	17.38±1.84
	TA	14.52	13.63	11.53	10.96	13.03	12.90	15.18	10.37	8.40	8.47	12.53±2.71	11.27±2.06
	SM	6.02	15.08	5.66	9.10	6.12	9.66	8.38	7.32	5.69	8.50	6.37±1.14	9.93±3.00
	BF	3.90	12.52	4.74	11.75	3.06	11.06	3.10	14.04	3.64	13.07	3.69±0.69	12.49±1.16
	MG	4.29	5.91	4.96	6.32	4.59	6.44	5.00	5.00	5.36	6.95	4.84±0.41	6.12±0.73
	LG	7.17	5.10	7.67	5.35	7.11	6.02	7.17	7.28	7.23	5.55	7.27±0.23	5.86±0.86
P3	RF	10.65	14.10	10.08	14.21	8.11	15.04	9.29	18.12	8.72	14.88	9.37±1.02	15.27±1.65
	VLO	11.93	24.06	12.76	26.68	11.67	26.32	13.74	26.17	16.25	26.11	13.27±1.85	25.87±1.04
	VMO	8.82	19.24	8.79	18.40	10.42	17.60	16.83	16.12	11.54	19.21	11.28±3.31	18.11±1.30
	TA	20.82	5.48	14.49	5.43	21.62	5.78	20.76	5.60	24.05	4.19	20.35±3.53	5.30±0.63
	SM	16.92	11.98	19.02	7.59	16.75	7.31	13.57	7.36	13.16	7.88	15.88±2.47	8.42±2.00
	BF	9.47	7.92	10.31	10.12	9.22	8.51	8.93	8.51	8.02	9.71	9.19±0.83	8.95±0.92
	MG	9.57	8.71	11.32	8.52	11.80	10.35	9.77	8.40	10.77	9.54	10.65±0.97	9.1±0.83
	LG	11.82	8.51	13.22	9.05	10.40	9.10	7.10	9.73	7.48	8.48	10.01±2.67	8.9±0.51
P4	RF	12.62	15.01	8.33	14.48	9.91	16.58	10.16	24.97	9.15	19.30	10.03±1.61	18.0±4.29
	VLO	19.24	28.00	20.69	29.15	21.90	28.43	22.11	20.77	21.31	27.84	21.05±1.15	26.8±3.43
	VMO	20.51	22.37	20.14	21.59	24.10	19.07	22.09	17.39	29.14	22.04	23.20±3.67	20.4±2.17
	TA	28.33	4.30	31.97	4.08	27.17	6.93	22.95	3.92	18.60	3.72	25.80±5.15	4.5±1.33
	SM	5.00	9.79	4.92	8.71	4.23	8.39	4.78	11.91	4.40	7.19	4.67±0.34	9.2±1.78
	BF	6.06	8.03	6.07	7.35	4.79	5.11	6.95	5.96	7.72	5.92	6.32±1.10	6.4±1.18
	MG	4.95	5.47	4.57	6.06	4.84	6.16	6.33	5.81	5.90	6.21	5.32±0.76	5.9±0.31
	LG	3.29	7.04	3.30	8.57	3.06	9.32	4.64	9.27	3.78	7.77	3.61±0.63	8.3±0.99

RF: rectus femoris; VLO: vastus lateralis obliquus; VMO: vastus medialis obliquus; TA: tibialis anterior; SM: semitendinosus; BF: biceps femoris; MG: medial gastrocnemius; LG: lateral gastrocnemius as well as the crossing pattern, which would be expected to help strengthen the lower body. The simulator might help ski athletes improve their muscle strength and ski technique on snow. Ski athletes could use the simulator to maintain their functional and strength capabilities for skiing, especially during a non-ski training period like summer.

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