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# Comparative Analysis of Lower limb sEMG and Kinematics in Skiing Simulator with Exoskeleton Knee Support: Case study

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## 1. Introduction

Exoskeletons, wearable machine devices designed to reduce strain on joints, play a crucial role in sports such as skiing, where lower extremity injuries are prevalent (Blanco et al., 2019). Among skiers, knee injuries are particularly common, representing approximately 6.4% to 17% of all reported injuries, with ACL injuries accounting for 50% of knee-related issues (Escarpe et al., 2019). The dynamic nature of skiing, characterized by high-velocity movements, significantly increases the risk of lower limb injuries, which not only impact performance but also pose substantial challenges for athletes in terms of recovery and overall well-being.

The act of skiing involves complex interactions between muscle groups, particularly during turns, where muscle activation patterns vary based on the technical level of the skier, thus strengthening leg muscles is crucial for enabling better control and coordination during maneuvers (Moon et al., 2015). By optimizing muscle activation patterns and movement mechanics, skiers can achieve smoother and more efficient performance. Exoskeletons devices are designed to assist these muscle groups by reducing the load on the joints and potentially altering muscle activation patterns (Blanco et al., 2019). This study, therefore, explores the surface electromyography (sEMG) and kinematics patterns for an intermediate skier during ski movements with and without the aid of the Ski-Mojo exoskeleton device, aiming for a better understanding of the capabilities and limitations of this devices in ski.

## 2. Methods

An intermediate-level skier, participated in the study. The ski simulator (Pro Ski Simulator, P-Type Model) was used to replicate skiing motions. The intensity was standardized to level four using rubber straps. Kinematic of trunk and lower limb joints were measured by inertial measurement units (MVN BIOMECH Awinda, Xsens Technologies) and sEMG measurements were collected using b sensors, with a sampling rate of 2100 Hz for the Rectus femoris (RF), vastus lateralis (VL), tibialis anterior (TA), biceps femoris (BF), semitendinosus (SM), and lateral gastrocnemius (LG). Due to the symmetry of the movement, sEMG measurements were taken from the left leg only. The experimental procedure consisted of a warm-up, and a main exercise session. The motion was performed as a full carving ski turn on both sides, repeated 5 times per trial, with a 1-minute rest period between each randomized trial, both with and without the Exoskeleton.

Data post-processing included sEMG noise filtering using a 300 ms root-mean-square window, followed by a normalization relative the exoskeleton-free test's maximal activation (Albertus-Kajee et al. 2011). Motion segmentation on the ski simulator was based on foot orientation along the x-axis, with the simulator's center position as the reference point. The carving phases from top-right-top and top-left-top were labeled as P1 and P2, respectively (Figure. 1).

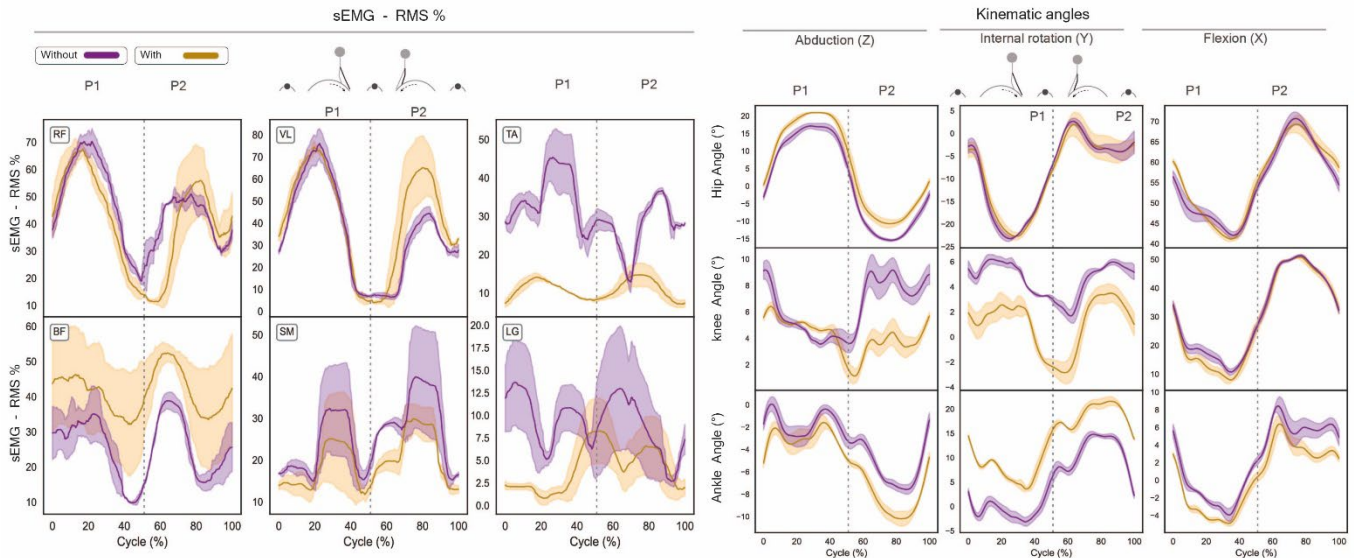
## 3. Results and discussion

The sEMG patterns (Figure 1.a) show the comparison with and without exoskeleton during movement. Throughout all skiing phases, the RF and VL exhibited the highest activation during P1, playing a crucial role in knee stability (Moon et al., 2015). The introduction of the exoskeleton led to more uniform muscle activation patterns, with increased activation observed in the BF and VL, possibly due to unfamiliarity with the device. During P1 and P2 phases, the TA demonstrated expected activation, responsible for lifting the left foot and maintaining ankle stability, with a 71% reduction in activation when using the device. Meanwhile, the LG contracted to flex the ankle and provided stability to the left foot extended outward during P1, with a 59% reduction in activation.

Moreover, the effect of the exoskeleton on range of motion (ROM) and peak angle was analyzed for each joint (Figure 1.b). In the sagittal plane, knee flexion ROM increased by 5% with the exoskeleton, with a minor peak during P2, while ankle ROM decreased by 9%, also showing a minor peak (Table 1). In the coronal plane, exoskeleton use led to a 13% increase in

ankle abduction ROM and a 3% reduction in hip abduction.

load on the outer leg during turns. Notably, the exoskeleton reduced muscular activity in TA, LG, and



**Figure 1** Comparison of mean lower limb joint angles and sEMG muscles (standardized root mean square) across trials, including  $\pm$  standard deviation, with and without exoskeleton.

**Table 1.** Mean  $\pm$  std of sEMG and Maximum Joint Angles ( $^{\circ}$ ) with/without Exoskeleton.

		Mean $\pm$ std				
		With		Without		
		P1	P2	P1	P2	
sEMG (RMS %)	RF	45.87 $\pm$ 17.49	35.03 $\pm$ 15.87	50.79 $\pm$ 16.44	40.17 $\pm$ 8.4	
	VL	47.1 $\pm$ 22.68	36.78 $\pm$ 21.99	46.14 $\pm$ 22.76	24.46 $\pm$ 14.06	
	TA	10.96 $\pm$ 2.05	11.12 $\pm$ 2.66	34.88 $\pm$ 6.88	27.39 $\pm$ 6.14	
	BF	40.13 $\pm$ 4.93	42.37 $\pm$ 6.59	25.18 $\pm$ 8.84	25.7 $\pm$ 8.49	
	SM	17.74 $\pm$ 4.84	21.59 $\pm$ 5.98	22.43 $\pm$ 6.66	29.24 $\pm$ 7.81	
	LG	2.9 $\pm$ 2.26	5.34 $\pm$ 1.86	9.81 $\pm$ 2.60	8.59 $\pm$ 3.27	
		Max				
Joint angle ( $^{\circ}$ )	Z	Hip	20.94	11.12	17.12	6.46
		Knee	6.42	5.69	9.17	9.17
		Ankle	-1.59	-4.69	0.05	-1.35
Y	Hip	-3.51	1.95	-2.62	2.64	
	Knee	2.55	3.49	6.19	5.98	
	Ankle	14.72	21.59	5.28	14.79	
X	Hip	60.21	69.3	56.43	70.71	
	Knee	33.75	50.74	34.13	51.27	
	Ankle	2.97	6.39	5.62	8.43	

#### 4. Conclusions

The presented study investigated the impact of an exoskeleton on muscle activation patterns and kinematic variables during skiing movements. Analysis revealed that muscle activation in the RF, VL, TA, and LG muscles followed expected patterns, with P1 exhibiting the highest activation due to increased

SM stabilizing muscles during P1 while promoting smoother and more coordinated patterns in both sEMG and kinematic variables.

Regarding kinematics, the exoskeleton showed similar movement patterns to those without it, but with a corrected range of values closer to those of professional skiers (Jeong-yoon et al., 2014). Considering that professional skiers exhibit greater range of motion (ROM) in joint angles than beginner skiers (Moon et al., 2015), this indicator could demonstrate the role of the exoskeleton in improving technique. Indeed, the reduction in the maximum internal rotation angle was approximately 45% during P1 when the leg is in an extended position. This result is particularly significant in addressing the risk of ACL injury associated with hyperextension internal rotation.

Further research should involve more athletes to establish muscle activation and kinematic patterns throughout skiing motion. Additionally, the exploration of exoskeleton use in real skiing environments under more demanding conditions remains largely unexplored, being of interest for injury prevention and performance improvement.

#### Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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