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ScienceDirect
Procedia Engineering 2 (2010) 2537–2542
Procedia Engineering
www.elsevier.com/locate/procedia

8th Conference of the International Sports Engineering Association (ISEA)

Comparative analysis of muscle activation patterns between skiing on slopes and on training devices

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Received 31 January 2010; revised 7 March 2010; accepted 21 March 2010

Abstract

The increasing popularity of ski as winter sport and the difficulties related to its accessibility and environmental conditions led to the development of specific training devices for practise, both for improving technique and for training after injuries.

In particular the aim of this work was to study the efficacy of two training devices: Skimagic® and Skier's Edge®, comparing their functionality to ski on natural snow.

The efficacy of training devices was investigated after comparing the EMG activation patterns of snow skiing with the other two training conditions; good correlation of activation patterns should correspond to a better simulation of the skiing movement.

Keywords: *Skiing; muscle activation patterns; training devices*

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1877-7058 © 2010 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2010.04.028

1. Introduction

Skiing is a very popular sport discipline involving a full body motion in an open environment. The muscular recruitment patterns at the lower limbs are related to the ski discipline, the skill levels and the snow properties: in most cases anti-gravitational muscles are reported to work in eccentric mode [1]. Data acquisition of EMG signals is quite complex in such environment [2] and requires an approach integrated with kinematic and kinetic data to give a real insight of the skiing technique.

Despite its popularity, very few skiing training devices are available to athletes and beginners for training away from the slopes or rehabilitating after injuries [3, 4, 5].

The aim of the present work was to make a comparison of muscle activation patterns during skiing between three different skiing conditions. A slalom skiing on natural snow in a medium steep slope was compared with two training devices: a full scale treadmill (Skimagic®) and a portable home training device (Skier's Edge®).

2. Methods

Two expert male skiers (age: 24.9 ± 1.3, weight: 72.5 ± 3.5, height: 170.2 ± 0.3) free from recent injury or pain were involved in the study. Subjects are ski instructors since 5 years and well experienced with Skimagic®.

The study was composed of three sessions (Fig. 1).

- In the first session, after some free runs on ski as a warm-up, subjects were asked to perform a slalom skiing on natural snow on a moderate slope. Each run was composed of 12 turns and was repeated by subjects three times. Short slalom poles (span 1.5 m, pace 8m) were placed on the snow to increase the repeatability between runs. During the data collection weather conditions were good; temperature was very cold and the snow was hard.
- The second session took part on Skimagic®. Skimagic® is a full scale (6x6 m) treadmill that runs upward powered by a power supply of 25 kWh, during its operating it needs to be wet to better mimic friction conditions of its surface in comparison to snow. During the session it run at a speed of 22 km/h and its slope was set at 25° to recreate the same conditions of the first session on the snow. After some minutes of free runs as a warm-up, subjects were asked to ski on the device performing a slalom of medium width, to mimic turns around slalom poles. Each run was composed of at least 12 turns.
- The third session involved the use of Skier's Edge®. Skier's Edge® is a portable home device that permits the movement of the user along coronal and sagittal planes. Subject is standing on two footboards which can rotate along their longitudinal and medial axes while rubber straps are used to set the intensity of the strength performed by the skier. After some minutes of exercise on the device, with the double aim of acting as a warm-up and getting the subjects familiar with the device, subjects were asked to perform three runs of at least 12 turns for each side.

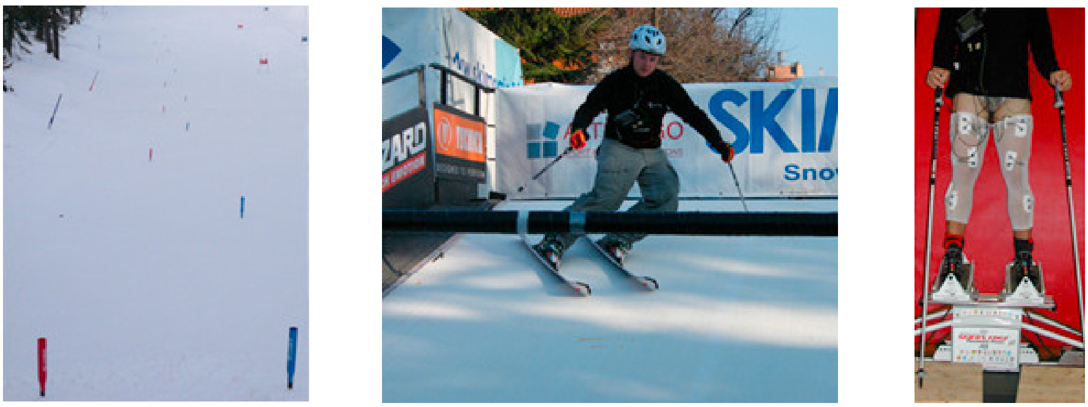

Fig.1. Set-up of the different sessions: (a) Natural slope; (b) Skimagic®; (c) Skier's Edge®

In order to analyze muscle activation patterns, EMG signals and kinematics data at the knee were collected during each session.

A PDA-PocketEMG® (145x95x20 mm, 0.3Kg) with 16 channels, placed at the chest of the skier, was used to collect muscle data on both legs.

Five muscles were analyzed for each lower limb, the muscles are: Rectus Femoris, Vastus Medialis, Biceps Femoris, Tibialis Anterior and Gastrocnemius Lateralis (they will be named RF, VAM, BFCL, TA and GAL in the following section). A Biometrics® biplanar electrogoniometer was used to collect synchronously the flexion-extension and ab-adduction angles at the right knee. All the data were collected at a frequency of 1 KHz.

At the end of each session, Maximum Voluntary Contractions (MVC) were performed on all referred muscles with a standardized protocol in use in our Department.

EMG raw signals from the 10 muscles were rectified, integrated with a mobile window of 150 ms, filtered with a 5 Hz low pass Butterworth filter and normalized with respect to the MVC of the proper session of data collection. Values of flexion-extension angle of the knee were used to define cycles of skiing: each cycle was defined as a sequence of internal-external-internal turns. In particular, the cycle for the 5 muscles of the right lower limb was defined by two sequential maximum values of the knee flexion angle. Similarly, two sequential minimum values of right flexion angle define the cycle of left limb. Each EMG signal was then averaged across at least 3 cycles of the same run and also across different runs, for each different session.

3. Results

The results of the analysis described in previous session for subject 1 are presented as an example in Figures 2-4. In every single picture the three conditions of this study are compared: control condition (skiing on natural snow) is presented as black thick, skiing on Skimagic is in black thin and training on Skier's Edge is in grey thick lines. Figure 2.b presents also the standard deviation to provide an example of its range for the EMG collected.

The values collected by the electrogoniometer at right knee during a mean cycle are shown in Figure 2.a (in degrees). All the values are positive because they represent a flexion starting from a neutral position (standing) at 0°. All the other figures represent the mean curves of EMG activation for the analyzed muscles during one cycle with values expressed as % of MVC.

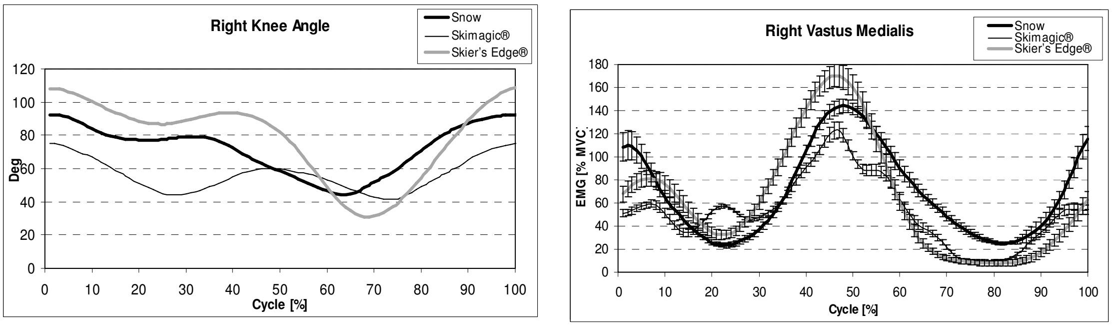

Fig. 2. (a) Right Knee Angle mean curves; (b) Right Vastus Medialis mean activation curves with standard deviation

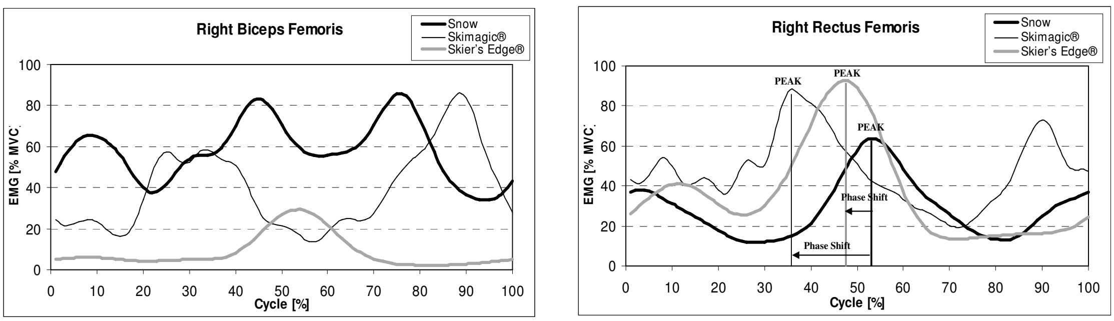

Fig. 3. (a) Right Biceps Femoris mean activations curves; (b) Right Rectus Femoris mean activations curves;

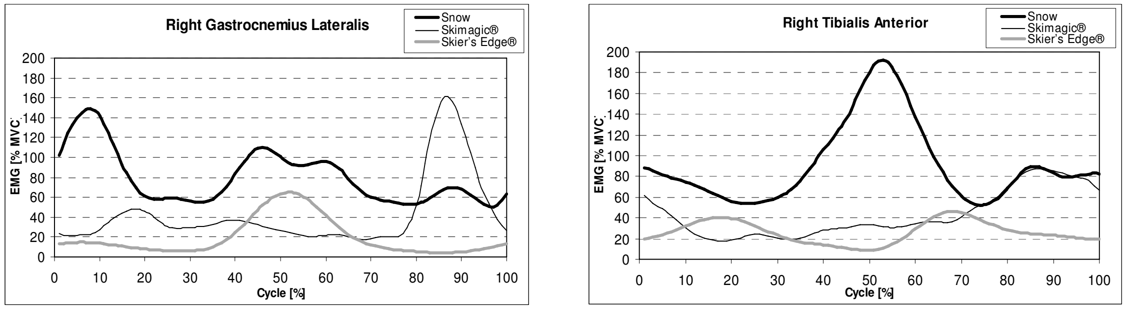

Fig. 4 . (a) Right Gastrocnemius Lateralis mean activation curves; (b) Right Tibialis Anterior mean activation curves;

For each muscle on both lower limbs two quantities were evaluated to compare the EMG activation patterns among the three conditions under study: these were the Peak activation value (Figure 3.b) and the Mean activation value within a cycle, defined as the average of the activation during the cycle. In particular, values of EMG activity collected on snow session were expressed in % of MVC and considered as the control values; values collected in the two other conditions were expressed in terms of relative differences (in %) with respect to the control condition (skiing on snow).

In addition, the differences in timing of the peaks were expressed as Phase Shifts relative to the snow skiing control session. The values indicate the percent of cycle where are the peaks of maximum activation, for the other two conditions the values are the difference (in % of cycle) from this one.

In Table 1 and Table 2, results from data analysis related to subject 1 and 2 are presented: values corresponding to the control condition (skiing on snow) are in bold.

Table 3 summarizes results of the first two tables: the results of each muscle are expressed as grand mean, averaged across both lower limbs and across subjects. Again, control condition values are expressed in percent of MVC and in bold, while values from the other conditions are expressed as the difference (in %) of activation from control condition.

Table 1. Muscles activation values for subject 1

	SUBJECT 1	**VAM**			**RF**			**BFCL**			**TA**			**GAL**		
	Condition	**Snow**	SkiM.	SkiE.	**Snow**	SkiM.	SkiE	**Snow**	SkiM.	SkiE.	**Snow**	SkiM.	SkiE.	**Snow**	SkiM.	SkiE.
	Units	**% MVC**	Δ% Snow	Δ% Snow	**% MVC**	Δ% Snow	Δ% Snow	**% MVC**	Δ% Snow	Δ% Snow	**% MVC**	Δ% Snow	Δ% Snow	**% MVC**	Δ% Snow	Δ% Snow
Right	Peak activation	**144.1**	-14.7	+18.2	**63.8**	+38.6	+45.4	**85.9**	0.0	-66.0	**192.0**	-54.7	-75.9	**149.4**	+7.8	-56.6
	Mean activation	**68.9**	-23.5	-8.1	**28.9**	+66.3	+27.3	**58.1**	-32.0	-85.1	**91.1**	-53.2	-71.1	**80.0**	-46.3	-76.0
Left	Peak activation	**228.3**	-18.6	-36.3	**65.2**	-6.4	+56.1	**180.1**	-74.6	-86.1	**56.3**	+8.2	+6.3	**401.2**	-86.1	-83.2
	Mean activation	**86.6**	+4.3	-40.0	**43.4**	-19.8	-7.7	**129.4**	-77.6	-92.3	**46.2**	-17.1	-40.2	**248.4**	-90.1	-89.3
	Units	**% Cycle**	% Cycle	% Cycle	**% Cycle**	% Cycle	% Cycle	**% Cycle**	% Cycle	% Cycle	**% Cycle**	% Cycle	% Cycle	**% Cycle**	% Cycle	% Cycle
R	Phase shift	**48**	-1	-2	**53**	-17	-6	**76**	+13	-22	**53**	+34	+13	**8**	+79	+44
L	Phase shift	**39**	+3	-9	**37**	+7	-5	**61**	-39	-27	**52**	+47	+7	**44**	+46	-8

Table 2. Muscles activation values for subject 2

	SUBJECT 2	VAM			RF			BFCL			TA			GAL		
	Condition	**Snow**	SkiM.	SkiE.	**Snow**	SkiM.	SkiE	**Snow**	SkiM.	SkiE.	**Snow**	SkiM.	SkiE.	**Snow**	SkiM.	SkiE.
	Units	% **MVC**	Δ% Snow	Δ% Snow	% **MVC**	Δ% Snow	Δ% Snow	% **MVC**	Δ% Snow	Δ% Snow	% **MVC**	Δ% Snow	Δ% Snow	% **MVC**	Δ% Snow	Δ% Snow
Right	Peak activation	**91.4**	+32.1	+24.7	**36.6**	+29.9	+58.1	**18.0**	+7.6	+18.0	**62.1**	-15.8	-61.5	**52.8**	-16.6	-21.2
Right	Mean activation	**77.0**	-15.1	-40.7	**36.2**	+2.8	-34.2	**10.3**	+19.6	-8.4	**40.0**	-31.0	-55.9	**38.5**	-36.0	-62.8
Left	Peak activation	**90.8**	+28.7	+78.8	**59.8**	+4.3	+0.5	**14.7**	+39.2	-48.9	**52.0**	-48.2	-45.1	**23.1**	n.a.	+128.9
Left	Mean activation	**71.3**	-27.3	-13.1	**34.6**	+12.9	-14.7	**9.6**	+12.3	-67.0	**32.5**	-50.7	-51.0	**25.4**	n.a.	-33.8
	Units	% **Cycle**	% Cycle	% Cycle	% **Cycle**	% Cycle	% Cycle	% **Cycle**	% Cycle	% Cycle	% **Cycle**	% Cycle	% Cycle	% **Cycle**	% Cycle	% Cycle
R	Phase (shift)	**47**	+7	0	**52**	0	-4	**63**	-48	-11	**52**	+39	+35	**73**	-43	-18
L	Phase (shift)	**53**	+4	-21	**60**	+2	-28	**55**	-33	-22	**58**	+7	+18	**46**	n.a.	-7

Table 3. Muscle activation mean

	VAM			RF			BFCL			TA			GAL		
Condition	**Snow**	SkiM.	SkiE.	**Snow**	SkiM.	SkiE	**Snow**	SkiM.	SkiE.	**Snow**	SkiM.	SkiE.	**Snow**	SkiM.	SkiE.
Measure	%	Δ%	Δ%	%	Δ%	Δ%	%	Δ%	Δ%	%	Δ%	Δ%	%	Δ%	Δ%
Unit	**MVC**	Snow	Snow	**MVC**	Snow	Snow	**MVC**	Snow	Snow	**MVC**	Snow	Snow	**MVC**	Snow	Snow
Grand mean activation	**76.0**	-14.4	-26.6	**35.8**	+11.2	-9.3	**51.9**	-55.9	-85.0	**52.5**	-40.8	-58.2	**98.0**	-68.7	-80.4

4. Discussion

First of all, it is relevant to notice that functional values of EMG activity collected during skiing can reach higher values than those collected during the MVC, as shown in literature [6]. This happened also in the present study, on some muscles of subject 1, as it can be seen from Table 1 and could have affected the large variability of some results. Data collected from subject 2, in fact, are more consistent between both limbs and between conditions too.

In most muscles the peaks of activation appear close to the middle of the cycle: it means that muscles of the leg of interest are doing the greatest effort while the limb is performing an external turn, according with previous studies [2]. This is always true for both subjects for muscles VAM and RF. Despite the last statement it has to be said that subject 2 showed also peaks of activation during internal turns, in some cases higher than those during external turns: this is probably related to his personal skiing technique.

Going further in the analysis of peak EMG values, it is possible to say that in both training devices the muscle patterns of activation have similar behaviors, especially for VAM and RF: this can be confirmed looking at the phase shift values. Peaks of activation, indeed, for both the training devices occur very close (in %) to the peaks collected in skiing on snow, and this can be taken as a positive evaluation of such devices.

At the same time it is difficult to find some common trends on the other muscles because of a greater variability; a higher mean activation for the control condition seems the general trend for such muscles. A possible interpretation of such plots can be found in the fact that the slalom tests and the corresponding simulation were demanding a mild effort level to the subjects: more clear trends would have been collected on racing slalom courses.

EMG signals recorded during control condition present high values of the mean activation during the cycle, as mentioned before. Muscles with a mean activation value closer to the control condition are again VAM and RF for both conditions, whereas the largest differences can be found in the activation of GAL and BFCL.

All muscles are less activated during the exercise on Skier's Edge® than on Skimagic® and the difference is quite big if compared to control condition. This could be due to different factors: a lower effort than the one performed during skiing because of the set-up and the lower vibration levels introduced from external environment (snow and treadmill respectively) that can affect muscles.

In fact the EMG activity produced by flexors in Skier's Edge® is very low: this is because the plyometric return after the first phase of pushing is mainly passive and performed by the elastic straps of the device.

For all these reasons the difference with the control condition (skiing on snow) expressed in terms of total muscle activity resulted to be -39.6% on the Skimagic® treadmill and -56.7% on the Skier's Edge® . These data can provide information basically about muscles training.

Further investigation will be focused on collecting kinematics and kinetics data to estimate values of forces and torques at knee joints during skiing on these simulators. These additional analyses will help in better characterizing the devices, looking at their efficacy not only in term of patterns of muscle activation but also in term of articular loads. This could be of interest in the choice of suitable rehabilitative devices for athletes who sustained knee injuries.

Acknowledgements

Lift facilities of Dolomiti Superski-Faloria [www.dolomitisuperski.it] area and Alterego srl [www.skimagic.it]

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