HOW CAN XSENS KINEMATIC SUIT ADD TO OUR UNDERSTANDING OF A SLALOM TURN: A CASE STUDY IN LABORATORY AND FIELD CONDITIONS

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Abstract:

Traditionally used methods for kinematic analysis of alpine skiing has limitations regarding data collecting and data processing. Also, analysis of measured parameters, interpretation, and implementation to practice are postponed. Therefore, aim of this paper was to determine differences in the performance of slalom turns between three conditions using a relatively new technology that allows fast data collecting and analysis. Twenty kinematic variables were analysed for each turn (both the left and right) and 26 turns were executed in each condition. All turns were performed by a national skiing demonstrator. Differences were determined by MANOVA (F=71.3; p=.00). Tukey's *post-hoc* test showed that the turns performed on the ski simulator differed in every variable from the turns performed in other two condition, and the free skiing turns differed from the corridor turns in the following variables: hip joint angle of abduction of the right leg in the left turn, p=.00; distance of the projection of the centre of mass relative to the right foot in the left turn, p=.00; hip joint angle of flexion of the left leg in the left turn, p=.02; hip joint angle of abduction of the left leg in the left turn, p=.01; distance of the projection of the centre of mass relative to the left foot in the left turn, p=.00; knee angle of flexion of the left leg in the right turn, p=.04). The kinematic parameters obtained using the XSENS suit during slalom turns performed on the ski simulator and ski slope suggested significant differences in the position of the lower extremities, which might be important for situational efficiency and technical performance. Our results can be used to improve the alpine skiing technique. They suggest more precise relations between space parameters, such as body position and the angles between different body segments during a slalom turn. Methodology of research and technology used could contribute to the development of new scientific approaches in biomechanical research of top-level sports.

Key words: *alpine skiing, kinematic analysis, kinematic suit, model values, ski simulator*

Introduction

On a professional level, slalom is a complex and demanding sport. Advances in ski equipment and snow preparation methods have led to more effective training and improved skiers' performance, so now the margins between the times that ensure victory are just hundredths of a second apart (Supej & Holmberg, 2019). As a skier needs to constantly adapt to changes in terrain, gate setup, slope, and snow conditions, and at the same time to be able to perform at his/her best, precise and detailed biomechanical analyses of different kinematic and kinetic factors and their incorporation in training are needed (Federolf, 2012; Hébert-Losier, Supej, & Holmberg, 2014; Spörri, Kröll, Schameder & Müller, 2018; Supej, et al., 2013; Supej, Hebert-Losier, & Holmberg, 2015). Already demanding biomechanical analyses are further burdened by the differences between turning techniques, the inter-dependency of turns, as well as by tactics and ski equipment (Chardonnens, Favre, Gremion, & Aminian, 2010; Cigrovski & Matković, 2015; Hydren, Volek, Maresh, Comstock, & Kraemer, 2013; Spörri, Kröll, Schwameder, & Müller, 2012).

Traditionally, the mentioned analyses were done using camcorder-based 3D measurements, which were not only time consuming but also insufficiently accurate. Another important limitation related to the fixed positioning of a camera was a low volume of gathered data (Antekolović, Cigrovski, & Horgas, 2015). Moreover, due to terrain configurations, cameras were sometimes difficult to position, and errors of up to 20 cm during 3D reconstructions could had been expected (Nachbauer, et al., 1996).

Although the knowledge on biomechanics of alpine skiers has improved in the recent years, little is yet known concerning the optimization of performance over an entire ski course (Hébert-Losier, et al., 2014). Recent advances in the global navigation satellite system (GNSS) technology allow a more precise biomechanical analysis of performance over an entire course and in real-time (Gilgien, et al., 2015; Supej, 2012; Supej, Kugovnik, & Nemec, 2008). The problem that still exists with the use of GNSS in the alpine skiing is in finding and matching a true location of the centre of mass (Gilgien, et al., 2015; Sporri, Kröll, Fasel, Aminian, & Müller, 2016). Therefore, combining inertial motion sensors with the GNSS improves data gathering and allows recording of the 3D body kinematics over an entire race course, thus providing accurate on-snow kinematic values (Brodie, Walmsley, & Page, 2008; Fasel, Sporri, Schutz, Lorenzetti, & Aminian, 2017; Krüger & Edelmann-Nusser, 2010; Supej, 2010), and enables monitoring of technique, performance, tactics, and training load (Heikenfeld, et al., 2018).

Off-season conditioning trainings for alpine skiing are important and previous investigation reports benefits of a ski simulator (Lee, Roh, & Kim, 2016; Moon, et al., 2015; Panizzolo, Marcolin, & Petrone, 2013). Müller, Benko, Raschner, and Schwameder (2000) developed a specific Ski Power Simulator (SPS), based on an analysis of top-level alpine skiers, which produces similar patterns of ground reaction forces and knee kinematics to that of a slalom turn on an actual ski slope. In our previous work we have seen benefits of a ski simulator for the development of motor abilities crucial for alpine skiing (Matković, Bon, Dukarić, Rupčić, & Cigrovski, 2017). The mentioned is explained by the in-simulator activation of muscles and ligaments of the lower extremities being similar to the musculature activation during alpine skiing (Moon, et al., 2015). Additionally, ski simulators are used during pre-season training to prevent possible injuries later, during ski season (Turnbull, Kilding, & Keogh 2009). While training on a ski simulator, a skier can perform specific movements similar to those performed during alpine skiing (Lee, et al., 2016; Nourrit-Lucas, Tossa, Zélic, & Delignières , 2015), and sometimes ski poles can be used while training on a simulator, which augments reality-based simulation and adds additional resemblance to alpine skiing (Moon, et al., 2015). But to be able to better understand the relationship between training load on a ski simulator and its influence on results in competitive alpine skiing as well as on skiers' health, more precise methods of kinetics and kinematic estimations are essential.

In this research, we tried to objectively determine positions of body segments that are systematically followed and analysed using the XSENS inertial suit during slalom training in order to improve skier's technique .The suit is increasingly used in the setting of different winter sports. Moreover, data gathered by the XSENS suit add additional accuracy. According to Supej (2009), the accuracy of the GPS measurement was at the level of 1 cm horizontal and 2 cm vertical and 0.5° in the 3D orientation.

The primary aim of the study was to define kinematic parameters of a slalom turn execution in different conditions; that is, while skiing on a ski terrain in a predefined corridor and during free skiing as well as in the laboratory conditions simulated ski terrain. We hypothesized similar relations between different body segments in predefined positions on a ski simulator and during slalom turns performed on a real ski terrain, either within the corridor or during free skiing.

Methods

Participants. The participant was a 25.1 years old female alpine ski demonstrator and previous national team member who voluntarily agreed to participate after being informed about aims and protocol of the investigation. During the investigation, her body weight was 57 kg and height 164 cm.

Variables. For the purposes of this investigation 20 variables for each slalom turn (right and left), performed during three distinct situations – on a ski simulator, during free skiing, and in a predefined corridor, were analysed. Overall, 78 turns were analysed, 26 in each condition, 13 to the left and 13 to the right side.

The measured kinematic parameters included angles in joints of the lower extremities (ankle, knee, hip) in degrees (°) as well as distance between the projection of the centre of body mass (CoM) and the inner and outer foot in relation to the axis of turn rotation in centimetres (cm).

The measured variables were*:* ankle joint angle of flexion of the left leg in the right turn (RL_ANKLE_F); ankle joint angle of flexion of the right leg in the right turn (RR_ANKLE_F); ankle joint angle of flexion of the left leg in the left turn (LL_ANKLE_F); ankle joint angle of dorsiflexion of the right leg in the left turn (LR_ANKLE_F); knee angle of flexion of the left leg in the right turn (RL_KNEE_F); knee angle of flexion of the right leg in the right turn (RR_KNEE_F); knee angle of flexion of the left leg in the left turn (LL_KNEE_F); knee angle of flexion of the right leg in the left turn (LR_KNEE_F); hip joint angle of flexion of the left leg in the right turn (RL_HIP_F); hip joint angle of flexion of the right leg in the right turn (RR_HIP_F); hip joint angle of flexion of the left leg in the left turn (LL_HIP_F); hip joint angle of flexion of the right leg in the left turn (LR_HIP_F); hip joint angle of abduction of the left leg in the right turn (RL_HIP_AB); hip joint angle of abduction of the right leg in the right turn (RR_HIP_AB); hip joint angle of abduction of the left leg in the left turn (LL_HIP_AB); hip joint angle of abduction of the right leg in the left turn (LR_HIP_AB); distance of the projection of the centre of mass relative to the left foot in the right turn (RCOM_L); distance of the projection of the centre of mass relative to the right foot in the right turn (RCOM_R); distance of the projection of the centre of mass relative to the left foot in the left turn (LCOM_L); distance of the projection of the centre of mass relative to the right foot in the left turn (LCOM_R).

Protocol of investigation. Kinematic parameters were measured by MVN BIOMECH XSENS kinematic suit. The MVN BIOMECH XSENS inertial suit consists of seventeen wireless motion trackers, battery, and has a 240 Hz output rate. It ensures real-time human motion analysis without an effect on the movement or rate of motion. After dressing the suit and adjusting the sensors, calibration of the system was performed while a skier was in ski equipment according to the standards of procedure advised by the manufacturer (Xsens technologies B.V., The Netherlands). The skier stood quietly in the N-position (feet parallel hip-width, body in upright position, arms down the body) for 10-15 seconds and then started walking forwards 5-7 metres, turned around and returned to the starting N-position for another 10-15 seconds to finish the calibration. The participant performed turn simulations on a Pro ski up simulator (Figure 1). The ski simulator, fixed to a flat surface, consisted of a platform on wheels, which moved sideways along two bowed parallel metal rails. The simulator has an option of adjustable resistance, which is accomplished by adding springs. Matching number of springs, located on the simulator basis, are attached to a cart on which the subject is standing. Springs fasten the wheeled platform to the rails and ensure it regains resting position in the middle of the apparatus. There are six levels of resistance each matching a particular body weight of an athlete, that is, one spring equals certain weight interval. In this case resistance of two springs was used, which matched weight interval from 50 to 65 kg. After dressing the suit and adjusting the sensors, calibration of the system was performed, and the participant performed simulations of a slalom turn to each side. The participant received detailed instructions on how to imitate rhythm and pace of a real slalom turn.

Kinematic parameters of a ski turn were measured during free skiing and while skiing in a defined ski corridor on the same terrain. Measurements were done during morning hours due to lower temperature and better snow conditions. The participant dressed the kinematic suit in the hotel and got to the ski terrain fully equipped. System calibration was performed according to the previously described protocol before taking a ski lift. Once again, the participant received detailed information about the characteristics of slalom turns she was expected to perform. Corridor was three metres wide (Figure 2). Each slalom turn had to be performed from the left to the right end of the corridor, and vice versa, exclusively on the ski edge. Altogether 26 turns were included in the final analysis (a few starting and ending ones were excluded). The reason for the mentioned was the time the skier needed to achieve rhythm and tempo characteristic for dynamic execution of slalom turns. Equipment (type of skies) was identical during free skiing and skiing down the predefined corridor.

The gates in the corridor were set according to the FIS rules, on the same terrain where the participant previously performed her free slalom ride. The start gate and the end gate were virtually connected by a shortest fall line. The first slalom gate was positioned 10 metres after the start, and 1.5 metres from the fall line. Every following gate was 10 metres apart to the opposite side from the fall line. There were 30 slalom gates and overall, 26 turns were analysed. The corridor slalom trail was composed of exclusively right and left turns, so that tempo and rhythm resembled those executed on the ski simulator and during a free slalom ride. The participant was asked to perform slalom turns in the predefined corridor as if in a slalom run (Figure 3). A few initial and finishing turns were excluded from the analysis due to the already mentioned reasons.

Data processing. Statistical package Statistica, version 13.3, was used for data analysis. Calculated were basic descriptive parameters for all 20 variables. MANOVA was used to determine the differ-

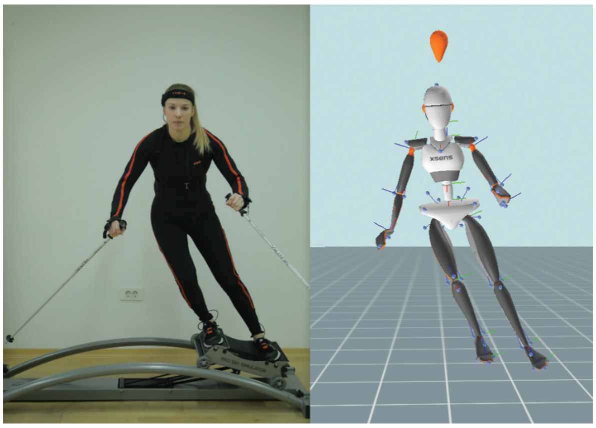

Figure 1. The participant during testing on the pro ski up simulator.

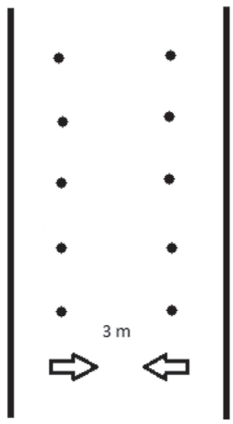

Figure 2. Corridor in which the participant performed slalom turns during free skiing.

ences in slalom turns between the three different conditions. In order to test the differences between the groups in each variable, the Tukey's *post-hoc* test was performed. Results were considered significant if p<.05.

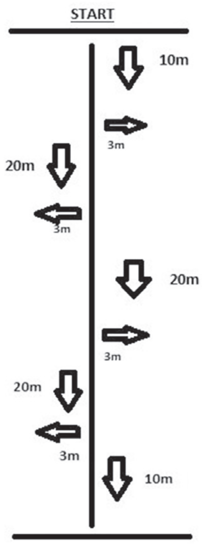

Figure 3. Defined slalom corridor for the purposes of the investigation.

Results

Descriptive parameters are shown in Table 1. Additionally, results of MANOVA are also presented, with statistically significant differences between all 20 variables (p=.00).

In Table 2, the results of MANOVA are presented, showing the differences between the turns performed on either the ski simulator, during free skiing, or in the defined corridor run.

The differences in turns between the three conditions were statistically significant (F=71.3; p=.00). The results of the Tukey's *post-hoc* test are presented in Table 3.

Table 2. Results of MANOVA for slalom turns in three different situations

	Test	Lambda	F	p
Criteria	Wilk's	0.000139	71.3	0.00*

Table 1. Basic descriptive parameters and results of MANOVA for the analysed variables in three different situations slalom turns were performed (ski simulator, free ride, corridor run)

Variables	Ski simulator M±SD	Free skiing M±SD	Corridor run M±SD	F	p
LR_KNEE_F	164.53±2.86	132.40±8.64	127.70±3.08	170	.00
LR_ANKLE_F	84.79±0.64	68.80±4.72	66.91±3.67	104	.00
LR_HIP_F	158.31±3.26	149.10±5.06	146.86±3.53	29	.00
LR_HIP_AB	159.96±1.11	162.46±2.61	157.64±2.71	15	.00
LCOM_R	33.72±1.08	60.21±1.51	68.15±2.30	1453	.00
LL_KNEE_F	113.78±1.82	97.83±5.30	96.96±4.48	68	.00
LL_ANKLE_F	61.54±0.94	76.19±3.14	77.54±2.05	205	.00
LL_HIP_F	128.51±2.05	109.63±5.51	105.49±2.47	144	.00
LL_HIP_AB	189.86±7.07	182.97±3.38	177.05±3.52	22	.00
LCOM_L	7.63±3.24	25.27±2.20	29.69±3.58	188	.00
RL_ANKLE_F	78.44±0.99	77.04±3.81	74.83±3.36	5	.01
RL_HIP_F	154.06±2.74	146.68±4.52	144.96±3.91	21	.00
RL_HIP_AB	153.38±1.51	163.96±2.33	165.54±2.71	114	.00
RCOM_L	36.07±0.86	67.40±5.75	63.98±3.71	242	.00
RR_KNEE_F	120.99±1.44	90.74±10.73	94.77±5.69	70	.00
RR_ANKLE_F	67.57±1.32	71.60±2.66	72.67±2.18	21	.00
RR_HIP_F	132.51±5.92	108.44±8.17	109.22±4.96	58	.00
RR_HIP_AB	195.45±1.22	175.94±2.80	127.70±3.19	230	.00
RCOM_R	10.28±1.02	34.98±4.36	66.91±2.91	288	.00
RL_KNEE_F	153.44±2.29	142.24±6.79	146.86±6.16	31	.00

Note. RL_ANKLE_F – ankle joint angle of flexion of the left leg in the right turn; RR_ANKLE_ – ankle joint angle of flexion of the right leg in the right turn; LL_ANKLE_F – ankle joint angle of flexion of the left leg in the left turn; LR_ANKLE_F – ankle joint angle of dorsiflexion of the right leg in the left turn; RL_KNEE_F – knee angle of flexion of the left leg in the right turn; RR_KNEE_F – knee angle of flexion of the right leg in the right turn; LL_KNEE_F – knee angle of flexion of the left leg in the left turn; LR_KNEE_F – knee angle of flexion of the right leg in the left turn; RL_HIP_F – hip joint angle of flexion of the left leg in the right turn; RR_HIP_F – hip joint angle of flexion of the right leg in the right turn; LL_HIP_F – hip joint angle of flexion of the left leg in the left turn; LR_HIP_F – hip joint angle of flexion of the right leg in the left turn; RL_HIP_AB – hip joint angle of abduction of left leg in right turn; RR_HIP_AB – hip joint angle of abduction of the right leg in the right turn; LL_HIP_AB – hip joint angle of abduction of left leg in left turn; LR_HIP_AB – hip joint angle of abduction of the right leg in the left turn; RCOM_L – distance of the projection of the centre of mass relative to the left foot in the right turn; RCOM_R – distance of the projection of the centre of mass relative to the right foot in the right turn; LCOM_L – distance of the projection of the centre of mass relative to the left foot in the left turn; LCOM_R – distance of the projection of the centre of mass relative to the right foot in the left turn.

Table 3. Results of Tukey's post-hoc test for all variables in three different conditions (1 – ski simulator, 2 – free skiing, 3 – defined corridor)

RL_KNEE_F				LR_KNEE_F			
Group	1(153.44)	2(142.24)	3(136.90)	group	1(164.53)	2(132.40)	3(127.70)
1		0.00*	0.00*	1		0.00*	0.00*
2	0.00*		0.04*	2	0.00*		0.09
3	0.00*	0.04*		3	0.00*	0.09	
RL_ANKLE_F				LR_ANKLE_F			
Group	1(78.44)	2(77.04)	3(74.83)	group	1(84.79)	2(68.80)	3(66.91)
1		0.46	0.01*	1		0.00*	0.00*
2	0.46		0.16	2	0.00*		0.36
3	0.01*	0.16		3	0.00*	0.36	
RL_HIP_F				LR_HIP_F			
Group	1(154.06)	2(146.68)	3(144.96)	group	1(158.31)	2(149.10)	3(146.86)
1		0.00*	0.00*	1		0.00*	0.00*
2	0.00*		0.49	2	0.00*		0.34
3	0.00*	0.49		3	0.00*	0.34	
RL_HIP_AB				LR_HIP_AB			
Group	1(153.38)	2(163.96)	3(165.54)	group	1(159.96)	2(162.46)	3(157.64)
1		0.00*	0.00*	1		0.02*	0.03*
2	0.00*		0.18	2	0.02*		0.00*
3	0.00*	0.18		3	0.03*	0.00*	
RCOM_L				LCOM_R			
Group	1(36.07)	2(67.40)	3(63.98)	group	1(33.72)	2(60.21)	3(68.15)
1		0.00*	0.00*	1		0.00*	0.00*
2	0.00*		0.09	2	0.00*		0.00*
3	0.00*	0.09		3	0.00*	0.00*	
RR_KNEE_F				LL_KNEE_F			
Group	1(120.99)	2(90.74)	3(94.77)	group	1(113.78)	2(97.83)	3(96.96)
1		0.00*	0.00*	1		0.00*	0.00*
2	0.00*		0.32	2	0.00*		0.86
3	0.00*	0.32		3	0.00*	0.86	
RR_ANKLE_F				LL_ANKLE_F			
Group	1(120.99)	2(71.60)	3(72.67)	group	1(61.54)	2(76.19)	3(77.54)
1		0.00*	0.00*	1		0.00*	0.00*
2	0.00*		0.41	2	0.00*		0.28
3	0.00*	0.41		3	0.00*	0.28	
RR_HIP_F				LL_HIP_F			
Group	1(132.51)	2(108.44)	3(109.22)	group	1(128.51)	2(109.63)	3(105.49)
1		0.00*	0.00*	1		0.00*	0.00*
2	0.00*		0.95	2	0.00*		0.02*
3	0.00*	0.95		3	0.00*	0.02*	
RR_HIP_AB				LL_HIP_AB			
Group	1(195.45)	2(175.94)	3(177.96)	group	1(189.86)	2(182.97)	3(177.05)
1		0.00*	0.00*	1		0.00*	0.00*
2	0.00*		0.12	2	0.00*		0.01*
3	0.00*	0.12		3	0.00*	0.01*	
RCOM_R				LCOM_L			
Group	1(10.28)	2(34.98)	3(34.98)	group	1(7.63)	2(25.27)	3(29.69)
1		0.00*	0.00*	1		0.00*	0.00*
2	0.00*		0.77	2	0.00*		0.00*
3	0.00*	0.77		3	0.00*	0.00*	

Note. RL_ANKLE_F – ankle joint angle of flexion of the left leg in the right turn; RR_ANKLE_ – ankle joint angle of flexion of the right leg in the right turn; LL_ANKLE_F – ankle joint angle of flexion of the left leg in the left turn; LR_ANKLE_F – ankle joint angle of dorsiflexion of the right leg in the left turn; RL_KNEE_F – knee angle of flexion of the left leg in the right turn; RR_KNEE_F – knee angle of flexion of the right leg in the right turn; LL_KNEE_F – knee angle of flexion of the left leg in the left turn; LR_KNEE_F – knee angle of flexion of the right leg in the left turn; RL_HIP_F – hip joint angle of flexion of the left leg in the right turn; RR_HIP_F – hip joint angle of flexion of the right leg in the right turn; LL_HIP_F – hip joint angle of flexion of the left leg in the left turn; LR_HIP_F – hip joint angle of flexion of the right leg in the left turn; RL_HIP_AB – hip joint angle of abduction of left leg in right turn; RR_HIP_AB – hip joint angle of abduction of the right leg in the right turn; LL_HIP_AB – hip joint angle of abduction of left leg in left turn; LR_HIP_AB – hip joint angle of abduction of the right leg in the left turn; RCOM_L – distance of the projection of the centre of mass relative to the left foot in the right turn; RCOM_R – distance of the projection of the centre of mass relative to the right foot in the right turn; LCOM_L – distance of the projection of the centre of mass relative to the left foot in the left turn; LCOM_R – distance of the projection of the centre of mass relative to the right foot in the left turn. * p<.05

According to the results, slalom turns performed on the ski simulator differed statistically significantly in all kinematic parameters from the turns performed during free skiing and skiing in the predefined corridor (p=.00). Additionally, we found significant differences in the following variables: LR_HIP_AB, p=.00; LCOM_R, p=.00; LL_HIP_F, p=.02; LL_HIP_AB, p=.01; LCOM_L, p=.00; RL_KNEE_F, p=.04, between the free slalom turns and slalom turns in the defined corridor.

Discussion and conclusion

In order to gain a better understanding of the kinematics of a slalom turn during training and actual skiing, an accurate and precise estimation of the athlete's kinematics is an essential prerequisite (Soligard, et al., 2016). First, it is important to emphasize that in the present study we analysed variables during the same position of the skier in all three conditions, while the participant's skies were parallel with the ski slope (fall line). This is the exact moment where skies are farthest apart from the projection of the CoM and it represents the central point of a turn. At the ski simulator this is the point in which feet are in the most distant position from the projection of the CoM. Using the XSENS kinematic suit we were able to record the whole ski run in the defined corridor and whole duration of a free skiing on the same terrain. Accuracy of the recording adds to a high reliability of results seen in a similar study (Supej, et al., 2008; Supej, 2009). Moreover, the results of the kinematic analysis are readily available and enable fast and efficacious transfer of objectively recorded data to the ski teams (Heikenfeld, et al., 2018).

Compared to the inertial sensor-based method, where marker-based optoelectronic motion capture system with attachable sensors is used, the XSENS suit in its current form does not interfere with the athlete's movements and is completely non-invasive. When this is compared to the results presented by Fasel et al. (2017), who measured the ski turn by the inertial sensor-based method and therefore had to account for errors caused by sensors' displacement due to muscle tissue artefacts produced during a turn, XSENS is a more precise method for estimating both athletes' joint positions and the position of the CoM kinematics during a slalom turn (Gilgien, et al., 2015). Our results support the differences between the slalom turn performed on a ski simulator and those performed during free skiing and skiing in the predefined corridor. Determined differences in the variables regarding distance of the projection of the CoM with respect to the outer and inner leg are especially important from the aspect of ski technique quality. If the turn is executed technically sound, the skier establishes support through the ski on a snowy surface dominantly on the outer leg in relation to the axis of rotation of the turn (Ferguson, 2009). To be successful and at the same time to resist the force acting on him/her during the turn, a skier must maximally distance the outer leg from the projection of the centre of gravity (Reid, et al., 2009). We reported an average distance of the projection of the CoM from the outer foot on a ski simulator to be shorter by 30.7 cm in the right turn and by 26.49 cm during the left turn compared to those measured while free skiing. Similar differences were noted also when the turns performed on the simulator were compared to those performed during skiing in the predefined corridor (right turn=34.43 cm, left turn 27.91 cm). The mentioned can be explained by the construction characteristics of the ski simulator, which limited movements. Namely, the CoM is closer to the outer leg while performing ski turns on a simulator, but also to the inner leg when compared to skiing on an actual slope (Moon, et al., 2015). An average distance of the CoM from the outer foot was LCOM_R=33.72; RCOM_L=36.07 during a simulated ski turn. Values of the same variables were much higher during free skiing (LCOM_R=60.21; RCOM_L=67.40), as well as while skiing in the predefined corridor (LCOM_R=68.15; RCOM_L=63.98). Similar results were published by Mani and co-authors (2014), who explained them by the changes in the activation of postural muscles, which resulted from the need to promptly change the direction due to specificity of a ski terrain or snow conditions. Similarly, Panizzolo and co-workers (2013) point to the differences between ski simulator turns and turns on a ski terrain, primarily related to equipment and training methods. We additionally found the differences between the angle of abduction in the right hip joint during the left turn and the left hip joint during the right turn in all three conditions. The smallest angle was recorded for a turn on the ski simulator (153.38°, 159.96°). Mentioned lateral deflections are responsible for achieving the optimal balanced position of legs with respect to the CoM and are important for the initiation of the next turn (Gilgien, Sporri, Kroll, Crivelli, & Muller, 2014).

According to Fasel and co-workers (2017), who used the inertial sensor-based method to estimate the athlete's relative joint positions and CoM kinematics in alpine skiing, the displacement of attachable sensors led to measurement errors especially seen in knee joints that were 3-4 times higher than for the hip joint position estimates. The mentioned is probably explainable by soft tissue artefacts of the thigh since it is known that, during a turn execution, the inner leg, although it bears less force, has higher flexion angles in the hip and knee (Kroll, Sporri, Fasel, Muller, & Schwamader, 2015).

Additionally, we found differences between kinematic parameters of the slalom turn executed in the predefined corridor and during a free ride (LR_

HIP_AB, p=.00; LCOM_R, p=.00; LL_HIP_F, p=.02; LL_HIP_AB, p=.01; LCOM_L, p=.00; RL_KNEE_F, p=.04). Especially interesting are the differences between the conditions in the abduction angle of the right leg during the left turn (free ride – LR_HIP_AB=162.46; predefined corridor – LR_HIP_AB=157.64) and in distance between the projection of the CoM during the left turn with respect to the right foot (free ride – LCOM_R=60.21; predefined corridor – LCOM_R=68.15). As previously mentioned, support on the outer leg is essential for the slalom turn execution (Nourrit-Lucas, et al., 2015). Although the participant was encouraged to ski at the same pace and rhythm in both the predefined corridor and free ride, it is evident that she adjusted her skiing to the conditions on the slope, depending on the phase of a turn, speed and steepness in order to maintain balance. When skiing in the predefined corridor, a skier needs to adjust skiing to the gates, which determine his/her rhythm and pace. It is of utmost importance to adjust body position in a way that leads to the optimal moment for the turn initiation. In the predefined corridor, due to the set rhythm through gates, the burden on the outer ski was higher, leading to a greater angle between the upper body and upper leg. On the other hand, while free skiing, a skier adjusted her position according to the slope requirements (Kipp, Reid, Gilgien, Haugen, & Smith, 2010). Although lengths of turns were almost the same in both situations, one can argue that the defined corridor imposed the turn which led to the deflection different from the deflection during free skiing. Modern competitors want to make as short a section of the circle as possible during the slalom turn, so that the path they pass through the turn is shorter (Lešnik & Žvan, 2007). During the mentioned, they try to be in a dynamic balance position on the outer leg; to be able to do so, they must make lateral deflections (LeMaster & Supej, 2013). The magnitude of the lateral deflection depends on a turn phase and skiers' speed.

In a study on slalom competitors' technique, knees angulation was used to initiate carved turns, directly followed by hips angulation to regulate inclination balance (Supej, Nemec, & Kugovnik, 2005). An analysis of short turns performed using carving skis indicated a large part of skidding by beginners, due to lower edging of the body (Vaverka & Vodickova, 2010). Finally, it has been demonstrated that faster skiers have greater angulations, greater side leaning and larger distance between skis (Hraski & Hraski, 2009). Our results in the variable distance between the CoM with respect to the outer leg, which was greater in the predefined corridor than during free skiing, support the mentioned. Slalom is a technical and demanding discipline of alpine skiing which requires learning according to a specific methodological order (Schöllhorn, Hurth, Kortmann, & Müller, 2009). Skiing technique is important for sports success and needs to be emphasized (Antekolović, et al., 2015). Moreover, relations between specific body segments need to be achieved (Hraski & Hraski, 2009). Skier tries to separate upper body movements from the lower body ones (Loland, 2009). The lower body directly influences turn performance, while the upper body contributes to turn execution by adding stability and balance during the turn (Hydren, et al., 2013). Movements in the lower body synchronously take place in several planes, and if they are executed in a timely fashion, a turn is more successful. When an error is made during turn execution, upper body parts are actively included to correct the error. If mentioned is insufficient, lower body parts are included but through this, an ideal trajectory, rhythm and speed are lost (Hebert-Losier, et al., 2014).

Ski simulators are in use by elite skiers during off-season training as an addition to conditioning training in order to maintain and/or improve functional capacities (Lee, et al., 2016). Our results suggest against ski simulator usage for the improvement or learning of slalom technique. Kinematic parameters determined through the XSENS kinematic suit point to the important differences in the positioning of lower extremities on a simulator and in terrain skiing; the mentioned is important for situational effectiveness and technical execution of a slalom turn. On the other hand, on a ski simulator skier can develop specific capabilities that are similar to those needed during terrain skiing. The mentioned includes functional (aerobic) capacities and motor abilities such as dynamic balance, coordination, and strength as well as eccentric muscle activation in lower extremities, dominant during turn executions (Hoppeler & Vogt, 2009). Moreover, a ski simulator can be used for the injury prevention purposes, in order to minimize injury risks later during competitive season (Turnbull, et al., 2009).

There are some limitations of the conducted study that we want to point out. For future investigations the sample should consist of a larger number of participants with the same level of skiing skill. That could provide stronger evidence and possibility to conclude about differences in slalom turns performed in the three observed conditions. Also, although similar lower extremities' muscles and ligaments activation can be reached in simulation, it does not fully match body movements performed while executing actual slalom turns on skies. Therefore, conclusions concerning differences in ski turn performances on an actual slope and on a ski simulator must be taken into consideration with certain precaution.

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