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Kinematic characteristics of the lower extremity during a simulated skiing exercise in healthy participants

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Abstract. [Purpose] Currently, various simulators are produced and used for athlete's exercise, rehabilitation, and training. In this study, we analyzed the kinematic factors of sectional and total movements in healthy participants by providing group-dependent information during simulated exercise. [Subjects and Methods] Participants in this study included 26 male adults (non-experts and experts); experts held a certificate issued by the Korea Ski Instructors Association. The elapsed times in each phase, the difference in the lower extremity angles, and muscle activity were computed through analysis of kinematic factors. [Results] We observed that motions in the experts took shorter time to perform than that in non-experts, and showed larger variation of lower limb joint angle in most events during simulated skiing. There were also significant group-dependent differences in the peak and mean EMG values during simulated skiing. [Conclusion] A non-expert's posture leads to enhanced muscle activity to keep the lower body in balance. We suggest the following training guideline: initially, non-experts should maintain appropriate range of motion with lower-intensity exercise to improve muscle endurance. It can be useful in providing preliminary data for future training and rehabilitation studies, as well as improvements in muscle strength and balance.
Key words: Lower extremity, Muscle activity, Simulated skiing

INTRODUCTION

High postural performance in normal and challenging conditions is crucial not only for many daily activities but also for attaining excellence and avoiding injuries in many sports. In alpine skiing especially, postural exercises are introduced in the training programs of expert skiers. Training for postural control can improve postural performance in healthy and non-injured athletes[1]. Specific indoor balance training is beneficial in learning alpine skiing[2] and muscle strength training for ordinary people who have restrictions on outdoor activities. To allow people to enjoy sports such as skiing conveniently in a confined space during non-winter seasons, ski activities, through a ski simulator, provide a way to efficiently practice ski-turn motor performance[4]. Recently, research has focused on the development of ski simulators and exercise using them. Additionally, studies on the utilization of ski simulators to prevent injury are in progress. Lee et al.[3] reported that training with a ski simulator contributes to body movement as well as strengthening the hamstrings, which helps prevent sports-related injuries.

Muller et al.[4] developed a specific training device called ski power simulator based on a kinetic and kinematic analysis of alpine slalom performed by senior and junior Austrian national teams. Panizzolo et al.[5] have focused on 3-D motion analysis systems with reflective surface markers. In addition to this, Panizzolo et al.[5] have used ski simulators to study equipment

characteristics and exercise methods and compared their measurements with those measured in similar conditions while skiing on snow. Results of their study suggest that the two devices (skier's edge and skimagic treadmill) are not effectively applicable for strength training, but the pattern of EMG activity was closer to real snow skiing.

Currently, various simulator products are produced by many organizations, and ski simulators are used for personal and public rehabilitation as well as training. Furthermore, differences between individuals exist depending on the level of ski technique and the type of simulator. If the purpose of the ski simulator is to provide effects similar to actual skiing, it should encourage accurate posture and provide kinematic information not only for athletes but also for many daily and recreational skiers. At a time when Korea and China are preparing to host the 2018 and 2022 Winter Olympic Games, interest in skiing is growing. In addition to an increase in the skiing population in Asian countries, the rapid increase in the absolute number of injuries incurred while skiing has made the sport a major issue of interest in the area of sport injuries[3].

Being able to easily partake in a sports activity such as skiing in a confined area is thought to be useful in providing preliminary data for future training and rehabilitation studies, as well as improvements in muscle strength and balance. The primary aim of this study was to capture the kinematic characteristics in lower extremity range of motion (ROM) between two groups (non-expert and expert) and the effect of lower limb muscle activity during ski simulator exercise. A secondary aim of this study was to use the information collected to help maintain a safer and more accurate posture and efficiently use the joint's range of motion and agonistic muscles in a ski simulator exercise.

SUBJECTS AND METHODS

Twenty-six male adults (non-expert 13, expert 13) with no previous/current foot injury participated in this study. Subjects with any pathologies that could have affected the research and its results were excluded from the study[6]. Expert participants held a certificate issued by the Korea Ski Instructors Association and knew how to use a ski simulator. The study sample size was calculated using G*Power Version 3.1[7]. With a 0.05 significance level and 0.8 power, a sample size of 12 participants per groups was calculated. The experiment was approved by the Pukyong National University Institutional Review Board. This experiment was conducted after its purpose and methods were sufficiently explained to the participants and they had consented to participate in this experiment. This experiment was conducted at a motion analysis laboratory in B City. The ski simulators (Pro ski simulator; Slovenia) were fixed onto a flat surface. For accurate results, sufficient time was given to each subject to practice, and then, the actual skiing footage was filmed for 30 seconds. Subjects wore tight pants in order to reduce discomfort and errors while collecting data. They held a pole in each hand; the middle intensities in the ski simulator were used in this study. In order to analyze the kinematic data dependent on each group, 5 infrared cameras (Visol, Korea) were used to record the participants' performance of each movement. Motion data were sampled at 200 Hz. In order to set the reference frame, a calibration was conducted using a control box and surface markers were placed on 19 areas of the lower limbs to obtain the location coordinates of segments and joints (Table 1).

Prior to testing, a relaxed standing calibration trial was captured first. EMG signals of 4 muscles of interest were selected on both legs, and skin preparation and electrode placement over the intended muscles were performed in accordance with the SENIAM[8] concerted protocol. In order to prevent the noise due to extension lead between the surface electrodes and measuring instrument, the extension lead was fixed using tape. We measured the maximum voluntary isometric contraction (MVIC) of the individual muscles and the position of the surface electrode was attached to the rectus femoris, biceps femoris, tibialis anterior and gastrocnemius. The sampling frequency was established at 1,024 Hz. Motion analysis (Visol; Korea) and electromyography analysis (Laxtha; Korea) programs were used for data processing. For the data, the 41 control point system applied in calibration was used. The actual spatial coordinates were obtained and 3D coordinates of the human body were computed. The model of the human body was defined as a rigid body system. To remove digitizing errors and noise, the source data was filtered through the butterworth low pass filter. The cut-off frequency was set to 6 Hz and the 2D coordinates obtained from each digital camcorder were confirmed through the interpolation by cubic spline function. 3D coordinate calculations were analyzed using the DLT (Direct Linear Translation) method in kwon3d software.

The computation of data were categorized into kinematic factors regarding muscle activities and then analyzed. The electromyography data were filtered through a 10 Hz high pass filter using Telescan (Laxtha) to minimize the noise afterwards. The obtained root mean square (RMS) value was standardized into a MVIC value and the %MVIC value was calculated. For the analysis of motion on the ski simulator, the points in time when the participants were at the center, when they were at the right peak and when they returned to the center were defined as Event 1, Event 2, and Event 3, respectively (Fig. 1). For an easy analysis of the movement in ski simulators, the signal recorded on the video data was used to set the analysis segments. In the event that the video lasted over 30 seconds, the best movement was chosen and classified into 3 events and 2 phases.

Using these methods, the elapsed times in each phase, the difference in the lower extremity angles, and muscle activity were computed through analysis of kinematic factors. Participants' performance was statistically analyzed using SPSS version 23.0. An independent samples t-test was conducted to examine changes in the lower joint motions, elapsed times, and muscle activity between the two groups. Differences were considered statistically significant at a p-value of less than 0.05.

Table 1. Surface markers of the lower limb joints

Body model	Utilized data
1	Mid posterior superior iliac spine
2	Right anterior superior iliac spine
3	Left anterior superior iliac spine
4	Right lateral thigh
5	Left lateral thigh
6	Right medial epicondyle
7	Left medial epicondyle
8	Right lateral epicondyle
9	Left lateral epicondyle
10	Right lateral shank
11	Left lateral shank
12	Right lateral malleolus
13	Left lateral malleolus
14	Right medial malleolus
15	Left medial malleolus
16	Right heel
17	Left heel
18	Right toe
19	Left toe
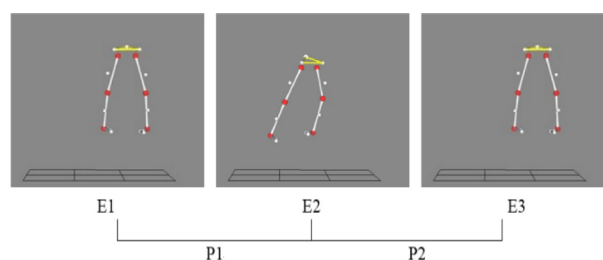
Fig. 1. Event and phase of simulator exercise

RESULTS

Observation of the elapsed times in each phase showed that non-experts spent 0.41 seconds in phase 1 and 0.40 seconds in phase 2. In the expert group, 0.35 seconds and 0.38 seconds were spent in phase 1 and 2, respectively. The total time spent was 0.82 seconds for non-experts, which was significantly longer than the 0.73 seconds observed in the experts ($p<0.001$). Table 2 shows the comparison results of lower extremity ROM from the experiments. Observation of the range of change in lower extremity angles showed that a difference in angles was observed in most intervals between the two groups, and these differences were statistically significant. Hip joint in the initial position E1 had a flexion-extension angle of 70.06 degrees ($p<0.01$) on the left and 67.22 degrees ($p<0.001$) on the right for the experts, which was smaller than the angles observed for the non-experts. Observation of the right maximum segment E2 for the experts showed that the angle was 68.79 degrees ($p<0.01$) on the left and 77.04 degrees on the right. In E3, the flexion-extension angle was 78.74 degrees ($p<0.01$) on the left and 66.37 degrees ($p<0.001$) on the right, which was smaller than the angle observed for the non-experts, a difference that was statistically significant. In the knee joint in the initial position E1, the flexion-extension angle was 104.05 degrees ($p<0.001$) on the left and 118.00 degrees ($p<0.05$) on the right for the experts, which was smaller than the angles observed for the non-experts. Observation of the right maximum segment E2 for the experts showed that the angle was 154.23 degrees on the right, which was larger than the angle of 142.72 degrees observed for the non-experts; this difference was statistically significant ($p<0.05$). In E3, the flexion-extension angle was 118.54 degrees ($p<0.001$) on the left and 111.75 degrees ($p<0.001$) on the right, which was smaller than the angle observed for the non-experts; this difference was statistically significant. For the ankle joint in the initial position E1, the flexion-extension angle was 82.15 degrees on the left and 88.51 degrees on the right for the experts, which was smaller than the angles observed for the non-experts. In right maximum segment E2 for the experts, the angle was 118.87 degrees on the right, which was larger than the angle of 104.70 degrees observed for the non-experts; this difference was statistically significant ($p<0.05$). In E3, the flexion-extension angle was 81.07 degrees ($p<0.05$) on the left and 87.36 degrees ($p<0.05$) on the right, which was smaller than the angle observed for the non-experts; this difference was statistically significant. Table 2 shows the comparison results of lower extremity muscle activity (maximum and average) from the experiments, respectively. Observation of lower extremity maximum muscle activity showed that for the rectus femoris, non-experts (45.86%) exhibited more muscular activity compared to the experts (45.35%). Most non-experts maintained a high value of %MVIC during the ski simulator exercise. For the tibialis anterior, non-experts (45.74%) also showed a significantly higher %MVIC value than the experts (32.07%) ($p<0.05$). For the biceps femoris, non-experts (19.13%) showed a higher %MVIC value compared to the experts (16.61%). For the gastrocnemius, non-experts (29.47%) showed a higher %MVIC value than the experts (22.34%). Mean muscle activity showed that for the rectus femoris, experts (15.13%) exhibited more muscular activity than non-experts (15.03%), and for the tibialis anterior, non-experts (14.66%) showed a higher %MVIC value ($p<0.05$) than the experts (9.01%). For the bicephalus femoris, non-experts (15.44%) showed

Table 2. The joint angles and elapsed times between beginner and advanced group

	Event 1		Beginner	Advanced
Joint angle (deg)	Hip	Left	87.1±8.3	70.1±13.2**
		Right	83.0±7.5	67.2±5.7***
	Knee	Left	128.1±3.5	104.6±11.8***
		Right	121.6±3.7	118.0±4.7*
	Ankle	Left	82.3±11.6	82.2±7.1
		Right	90.0±11.3	88.5±5.6
	Event 2		Beginner	Advanced
	Hip	Left	80.3±8.7	68.8±19.3**
		Right	84.7±14.5	77.0±28.0
	Knee	Left	114.3±3.8	113.2±11.8
		Right	142.7±8.3	154.2±9.3*
	Ankle	Left	92.6±13.7	94.5±33.1
		Right	104.7±17.4	118.9±27.5*
	Event 3		Beginner	Advanced
	Hip	Left	90.5±5.3	78.7±10.3**
		Right	82.3±4.2	66.4±6.5***
	Knee	Left	129.2±3.5	118.5±6.0***
		Right	122.0±2.8	111.8±6.0***
	Ankle	Left	84.4±4.2	81.1±5.6*
		Right	97.5±11.4	87.4±5.0*
	Phase		Beginner	Advanced
Elapsed times (sec)	P1 (E1–E2)		0.4±0.1	0.4±0.1
	P2 (E2–E3)		0.4±0.1	0.4±0.1
	Total (P1–P2)		0.8±0.1	0.7±0.1**
	Max		Beginner	Advanced
Muscle activity (%MVIC)	RF		45.9±11.4	45.4±4.1
	TA		45.7±14.8	32.1±8.5*
	BF		19.1±3.1	16.6±14.8
	GC		29.5±18.1	22.3±10.5
	Mean		Beginner	Advanced
	RF		15.0±3.6	15.1±2.7
	TA		14.7±6.3	9.0±2.6*
	BF		15.4±2.8	7.4±2.3***
	GC		3.4±2.1	4.1±1.4*

P1: Phase 1; P2: Phase 2
*<0.05, **<0.01, ***<0.001

a higher %MVIC value (p<0.001) than the experts (7.35%). There was a statistically significant difference in %MVIC in the gastrocnemius with non-experts (3.38%) showing a lower %MVIC value than experts (4.11%) (p<0.05).

DISCUSSION

The recent technologies in fitness equipment (ski simulator) including kinematic factors provide various exercise forms to athletes. While previous studies analyzed or extracted athlete's status[9] (mostly alpine ski–related posture), they were unable to provide information about an ordinary group undergoing a simulated skiing exercise. Although differences between individuals exist depending on the exercise intensity and the various kinds of simulators, there was no comparable guideline for simulator exercise for various subjects until now.

In this study, we observed the differences in kinematic factors of sectional and total movements in healthy participant groups during simulated exercise. Our results revealed that motions of experts took less time to perform than non-experts (p<0.05). Previous studies[10] revealed there were better performances in terms of COM velocity in a group of athletes compared to a control group. Even in our research, skiing of experts showed a rapid movement in both phases (P1, P2). It

is thought that skiing motion can be performed for a shorter period of time and with a bigger radius of rotation. Lower limb joint angular displacements during exercise are important factors determining ROM and elapsed time. According to previous studies[11] professionals exhibited larger ROM of the joint angle than non-professionals, which signifies faster control of the ski plates by ski professionals. In addition, all ski professionals exhibited significantly smaller numbers than the non-professionals in all parameters except for joint angles. Expert skiers tend to minimize variation in their center of mass and maintain a more constant left-right stride length than beginner and intermediate skiers. This demonstrates that professionals exercise fairly consistent patterns on ski simulators. In comparison with this study, our results revealed that larger variation of lower limb joint angles were observed in experts during simulated skiing from the initial position E1 through the maximum peak E2 and return position E3. Most of the joint angles measured reached statistical significance (p<0.05). As shown by the previous studies on various mechanical properties, these results demonstrate that stretching the body's joints after bending them as much as possible increases the exercise efficiency. As in most sports, high-level skiing requires a combination of precision equipment and highly trained motor and perceptual skills if the athlete is to perform successfully[12].

Furthermore, a ski simulator is a training machine that simulates an environment of reduced resistance force between the snow's surface and ski plates using a band. Due to these mechanical features, the ski simulator exercise is considered to have a similar effect to that of an elastic resistance exercise. Anderson et al.[13] reported that the elastic resistance exercise is effective for training small muscle groups compared to strength training using free weights. Previous studies[14–16] have reported that athletes who trained with elastic resistance bands demonstrated greater strength of the lower limbs than those who trained with free weights alone.

In our study, non-experts showed a higher %MVIC value than experts, there were also significant group-dependent differences in the peak and mean EMG values (p<0.05). As the elastic band undergoes a linear increase in tension from the beginning of the contraction to the full ROM, this tension may make it difficult to maintain a balanced posture. This facilitates the transition to the next movement with higher muscle activity in non-experts. In the future, it is expected that various people will be able to use a ski simulator exercise program to improve their stability and balance more efficiently and safely. These results can be applied to ski injury studies, exercise improvement, and strengthening programs as well as physical training programs.

We derived kinematic characteristics including the elapsed times, lower limbs joint angles, and muscle activity between two healthy participant groups. In our study, we found that a non-expert's posture leads to enhanced muscle activity to keep the lower body in balance. We can suggest the training guideline: non-experts should maintain appropriate ROM with lower-intensity exercise to improve muscle strength and endurance. These results can be useful in providing preliminary data for future training and rehabilitation studies, as well as improvements in muscle strength and balance.

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