Comparative Evaluation of Two Skiing Simulators as Functional Training Devices for Recreational Skiers

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Abstract

The aims of this study were to examine two ski simulators, Skimagic and Skier's Edge, and to evaluate their efficacy as functional training devices for skiers. Vertical ground reaction forces, knee flexion angle kinematics and muscles activity were recorded on these devices and compared with those measured in similar condition while skiing on snow. Five ski instructors performed three randomized testing sessions (snow, Skimagic and Skier's Edge). During the testing sessions, vertical ground reaction forces were recorded by means of pressure insoles in synchronisation with a portable data logger that collected values of knee flexion-extension and EMG activation of rectus femoris and vastus medialis. EMG activations and ground reaction forces measured while skiing on simulators were lower than on snow. Although less overall EMG activation was present on the simulators, the pattern of EMG activity was closer to real snow on Skimagic than on Skiers' Edge. Results of the present study suggested that the two devices are not effectively applicable for strength training. However, based on the recorded EMG patterns, the Skimagic treadmill is potentially suitable to act as a functional training device for recreational skiers provided that an increase of speed and slope on Skimagic could induce a closer matching of the studied biomechanical parameters with the snow skiing conditions.

Key words: Muscle activation patterns, ski, ski training devices, eccentric training.

Introduction

Alpine skiing is typical of seasonal disciplines and involves a full body motion in an outdoor environment. The analysis of ski technique based on load distribution and muscle activation in the lower limbs and core muscles is fundamental, not only to improve performance and to prevent potential injuries, but also to design specific training protocols. Previous skiing research investigated the biomechanical aspects of swinging techniques by using customized force plates between boots and bindings and assessing quadriceps muscle activity, knee angular displacement and velocity (Berg and Eiken, 1999; Berg et al., 1995; Müller, 1994). The results of these investigations confirmed that the outer leg provided the main contribution during the middle of the swing turn with a predominance of eccentric muscle action (Berg and Eiken, 1999; Berg et al., 1995).

The first radical change in the skiing technique was due to the introduction of carving skis which resulted in an increase of coloading of the inner leg (Müller and

Schwameder, 2003). This new technique suggested a change in function of the main knee extensor muscles (Kröll et al., 2010). As a result, the teaching of both the correct movement progression and the development of specific dry-land conditioning programs need to be taken into account. Considering the predominance of eccentric action in alpine skiing, Gross et al. (2010) investigated the effects of introducing eccentric cycling into the weight training programs of junior male alpine skiers. Nilsson and Haugen (2004) compared knee angular displacement and extensor muscles activity on telemark slope skiing and in two dry-land specific strength exercises (barbell squats and telemark jumps) suggesting specific adjustments to improve the efficacy of the two above mentioned exercises.

Also inline skating was proposed as a dry-land exercise respectively for the rehabilitation process (Zeglinksi et al., 1998) and for the technical training of the alpine slalom racers (Kröll et al., 2005). Another interesting insight to ski training can be proposed by ski simulators. Ski simulators may be considered important in developing more effective training programs since they specifically improve strength and technical adaptations.

Raschner et al. (1997), starting from biomechanical data recorded on the slope, developed two ski simulators and assessed their functionality comparing knee kinematics and insoles pressure distribution with on field data. Müller et al. (2000) developed a specific training device called Ski Power Simulator (SPS) based on a kinetic and kinematic analysis of alpine slalom performed by senior and junior Austrian national teams. Findings suggested that the simulator adequately reflected the pattern of the ground reaction forces, as well as the knee kinematics that occurred when performing slalom on slopes. Spitzenpfeil et al. (2005) compared seven well-trained skiers performing runs on a moderate slope with the exercise on the Skier's Edge. Their experimental results showed that ground reaction forces and physiological demands (oxygen uptake and heart rate) during alpine skiing were significantly higher than on the simulator. Another study (Aleshin et al., 2009) investigated an interactive training system which simulated both dynamic loads on a skier and his 3D visual perception of a slope. It is composed by the SkyTec Interactive Trainer simulator and the visualization system based on the induced virtual environment technology. Authors reported that the system can be efficiently used for novice training and also for professional athletes. The

skier's boots are bind to two footplates applied to a slider that can shift laterally at high speeds, proportional to the footplates roll angles: the skier's posture however does not include a forward lean.

An emerging skiing simulator that has not been studied yet (except on a pilot research conducted by the authors (Panizzolo et al., 2010)) is the Skimagic (www.skimagic.it), which allows the skier to perform turns of different radii, wearing its own boots and skis. The novel aspect of this device is that the skier is able to perform a skiing exercise wearing his own equipment without additional constraints to the body in an outdoor environment.

The aim of the present study was to examine the Skimagic and Skier's Edge as training devices for skiers, comparing vertical ground reaction forces, knee angle kinematics and knee extensor muscles activity with those measured while skiing on snow. Furthermore, additional analysis was conducted on vastus medialis and rectus femoris muscle activities because of their functional differences in skiing (Kröll et al., 2010). The eccentric and concentric phases of the vastus lateralis and rectus femoris were also studied since they are important when developing a functional training programme (Hoppeler and Vogt, 2009).

Methods

Participants
Five adult male expert skiers (27.0 ± 5.2 years, 67.8 ± 6.8 kg and 1.72 ± 0.03 m) participated in the study. All the subjects were ski instructors from North Italian ski schools. Each subject was free from recent injuries or pain in the lower limbs and was requested to read and sign an informed consent form about the tests.

Training devices
Two ski training devices were used in this study: Skimagic and Skier's Edge. Skimagic (Alterego, Italy) is a full scale (6x6 m) inclined treadmill equipped with a spinning mat covered by synthetic fur: the mat needs to be wet during operation to better mimic the surface friction conditions of snow. The maximum speed of Skimagic is 22 km/h and its maximum inclination is 25° (Figure 1-top).

Skier's Edge (The Skier's Edge Company, USA) is a portable home device that requires the participant to stand on two footboards which can rotate along their longitudinal and transversal axes, to allow feet movement in the frontal and sagittal planes. Rubber straps are used to set the intensity of the effort required by the skier as they perform the slalom movements (Figure 1-bottom).

Instrumentation
During the three sessions of the study, knee kinematic, surface electromyography (EMG) from the quadriceps muscles, together with vertical ground reaction forces were measured.

Kinematic data were recorded by means of a biplanar electrogoniometer (Biometrics, UK) placed on the leg lateral surface that permitted the collection of the flexion-extension angle of the right knee.

EMG signals of two muscles of interest were selected on the right leg: Rectus Femoris (RF) and Vastus Medialis (VAM); skin preparation and electrode placement over the intended muscles were performed in accordance with the SENIAM concerted protocol (Hermens et al., 2000).

Kinematic data and EMG signals were synchronously recorded (1kHz) using a portable data logger with 16 channels (PDA-PocketEMG, BTS Bioengineering, Italy) that was placed on the chest of the skier.

Force data were collected for both feet using a pair of pressure insoles (Pedar-X, Novel, Germany) that quantified vertical forces at the centre of pressure (Stricker et al., 2010). Optimal insoles size was chosen for each participant and connected to a mobile unit placed in a customized belt on the back of the subject. These data were collected at a frequency of 100 Hz, since this frequency represents the maximum sampling rate of the Novel system. A manual trigger was used to synchronize the data collected with PDA-Pocket to the data collected with Pedar-X.
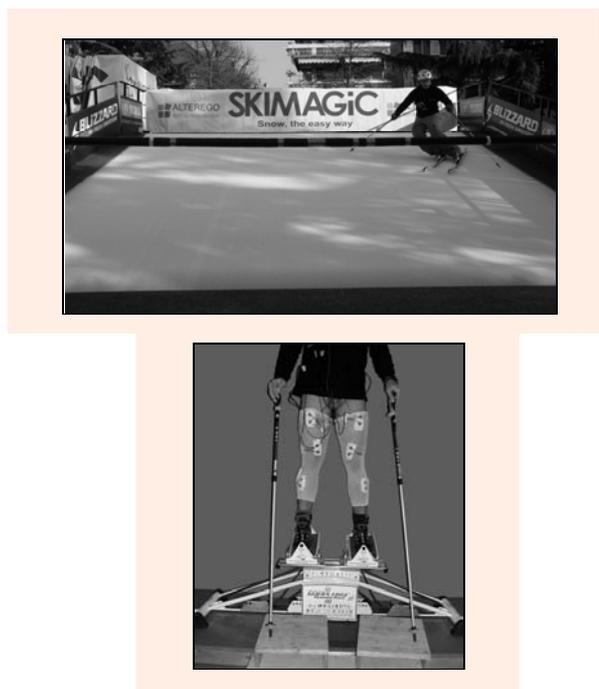

Figure 1. Skimagic (top) and Skier's Edge (bottom).

Testing protocol
The study was composed of three different sessions: (i) snow, (ii) Skimagic, (iii) Skier's Edge, performed on two different days for each subject (Skimagic and Skier's Edge were performed the same day) and randomised to minimize any learning effect.

In the snow session, after three free ski runs as a warm-up, subjects were asked to perform slalom skiing on natural snow with a slope of 28° (Monti-Zardini slope, Faloria resort, Cortina D'Ampezzo, Italy). Each run was composed of 12 turns and was repeated three times by each subject. Short slalom poles (span 1.5 m, pace 8 m)

were placed on the snow to ensure the consistency between runs. During data collection the weather conditions were stable: the temperature was -3°C, the snow was estimated hard and it was sunny.

The second session took part on the Skimagic treadmill. During the Skimagic session the treadmill ran at a constant speed of 22 km/h (maximum speed allowed by the device) and was inclined at 25° to reproduce the same testing conditions of the first session on the snow. After ten minutes of free runs as a warm-up on the ski device, subjects performed a slalom of medium width, to mimic the turns around slalom poles used in the snow session. Each run was composed of at least 12 turns.

During the Skier's Edge session, rubber straps that regulate the intensity of the strength performed by the skier were set at their maximum stiffness value. After 10 minutes of warm-up and familiarisation to the device, subjects were asked to perform three runs with at least 12 turns for each side.

At the end of each session of testing, isometric maximum voluntary contractions (MVC) of the knee extensors were performed following the guidelines indicated by Burden (2010); MVC of RF and VAM were collected using resistance to knee extension. Subjects were trained to properly perform MVC prior the data collection and verbally motivated by the researchers during the execution of this task.

In the snow and Skimagic sessions subjects used a pair of special slalom skis (SLR 165, Nordica, Italy) and their own boots. Because of the difficulties experienced by the subjects in keeping the balance on the Skier's Edge footplates, and in performing a correct exercise on the device, it was decided to perform the tests with a pair of sport shoes. Nevertheless, for consistency with the previous sessions, also in this condition subjects used ski poles.

Data analysis

Customized protocols were developed for data analysis using SMART Analyzer (BTS Bioengineering, Italy) and Matlab (The MathWorks Inc., USA).

Flexion-extension angle of the right knee was filtered with a fourth order low pass Butterworth filter (cut-off frequency of 5 Hz) and then used to define turn cycles following the definition given by Berg et al. (1995). Each turn cycle was defined as two consequent values of minimum knee flexion so that each cycle was composed of one left turn plus the sequential halves of the two associated right turns (Figure 2); 180° was considered full knee extension.

An approximation of skiing speed, defined as turning rhythm, was calculated for each testing condition measuring the time between two consequent values of minimum knee flexion.

The EMG raw signals collected from the muscles under investigation were rectified, integrated with a mobile window of 150 ms, filtered with a fourth order low pass Butterworth filter (cut-off frequency of 5 Hz) and normalized with respect to the MVC of the corresponding session of data collection to permit within and between subjects comparisons.

Based on the definition of the turn cycle given above, EMG signals were normalized to 100 data points and averaged across cycles of both the same and different runs, so that a minimum of six cycles were analysed for each subject and each testing condition.

Within the turn cycle an eccentric phase of the quadriceps muscles (VAM and RF) was defined as the phase maximum to minimum knee angle. In contrast, the concentric phase was defined as the period from minimum to maximum knee angle (Berg et al., 1995; Nilsson and Haugen, 2004). Lastly, data were averaged between subjects for each testing condition.

Vertical ground reaction forces were computed directly by Pedar-X system and filtered with a fourth order low pass Butterworth filter with a cut-off frequency of 5 Hz. Using the definition of turn cycle, force curves were created for each subject and for each testing condition. These curves were normalized to 100 data points and a minimum of six turns for each subject for each condition of testing was considered. As a result, analysis was conducted on the same cycles used in the processing of EMG signals.

Statistical analysis

A one-way ANOVA for repeated measurements for the independent skiing condition variable (snow, Skimagic, Skier's Edge) was used to analyse differences in muscle activation (mean EMG linear envelope during both the turn cycle and the separate concentric and eccentric phases), knee kinematics (total range of motion) and force (peak and mean) within a turn cycle. If statistically significant differences were detected ($p < 0.05$), a Bonferroni post hoc test was calculated to ascertain which conditions were significantly different.
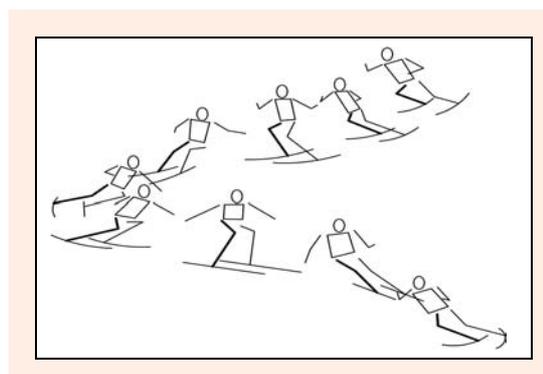

Figure 2. Example of a sequence of turn cycle of skiing.

In addition, to better investigate differences in the shape of the force curves and provide an insight on its temporal course, a principal component analysis (PCA) was used to compare the three conditions of testing (MATLAB, The MathWorks Inc., USA). The PCA was performed on the force profile across the total turn cycle. A two-tailed, paired Student's t-test was run on the first principal component (PC1) to define statistically significant differences ($p < 0.05$) in the shape of the vertical forces between Skimagic and Skier's Edge with respect to snow. Effect sizes were calculated using Cohen's d method.
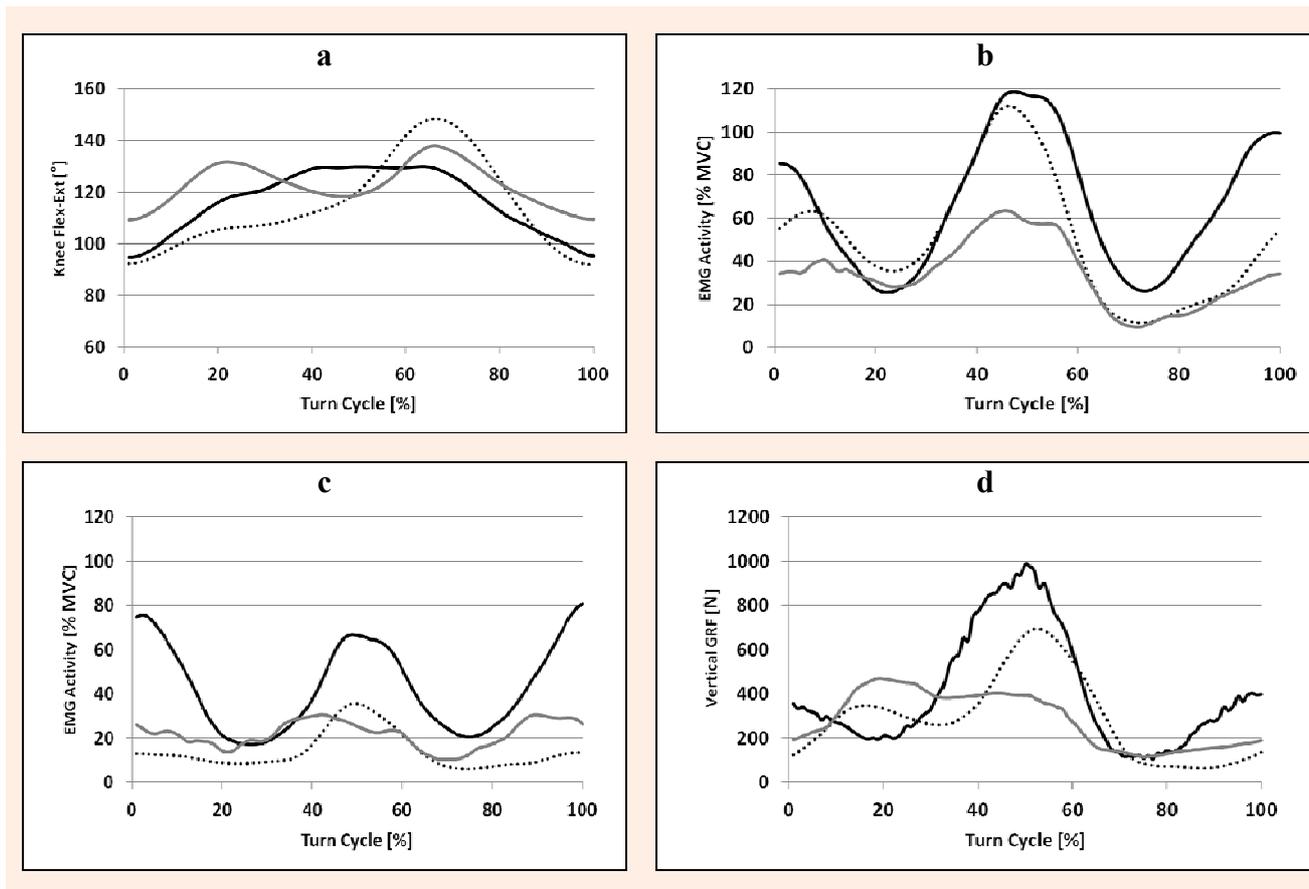
Figure 3. Group mean curves of: flexion-extension angle **(a)**, VAM EMG linear envelop **(b)**, RF EMG linear envelop **(c)** and vertical ground reaction force **(d)** plotted over a turn cycle for the three conditions of testing. Snow is represented with solid black lines, Skier's Edge with dotted black lines and Skimagic with grey lines.

Results

Knee kinematics

Average curves of flexion-extension of the right knee for the three testing conditions are presented in Figure 3a. Knee flexion-extension mean range significantly differed among the three conditions (p = 0.0027). Further post hoc tests showed a difference (p < 0.05, Effect size: 1.34, Power: 0.14) between both the snow condition (Δ≈41°) and Skier's Edge (Δ≈57°) and between Skimagic (Δ≈31°) and Skier's Edge (p < 0.01, Effect size: 2.08, Power: 0.27). Nevertheless, from the point of view of the curve profile, the knee flexion-extension angle profile during the exercise on Skier's Edge was closer to the snow profile than to the Skimagic one: in this case the knee exhibited a double extension peak within the turn cycle.

During the turn cycle on snow, based on the turn cycle definition described above, the right knee starts from a flexed position, reaches its maximum extension (around 40% of the cycle), and then maintains this value till it starts (≈65% of the cycle) to flex again during performing the second half of the right turn. Although showing a profile closer to skiing on snow than Skimagic, the knee kinematics on Skier's Edge presented a more evident peak of extension which was achieved slightly later in the cycle (66.2 ± 1.3%) with respect to the snow. The knee kinematics on Skimagic demonstrated two peaks of extension within a turn cycle, respectively at

22.0 ± 4.5% and at 66.8 ± 4.9% of the cycle itself. Turning rhythm was of 1.14 ± 0.11 s, 3.80 ± 1.49 s and 1.93 ± 0.32 s respectively for Skier's Edge, Skimagic and snow.

The overall range of motion of the right knee, its maximum and minimum values of extension are presented in Table 1 for each condition of testing.

Muscle activity

During skiing on snow VAM and RF presented two main peaks of activation (Figure 3b-c). There was one peak at the beginning and one during the middle of the cycle corresponding to the inner and outer position of the leg, respectively. Also, different behaviour was noticed in the two muscles with the main peak of activation for VAM at the middle of the turn cycle but the main peak for RF was at the beginning of the cycle.

Mean value of normalized EMG linear envelope for VAM was significantly different across the three experimental conditions (p = 0.005, Table 1). Specifically there were significant differences between snow and Skier's Edge (p < 0.05, Effect size: 1.77, Power: 0.21) as well as between snow and Skimagic (p < 0.01, Effect size: 1.77, Power: 0.21). There were no statistical differences in RF EMG among the three experimental conditions (p = 0.1377). However, the mean value of the normalized EMG linear envelope with respect to the snow condition (Table 1) was lower in both the Skier's Edge

Table 1. Average values of flexion-extension of the knee, RF and VAM EMG linear envelop and vertical ground reaction force for the three conditions of testing. Data are means (±SD).

		SNOW	SKIER'S EDGE	SKIMAGIC
KNEE ANGLE (°)	**MAX**	135.7 (5.5)	148.6 (13.2)	139.9 (8.5)
	MIN	94.6 (6.4)	91.9 (19.1)	109.4 (12)
	DELTA	41.1 (5.6) *	56.7 (15.5) †	30.5 (8.6)
		SNOW	SKIER'S EDGE	SKIMAGIC
MEAN EMG (%MVC)	**VAM**	65.4 (13.2) *†	38.7 (16.7)	33.4 (21.8)
	RF	42.6 (14.2)	25.1 (12.7)	21.0 (19.1)
		SNOW	SKIER'S EDGE	SKIMAGIC
VERTICAL GRF (N]	**MEAN**	401.4 (91.3) *†	278.4 (53.0) *	256.8 (46.4)
	PEAK	1056.0 (163.3) *†	731.7 (266.4) *	562.6 (74.1)

* p < 0 .05 compared with SKIER'S EDGE; † p < 0.01 compared with SKIMAGIC

(approximately -41%) and the Skimagic (approximately -51%).

The analysis conducted on the eccentric and concentric phases of the muscle investigated are presented in Figure 4. These results showed a slightly higher activity during the eccentric phase with respect to the concentric phase in the snow condition for both VAM and RF. In contrast, while exercising on Skier's Edge, subjects showed a predominance of concentric activity for both VAM and RF. On Skimagic subjects showed a concentric over eccentric predominance for VAM but a similar intensity of the two phases for RF. The mean eccentric activity of the VAM was higher on snow compared to both Skier's Edge (p < 0.01, Effect size: 3.07, Power: 0.51) and Skimagic (p < 0.01, Effect size: 2.03, Power: 0.26).

Ground reaction forces

No differences were detected between the right and left vertical ground reaction forces within each subject during all testing conditions. Therefore, only results regarding the right leg are presented (Table 1).

The force curve on snow has its peak value around the middle of the cycle (48.6 ± 4.5%) while the leg is in the external position. A similar pattern was noticed on Skier's Edge, although there was the additional presence of a smaller peak at 15.4 ± 3.6% of the cycle (Figure 3d).

In contrast, the distribution of the force profile on Skimagic was completely different to that on snow. The Skimagic force curve shows a main peak at the 20.4 ± 4.5% of the cycle and a plateau around the 30-55% of the cycle. The differences in the overall shape of the Skimagic and Skier's Edge curves were also highlighted by the PCA1 which reported a statistically significant difference of these devices with respect to snow (p = 0.01, Effect size: 1.83, Power: 0.22 for Skier's Edge and P= 0.0006, Effect size: 3.64, Power: 0.65 for Skimagic).

The peak values of force curves showed significantly differences (p = 0.0045) and were higher on snow than on the Skier's Edge (p < 0.05, Effect size: 1.46, Power: 0.15) and Skimagic (p < 0.01, Effect size: 3.89, Power: 0.71). Also the mean force was statistically different among the three conditions (p = 0.004) with higher values detected on the snow with respect to Skier's Edge (p < 0.05, Effect size: 1.64, Power: 0.18) and Skimagic (p < 0.01, Effect size: 1.99, Power: 0.25).

Discussion

In the present study subjects skied on snow performing a carving technique. Previously implications on this technique on biomechanical parameters were extensively discussed by Müller and Schwameder (2003). In this study, knee range of motion was in accordance with
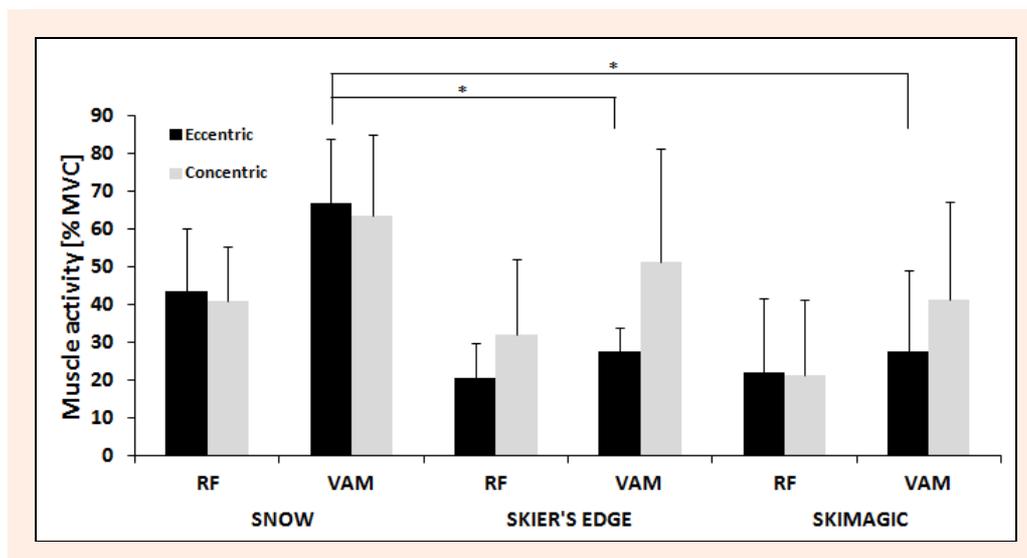

Figure 4. Group mean and standard deviation EMG linear envelop of VAM and RF during eccentric and concentric phase for the three conditions of testing. * Significant difference (p < 0.01).

previous literature (Berg and Heiken, 1999; Müller and Schwameder, 2003) but profile was closer to Kröll et al. (2010).

Both the shape and amplitude of the quadriceps EMG activation were in agreement with previous studies (Hintermeister et al.,1995). However, VAM and RF EMG showed a different activation pattern due to a different function exerted by the two muscles during the carving skiing. In particular, RF presented a higher EMG activation in the inside ski phase than in the outside ski phase, but an opposite behaviour was evidenced in the VAM. The reason of this difference was previously explained (Müller and Schwameder, 2003; Kröll et al., 2010) by an increased coloading of the inside leg, typical of the carving technique, and because the anatomy of the two muscles. More specifically the VAM is monoarticular but the RF is biarticular and so its activation is influenced by the position of the trunk. By combining the information provided by force data it could also be suggested that this functional difference is related to the force-length property of the muscle itself. It is well established (Allinger et al., 1996; Rassier et al., 2003) that the relationship between muscle activity and force produced by the muscle itself is not linear. In other words, a higher activation of the muscle does not always correspond to a higher force production. This is because each muscle has a region of optimum length for force production and this depends on type of contraction (Hill, 1953). Therefore, we can speculate that during the inside phase the angle of the knee did not allow the muscles to work at their optimal length and so may explain why, the first peak of RF (at the beginning of the turn cycle) represented the maximum activation of the overall cycle. This possibility is supported by the ground reaction forces, where the main peak was in the outer phase, suggesting that RF during the inner phase was working in a less efficient region of its force-length curve.

Vertical ground reaction forces were directly calculated using Novel pressure insoles placed inside the boots; also on this parameter results obtained on snow were in accordance with previous literature (Müller et al., 2000). The accuracy and reliability of Novel system in slalom has been previously assessed (Stricker et al., 2010; Nakazato et al., 2011) reporting an underestimate of the true values collected with this system. Nevertheless, the authors also stated the validity of the pressure insoles system for a descriptive analysis of skiing technique as done in the present study.

The aim of this study was to examine Skier's Edge and Skimagic and their possible employment in ski training protocols, to improve skiers technique and strength away from the winter slopes.

The vertical ground reaction force results clear demonstrated that the simulators devices required less physical effort with respect to the snow condition. This was confirmed by the EMG activity (of both muscles) which showed very low values of activation while skiing on the ski simulators with respect to snow. To improve their performance, athletes should perform sports-like training (Berg and Eiken, 1999), but the physical exertion

required by the two simulators was not similar to skiing on snow. This means that the two simulators, as they are, can not give an effective contribution to strength development, as previously reported for the Skier's Edge (Spitzenpfeil et al., 2005).

However, a key factor when designing sports-like trainings is the consideration of muscle activation patterns and the mode of contraction (such as concentric and eccentric) performed during the exercise. In this regard, despite the predominance of concentric action over eccentric in both devices, Skimagic showed a higher degree of eccentric contraction than the Skier's Edge; further, the functional differences proper of the carving technique in the RF muscle (Kröll et al., 2010) were present only on the Skimagic (Figure 3c). This induced the authors to presume that greater values of inclination and speed on the Skimagic may increase the gravity and inertial loadings to the skiers, therefore increasing the possibility of recording higher ground reaction forces and correspondingly higher knee extensor activation in the eccentric mode, making the simulator closer to recreational skiing.

Conversely, Skier's Edge presented a dramatically reduced coloading during the inner expressed by the null for the RF. Considering the type of muscle contraction, Skier's Edge did not mimic the snow condition since there was a large predominance of concentric over eccentric activation for both muscles. Firstly, this contraction pattern might be due to the fact that pushing is required at the beginning of each cycle to start the exercise on Skier's Edge and subjects were guided by footboards and rubber straps. Secondly, this contraction pattern may be due to the kinematics of knee on Skier's Edge since the plyometric return imposed by the rubber straps caused a very fast phase of flexion at end of the cycle (Figure 3a).

Despite these findings some of the limitations of the present study have to be stated.

Firstly, turning rhythm on the Skimagic was significantly lower than both snow and Skier's Edge rhythm, which might have affected the parameters investigated. It was not possible to match the skiing speed of the snow tests on the Skimagic, mainly because of its low maximum speed. In addition, the mechanics of the Skier's Edge itself (mostly imposed by the rubber straps) makes it impossible to perform an exercise with a slow pace comparable to that produced by the fastest speed of the Skimagic.

Another limitation may be the fact that subjects were performing the exercise on Skier's Edge wearing a pair of sport shoes and not ski boots, this might have influenced muscle activity as well as knee kinematics. Nevertheless, the limitations addressed here (small range of speeds applied and impossibility of wearing participant's own ski equipment) reflect the constraints of the devices used, with the mechanics and design of the devices not able to provide specific training programs that satisfy elite athletes requirements.

However, because of the small sample size involved in the study and the consequent low statistical

power, findings of the present study should be interpreted with care because they might be affected by small individual adaptations occurring on the training devices.

Conclusion

Two ski simulators were investigated for their viability to be used as sport-like training. Findings showed that the main limitation of the ski simulators was the low knee extensor muscle activations required. Therefore the simulators can not be considered as effective as other dry-land strength development exercises (Nilsson and Haugen, 2004; Turnbull et al., 2009). However, functional muscle pattern recorded in Skimagic was quite similar to skiing on snow showing the potential of this device to replicate a carving technique limiting to the variables investigated. Considering the effect of the slope inclination on EMG activity during skiing on snow (Kröll et al., 2010) we can speculate that an increase of both speed and inclination on Skimagic might increase the knee extensor activation and so make skiing on this device more similar to skiing on snow. On the other hand, the strong predominance of concentric over eccentric activation coupled with the impossibility of using proper skiing equipment, makes the action of Skier's Edge too different from skiing on snow to consider this simulator for specific functional training programs.

Because alpine skiing is a seasonal sport, this limits the time and the space that could be dedicated to its practise and, as a consequent of this, the cost associated for athletes are high. An appealing feature offered by the ski simulators is the possibility to be used without time and space constrains. Specifically on this point, it has to be added that while Skier's Edge offers all the advantages proper of a relative small and portable device (easy to move and to setup, no specific settings needed, low cost…) the characteristics of Skimagic make its adoption in the common training practise less popular. This simulator needs a large dedicated area and its setup, as well as its transport, require several hours. Moreover, its installation has to be performed close to an adequate source of water and power, necessaries to its functioning. All these factors combined led to a high cost which makes Skimagic almost impossible to be used regularly by an individual athlete but may be afforded by sport federations or big teams.

References

Aleshin, V., Klimenko, S., Manuilov, M. and Melnikov, L. (2009) Alpine skiing and snowboard training system using induced virtual environment. In: *Science and Skiing IV*. Eds: Müeller, E., Lindinger, S. and Stoeggl, T. Meyer & Meyer Sport (UK) Ltd. 137-144.

Allinger, T.L., Epstein, M. and Herzog, W. (1996) Stability of muscle fibers on the descending limb of the force-length relation. A theoretical consideration. *Journal of Biomechanics* **29**, 627-633.

Berg, H.E., Eiken, O. and Tesch, P.A. (1995) Involvement of eccentric muscle actions in giant slalom racing. *Medicine & Science in Sports & Exercise* **27**, 1666-1670.

Berg, H.E. and Eiken, O. (1999) Muscle control in elite alpine skiing. *Medicine & Science in Sports & Exercise* **31**, 1065-1067.

Burden, A. (2010) How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. *Journal of Electromyography & Kinesiology* **20**, 1023-1035.

Gross, M., Lüthy, F., Kroell, J., Müller, E., Hoppeler, H. and Vogt, M. (2010) Effects of eccentric cycle ergometry in alpine skiers. *International Journal of Sports Medicine* **31**, 572-576.

Hermens, H.J., Freriks, B., Disselhorst-Klug, C. and Rau, G. (2000) Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography & Kinesiology* **10**, 361-374.

Hill, A.V. (1953) The mechanics of active muscle. *Proceedings of the Royal Society London B* **141**, 104-117.

Hintermeister, R.A., O'Connor, D.D., Dillman, C.J., Suplizio, C.L., Lange, G.W. and Steadman, J.R. (1995) Muscle activity in slalom and giant slalom skiing. *Medicine & Science in Sports & Exercise* **27**, 315-322.

Hoppeler, H. and Vogt, M. (2009) Eccentric exercise in alpine skiing. In: *Science and Skiing IV*. Eds: Müeller, E., Lindinger, S. and Stoeggl, T. Meyer & Meyer Sport (UK) Ltd. 33- 42.

Kröll, J., Schiefermüller, C., Birklbauer, J. and Müller, E. (2005) Inline-skating as a Dry Land Modality for Slalom Racers – Electromyographic and Dynamic Similarities and Differences. In: *Science and Skiing III*. Eds: Müeller, E., Bacharach, D., Klika, R., Lindinger, S. and Schwameder, H. Meyer & Meyer Sport (UK) Ltd. 76-87.

Kröll, J., Wakeling, J.M., Seifert, J.G. and Müller, E. (2010) Quadriceps Muscle Function during recreational Alpine Skiing. *Medicine & Science in Sports & Exercise* **42**, 1545-1556.

Müller, E. (1994) Analysis of the biomechanical characteristics of different swinging techniques in alpine skiing. *Journal of Sports Science* **12,** 261-278.

Müller, E., Benko, U., Raschner, C. and Schwameder, H. (2000) Specific fitness training and testing in competitive sports. *Medicine & Science in Sports & Exercise* **32**, 216-220.

Müller, E. and Schwameder, H. (2003) Biomechanical aspects of new techniques in alpine skiing and ski-jumping. *Journal of Sports Sciences* **21**, 679–692.

Nakazato, K., Scheiber, P. and Müller, E. (2011) A comparison of ground reaction forces determined by portable force-plate and pressure-insole systems in alpine skiing. *Journal of Sports Science and Medicine* **10**, 754-762.

Nilsson, J. and Haugen, P. (2004) Knee angular displacement and extensor muscle activity in telemark skiing and in ski-specific strength exercises. *Journal of Sports Sciences* **22**, 357-364.

Panizzolo, F.A., Petrone, N. and Marcolin, G. (2010) Comparative analysis of muscle activation patterns between skiing on slopes and on training devices. *Procedia Engineering* **2**, 2537-2542.

Raschner, C., Müller, E. and Schwameder, H. (1997) Kinematic and kinetic analysis of slalom turns as a basis for development of specific training methods to improve strength and endurance. In: *Science and Skiing*. Eds: Müeller, E., Schwameder, H., Kornexl, E. and Raschner, C. E & FN Spon (UK) Ltd. 251-262.

Rassier, D.E., Herzog, W., Wakeling, J. and Syme, D.A. (2003) Stretch-induced, steady-state force enhancement in single skeletal muscle fibers exceeds the isometric force at optimum fiber length. *Journal of Biomechanics* **36**, 1309-1316.

Spitzenpfeil, P., Niessen, M., Rienaecker, N. and Hartmann, U. (2005) Evaluation of a specific training device in alpine skiing. In: *Science and Skiing III*. Eds: Müeller, E., Bacharach, D., Klika, R., Lindinger, S. and Schwameder, H. Meyer & Meyer Sport (UK) Ltd. 204-215.

Stricker, G., Scheiber, P., Lindenhofer, E. and Müller, E. (2010) Determination of forces in alpine skiing and snowboarding: Validation of a mobile data acquisition system. *European Journal of Sport Science* **10**, 31-41.

Turnbull, J.R., Kilding, A.E. and Keogh, J.W. (2009) Physiology of alpine skiing. *Scandinavian Journal of Medicine and Science in Sports* **19**, 146-155.

Zeglinksi, C.M., Swanson, S.C., Self, B.P. and Greenwald, R.M. (1998) Muscle activity in the slalom turn of alpine skiing and in-line skating. *International Journal of Sports Medicine* **19**, 447-454.

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Key points

- EMG activation and ground reaction forces were lower on both simulators with respect to snow.
- Both simulators were not able to provide an effective contribution to strength development for skiers.
- In term of functional training Skier's Edge showed a predominance of concentric action over eccentric which is in contrast with competitive skiing.
- Skimagic treadmill could be potentially suitable to act as a functional training device for recreational skiers only if an increase of speed and slope will induce a closer matching of the studied biomechanical parameters with the snow skiing conditions.

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