Kinematics Characteristic of Lower Extremity during Simulated Skiing Exercise

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We analyze the kinematic factors of sectional and total movements in healthy participants to providing group-dependent information during simulated exercise. Participants in this study's experiment were 26 male adults, the elapsed times in each phase, the difference in the lower extremity angles, and muscle activity were computed through analysis of kinematic factors. We revealed that motions of the experts took shorter to perform than 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. Referring to these results, such a non-expert's posture leads to enhance muscle activity to keep the lower body in balance. Non-experts should maintain appropriate ROM with lower-intensity exercise to improve muscle endurance initially, and it can be useful in providing preliminary data for future training and rehabilitation studies, as well as improvements in muscle strength.

KEY WORDS: simulated skiing, ski simulator, lower extremity.

INTRODUCTION: 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 is preparing to host the 2018, and 2022 winter Olympic game, 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 (Lee, Kim and Roh, 2012). Accordingly, this research analyzed the kinematic characteristic in lower extremity range of motion (ROM) between two groups (non-expert and expert) and the effect of lower limbs muscle activity during ski simulator exercise. Based on this, it aimed to help maintain a safer and more accurate posture and efficiently use the joint's range of motion and agonistic muscles in ski simulator exercise. In addition, 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.

METHODS: Participants in this study's experiment were 26 male adults (non-expert 13, expert 13) with no previous/current foot injury, participated in this study voluntarily subjects with any pathologies that could have affected the research and its results were not qualified for participation. Participants of experts held a certificate issued by the Korea Ski Instructors Association, and knew how to use a ski simulator. Size of the subjects was calculated by using G*power 3.1 version program by Faul, Erdfelder, and Buchner, 2009), and the number of calculated sample was 12 participants with 0.05 significance level, 0.8 power, 0.8 effect size being the large size and therefore, it satisfies the number of total 13 participants. The experiment was approved by the ethics committee of institutional review board of Pukyong national university. The ski simulators(Pro ski simulator; Slovenia) was fixed onto a flat surface, for accurate results, sufficient time was given to each subject for practice, and then, the actual skiing footage was filmed for 30 seconds. In order to analyze the kinematic data dependent on each group, a total of 5 infrared cameras (Visol, Korea) were used to record the participants' performance of each movement and motion data were sampled at 200 Hz. Then, 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, and EMG signals of 4 muscles of interest were selected on the both leg, and skin preparation and electrode placement over the intended muscles were performed in accordance with the SENIAM(2015) 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 MVIC (Maximum Voluntary Isometric Contraction) of the individual muscles and the position of sticking the surface electrode was established to be rectus femoris, biceps femoris, tibialis anterior, gastrocnemius and the sampling frequency was established to be 1024 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, 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 coordinates calculation were analyzed using the DLT (Direct Linear Translation) method in kwon3d software.The computation of data was 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 maximal voluntary isometric contraction (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, when they were at eh center again were defined as Event 1, Event 2, and Event 3, respectively. For an easy analysis of the movement in ski simulators, the signal recorded on the video data was used to set the analysis segments. Within the video taken over 30 seconds, the best movement except beginning and final part to minimize any difference action was chosen and it was 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, and participants' performance were statistically processed using SPSS version 23.0. The Independent t-test was conducted in order to examine changes in the lower joint motions, elapsed times, and muscle activity between two groups, and differences were considered statistically significant at a $p<0.05$.

Table 1
Surface markers of the lower limbs joint

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

RESULTS & DISCUSSION: The recent technologies for fitness equipment (ski simulator) including kinematic factors have allowed to provide various exercise forms to athlete. Whereas most of previous studies analyzed or extracted athlete's status (mostly alpine ski–related posture), they were unable to provide information that ordinary group want while simulated skiing exercise. Although differences between individuals exist depending on the exercise intensity and the various kind of simulator, 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 shorter to perform than non-experts ($p<.05$). According to this result, previous studies (Mani, Izumi, and Konishi, 2014) revealed there were better performances in terms of COM velocity in the athlete group compared to the control group. Even in our research, Skiing of experts showed a rapid movement of both phase (P1, P2), and it's 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 is an important factor determining ROM and elapsed time. According to previous studies (Kim, Yoo, and Ha, 2014), 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.

Table 2
The Joint Angles and Elapsed Times between Beginner and Advanced Group

Joint Angle (deg)	Event 1		Beginner	Advanced
	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*
Elapsed Times (sec)	Phase		Beginner	Advanced
	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**
Muscle Activity (%MVIC)	Max		Beginner	Advanced
	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

Expert skiers tend to minimize variation in center of mass height and maintain a more constant left-right stride length than beginner and intermediate, which 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 angle was observed in experts during simulated skiing from the initial position E1 through the maximum peak E2 and return position E3 from most of the joint angles measured this difference reached statistical significance ($p<.05$). As shown by the previous studies on various mechanical properties, these results demonstrate that stretching the body 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. Furthermore, ski simulator is a training machine that simulates as environment of reduced resistance force between the snow 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 (2010) reported that the elastic resistance exercise is effective for training small muscle groups compared to strength training using free weights. And previous studies also reported that athletes trained with elastic resistance bands demonstrated greater strength of the lower limbs than those trained with free weights.

CONCLUSION: Our results derived that non-experts showed a higher %MVIC value than experts, there were also significant group-dependent differences in the peak and mean EMG values ($p<.05$). As the elastic band undergoes a linear increase in tension from the beginning of the contraction to the full ROM, this tension generated may make it difficult to maintain a balanced posture, thus facilitating the transition to the next movement with higher muscle activity in non-experts. In the future, if thoroughly training their (non-experts) lower limb muscles which showed higher than experts in this study and providing a wide ROM during simulator exercise, it is expected that various peoples can use a ski simulator exercise program step-by-step, while improve their stability and balance more efficient and safely. And these results can be applied to ski injuries study, exercise improvement, and strengthening programs as well as physical training such as anaerobic and aerobic exercise for various peoples. We derived kinematic characteristic including the elapsed times, lower limbs joint angle, and muscle activity between two healthy participant groups. Referring to these results, we found that such a non-expert's posture leads to enhance muscle activity to keep the lower body in balance. And we can suggest the training guideline: non-experts should maintain appropriate ROM with lower-intensity exercise to improve muscle strength and endurance initially, and 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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