Comparative study of cross-country skiing on grip and skin skis

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ABSTRACT

The technology of cross-country skis for classic running is constantly evolving in the areas of ski construction or materials for ski construction. A study was focused to compare kinematic and kinetic parameters on grip and non-wax skis. Two groups of cross-country skiers participated in the with different skills quality. Kinematic and kinetic parameters of diagonal stride were observed: times of step cycle and phases, average and maximum pressure values of cycle phases. Pressure insole system was used for data collection. The Cohen size coefficient d was used. Differences between group of large effect size were found both on the flat and uphill for skiing on both types of skis (d = 0.82 - 17.26). Technically better skier showed minimal difference between skiing on both types of skis. For recreational skiers were found more differences on the uphill. Differences correspond to quality of movement patterns and ability of skiers to apply more efficiently technique on different types of skis on different type of terrain.
Keywords: Biomechanics, Ski base, Kinematics, Kinetics.

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INTRODUCTION

The technology of cross-country skis is constantly improving, and developments are being made in the areas of ski construction, materials, the ski base, as well as in new grip or gliding waxes. Thanks to these developments, skis for classical skiing, primarily for diagonal stride, have been enhanced over the last 50 years or so with a number of developments designed to facilitate waxing for recreational skiing and touring, and to improve the gliding and take-off characteristics in racing skis (Breitschädel, 2007). The evolution of cross-country skis, improving their basic properties, has been documented in many studies (e.g. Pellegrini, et al., 2018), using a large number of sophisticated devices and technologies. Hottenrot and Urban (2004) reported that technological development (66%) has had a greater contribution to performance improvement in cross-country skiing over the last 50 years or so than the actual improvement in athletes' performance (34%). This means that technology still has a lot to say in improving performance in cross-country skiing. Sintered thermoplastics have become the standard material for the ski base, which has significantly reduced the coefficient of friction (Breitschädel et al., 2010). Currently, elite skiers use 10-15 types of ski bases with specific properties for different snow conditions (Pellegrini et al., 2018). In recent years, a considerable amount of technological development has been devoted to the accurate characterization of friction in skiing, both in gliding and take-off (Breitschädel et al., 2010; Budde and Himes, 2017). The result of these efforts to improve the quality of cross-country skis for the classical technique became evident in the early 1970s, when the first skis with plastic ski bases began to be produced. Further opportunities arose to test and produce new types of ski bases which did not need grip wax for skiing up a slope, as these ski bases were fitted with so-called scales.

In the 1980s, so-called microstructure technology was developed for ski racing, which meant solving the problem of high-quality take-off in a climb without grip waxes with certain types of snow and climatic conditions and is still used in racing today. Since the beginning of the 21st century, Peltonen has been producing skis with a nanostructure on the ski base that is a form of non-waxing ski with good glide and take-off properties. In the last 6-7 years, another type of classical ski has emerged that does not need grip waxes but still has excellent take-off capabilities on all types of snow. These are the so-called skin skis, which have strips of fabric with hair (mohair) built into the take-off chamber of the ski base. Mohair is oriented in the direction of gliding and increases friction during take-off. This technology also provides a relatively good glide and is currently a very popular type of ski. This is the type of ski that is mainly used by recreational skiers who don't want to deal with grip waxes. Under certain conditions, this ski can also become a training ski for competitive cross-country skiers if waxing with grip waxes is a problem. It is used most in youth age categories. In race skiing, these skis are sometimes used under specific conditions, when waxing is a problem (high humidity, temperature around 0°C, smooth surface on the trail), under which they allow a good take-off and glide. Of course, the development of waxed skis has continued, and quite rapidly due to new technologies in ski construction, slide material and grip waxes (Swaren et al., 2014; Budde and Himes, 2017, Pellegrini et al., 2018).

Skin skis are used in diagonal stride or in double poling with kick. A number of studies have been carried out to describe the classical cross-country skiing technique from different perspectives: kinematic, kinetic, physiological, and muscle activity (Komi, 1987; Komi and Norman, 1987; Bilodeau et al., 1996; Smith et al., 1990; Bellizzi et al., 1998; Nilsson et al., 2004; Holmberg et al.,2005; Lindiger et al., 2009; Korvas, 2009, 2011; Mikkola et al. 2013; Andersson et al. 2014; Zoppirolli et al., 2015; Marsland et al., 2017; Pellegrini et al., 2022). From a locomotor point of view, diagonal stride is a quadrupedal activity in which forces are generated in the direction of movement by both the lower and upper limbs. The legs are the main contributors to the motor force production in diagonal stride. According to Bellizi et al., (1998), skiers generate 69% of their forward energy with the lower limbs, and 31% with the arms during diagonal stride at different speeds. The step cycle in diagonal stride is divided into the take-off, gliding and swing phases. Throughout the entire step cycle of diagonal stride, it is characteristic to transfer most of the weight to the front foot so that in the basic stance the skier reaches a position with the centre of gravity over the front foot and can perform all phases of the step cycle dynamically. The basis of propulsive leg force generation is to stop the ski and perform a dynamic take-off backwards (Nillsson et al., 2004; Lindinger et al., 2009). Diagonal stride is used on both flat ground and a slope, depending on the ability of the skier. Kinematic and kinetic analysis of the cross-country skier's movement are now standard tools in studies focusing on skiing technique at all ages and performance levels. Currently, these studies are conducted in the field under standard conditions and also in the laboratory on roller skis (Nilsson at al., 2004, Lindinger at al., 2009, Zoppiroli at al., 2020, Pellegrini at al., 2022).

Kinematic characteristics during cross-country skiing are most often investigated using 3D or 2D kinematic analysis. The most studied kinematic parameters are temporal. Lindinger (2009) determined that the step cycle averaged 1.21 sec in a group of high-quality skiers, with the contact phase with the snow averaging 0.74 sec (61.2%) and the swing phase averaging 0.47 sec (38.8%). Komi (1987) found a take-off time between 0.1 and 0.25 sec in high-quality skiers. Pellegrini et al. (2013) found that the step cycle time in high-quality skiers is 1.05 sec, the swing phase takes 41% of the cycle time, the take-off time is 0.21% and gliding 38%. Kinetic parameters were measured first using force platforms placed under the snow or force plates placed under the bindings (Rusko, 2003, Vähäsöyrinki at al., 2005). More recent research has used pressure insoles, which are easier for research, more mobile and more operational, however they have their limitations, as they only measure perpendicular pressure on the ski track (Lindinger et al., 2009, Korvas, 2011, Barnett et al., 2021, Pellegrini et al., 2022,). The values of the force under the skis during take-off have been investigated, e.g. by Moxnes and Hausken (2009), who found average values of around 1700 N on flat ground for hobby skiers, values of 2 – 3 mBW on a slope for an experienced skier, and in the range of 1.2 - 1.8 mBW for an average skier. Komi & Norman (1987) found take-off values between 1.5 mBW for skiing on flat to 3 mBW for skiing up a steep slope. Andersson (2014) tested skiers on roller skis who achieved an average value during take-off of about 2 mBW, and the value increased with higher speed. Lindinger et al. (2009) tested high-performance skiers and reported values during take-off in the range of 2-3 mBW.

A comparative study of cross-country skiing technique was carried out with two groups of skiers. The aim of the study was to compare selected kinematic and kinetic parameters while skiing on skin and grip skis, at the same running speed, in two technically different groups of cross-country skiers.

Research question: what will be the differences in selected kinematic and kinetic parameters during diagonal stride on grip and skin skis between quality and recreational skiers.

MATERIALS AND METHODS

Participants: ten cross-country skiers voluntarily participated in the study and were divided into two groups according to the quality of their diagonal stride technique. The first group (n = 5) consisted of skiers with good diagonal stride technique (established movement patterns). The second group were recreational cross-country skiers (n = 5), who demonstrated a lower quality of running technique (common deficiencies in the technique such as double support stance during the gliding phase in diagonal stride, insufficient range of arm movement during poling, and large vertical movement of the centre of gravity etc.). All participants were in good physical condition, which allowed multiple repetitions of the measured sections to be completed at the desired speed.

All participants signed an informed consent form prior to the start of the measurements and could voluntarily leave the research program during the experiment. The experimental protocol and all methods used in the study were approved by the ethics committee of the Centre for Sports Activities, Brno University of Technology.

Table 1. Characteristics of the groups of skiers.

Group	Age	Height	Weight
Skiers with good technique quality, n = 5	40±7	179±6	80± 6
Skiers with technical deficiencies, n = 5	22±2	181± 5	79±7

Measures

Prior to the start of the test, participants completed a standard warm-up process, which included practice of the speeds required in the test. The test area was very well prepared, the measurements were carried out on two well prepared sections of the racetrack. The first section was a 150-m-long flat, and the second was a 90-m-long slope with an average angle of 6°. The participants completed each section 3 times. For the flat run, the speed was set at 12 km/h, and for the uphill run at 11 km/h. Each participant completed the test on the flat and uphill sections on both types of skis three times. The lower speeds were set due to the fact that a group of recreational skiers also comfortably reached the test speed. The speed was controlled using a speedometer. There was sufficient time to have a rest between each section, at which time the pressure insoles were recalibrated for the next test.

For the measurements, each participant used performance-type grip and skin skis for classical style, which guaranteed good ski quality. The preparation of the skis corresponded to the climatic conditions. The tests were performed on natural relatively new snow, air temperature - 10°C, snow temperature - 5.2 C. Due to the good snow and climatic conditions, the grip skis of all participants could be prepared for take-off with the same wax, the only difference being the size of the grip wax layer, which corresponded to the take-off quality of the participants. The skin skis were treated according to the manufacturer's recommendations, a special cleaner was used for the skin. The gliding part of the skis were professionally prepared in the same way as the wax skis.

Procedures

For the collection of selected kinetic and kinematic data of the movement cycle, the Medilogic mobile pressure insole system (Medilogic, Germany) was used, which evaluates the pressures under the foot, from which both the time of the movement cycle and its individual phases can be derived on a time axis. The vertical pressure of the foot on the ski was recorded with the help of pressure insoles that each incorporated 100-190 pressure sensors regularly distributed over their entire surface. The recording was performed at a frequency of 100 Hz using special software from Medilogic. Calibration of the shoe insoles was performed before each measurement according to the company's manual. Sufficient accuracy of the measurements using the pressure insole was confirmed by the studies of Koch et al., (2016), Oerbekke et al., (2016), and Seiberl et al., (2018). All measured sections of the participants were video-recorded and used for expert evaluation of the running quality, to select the best section for data processing.

We monitored basic parameters of step cycle: the durations of each phase and of the entire step cycle, the percentages of each phase of the cycle, and the average and maximum pressure values of each phase. The step cycle of a single ski in diagonal stride was defined from the first touch of the ski to the snow track after finishing the swing phase, through the gliding phase, take-off and swing phases, to the next touch of the snow track by the same ski.

Analysis

With the help of the specific algorithm, very precisely defined the start and end of the skier's step cycle and each phase from the changes in the pressure on the insoles. The raw data were processed using our own algorithms developed in MATLAB version R2022, and numerical and graphical outputs of the average cycle values were produced. Of the measured sections, the one with the best quality was always selected for data processing. From the best test, the 30 consecutive step cycles that were visually free of coordination defects were selected for the flat and 20 for skiing on the slope.

Descriptive statistics were used and included mean, standard deviation and percentages. The Shapiro-Wilk test was used to test the normality of the data. The Cohen`s d effect size was calculated as an indicator of the magnitude of the effect, with d considered a small effect if d = 0.2 - 0.50, a medium effect if d = 0.5 - 0.80, and a large effect if d ≥ 0.8

RESULTS

The results of the selected parameters of skiing on the flat on grip and skin skis are presented in Tables 2 and 3 for both groups.

Table 2. Kinematic and kinetic values of Group A and B during skiing on the flat on grip skis.

Group A					Group B				
Temporal parameters of step cycle (sec)					**Temporal parameters of step cycle (sec)**				
Phase	Swing	Gliding	Take-off	Step cycle	Phase	Swing	Gliding	Take-off	Step cycle
M	0.57	0.65	0.25	I.47	M	0.35	0.4	0.29	1.04
SD	0.09	0.06	0.05	0.21	SD	0.09	0.07	0.06	0.05
Relative values of step cycle (%)					**Relative values of step cycle (%)**				
M	38.8	44.2	17.0		M	33.9	38.2	29.9	
SD	2.9	2.6	0.8		SD	I.39	1.5	0.1	
Pressure values on insole (N/cm²)					**Pressure values on insole (N/cm²)**				
	Gliding	Take-off average	Take-off max			Gliding	Take-off average	Take-off max	
M	4.22	6.19	9.19		M	3.04	5.05	7.68	
SD	1.16	1.58	2.16		SD	0.41	1.56	2.37	

Table 3. Kinematic and kinetic values of Group A and B during skiing on the flat on skin skis.

Group A					Group B				
Temporal parameters of step cycle (sec)					**Temporal parameters of step cycle (sec)**				
Phase	Swing	Gliding	Take-off	Step cycle	Phase	Swing	Gliding	Take-off	Step cycle
M	0.59	0.65	0.26	1.49	M	0.33	0.41	0.32	1.05
SD	0.07	0.07	0.05	0.38	SD	0.08	0.11	0.08	0.9
Relative values of step cycle (%)					**Relative values of step cycle (%)**				
M	39.7	43.2	17.3		M	33.9	38.7	30.4	
SD	4.5	4.9	1.1		SD	0.88	0.32	2.1	
Pressure values on insole (N/cm²)					**Pressure values on insole (N/cm²)**				
	Gliding	Take-off average	Take-off max			Gliding	Take-off average	Take-off max	
M	4.23	6.26	9.32		M	3.09	4.69	7.41	
SD	1.42	1.92	2.89		SD	0.61	1.49	2.05	

For the absolute values of the selected temporal parameters for gr. A, only small differences in effect size were found between skiing on both types of skis (d = 0.01 - 0.21). For the relative temporal values, the differences were found out also a small effect size for the swing and take-off (d = 0.21 and d = 0.28, respectively) and for the gliding there was a large effect size (d = 1.85). The difference for all observed phases of the step cycle had a small effect for the technically better skiers only (d = 0.01 - 0.05).

In group B, difference of small effect size were found for the absolute kinematic parameters such as the swing and gliding, as well as the step cycle (d = 0.11 - 0.19). Only for the take-off was there a large effect size (d = 2.02) for a longer time on the skin ski. In relative values, large effects size were found for the take-off and swing (d = 5.27; d = 2.30, respectively) with longer time for the swing and shorter one for take-off on the skin ski. For gliding, there was a small difference in effect size (d = 0.42). The differences in pressure values during skiing on both types of skis had a small effect for the gliding and for the maximum pressure value during take-off (d = 0.11; d = 0.24, respectively). The mean value of pressure in the take-off was found as medium-sized effect (d = 0.76), and this take-off pressure was found to be higher on grip skis.

The results of the selected parameters during uphill skiing on grip and skin skis are presented in Tables 4 and 5 for both groups.

Table 4. Kinematic and kinetic values of Group A and B during skiing on the uphill on grip skis.

Group A					Group B				
Temporal parameters of step cycle (sec)					**Temporal parameters of step cycle (sec)**				
Phase	Swing	Gliding	Take-off	Step cycle	Phase	Swing	Gliding	Take-off	Step cycle
M	0.55	0.56	0.30	1.41	M	0.33	0.30	0.31	0.94
SD	0.09	0.08	0.05	0.08	SD	0.05	0.08	0.07	0.06
Relative values of step cycle (%)					**Relative values of step cycle (%)**				
M	39.9	40.8	21.3		M	35.1	31.9	33.0	
SD	3.8	3.8	1.2		SD	0.14	0.87	0.92	
Pressure values on insole (N/cm²)					**Pressure values on insole (N/cm²)**				
	Gliding	Take-off average	Take-off max			Gliding	Take-off average	Take-off max	
M	3.69	6.65	9.71		M	2.21	4.36	7.3	
SD	0.67	1.37	2.78		SD	0.87	1.50	2.53	

Table 5. Kinematic and kinetic values of Group A and B during skiing on the uphill on skin skis.

Group A					Group B				
Temporal parameters of step cycle (sec)					**Temporal parameters of step cycle (sec)**				
Phase	Swing	Gliding	Take-off	Step cycle	Phase	Swing	Gliding	Take-off	Step cycle
M	0.55	0.63	0.27	1.45	M	0.30	0.33	0.31	0.94
SD	0.04	0.05	0.04	0.05	SD	0.06	0.09	0.08	0.07
Relative values of step cycle (%)					**Relative values of step cycle (%)**				
M	37.6	43.6	18.8		M	31.9	35.1	33.0	
SD	1.7	2.6	0.6		SD	2.3	1.9	2.1	
Pressure values on insole (N/cm²)					**Pressure values on insole (N/cm²)**				
	Gliding	Take-off average	Take-off max			Gliding	Take-off average	Take-off max	
M	4.09	6.46	9.63		M	2.9	4.75	7.59	
SD	0.54	1.67	2.15		SD	0.71	1.42	2.07	

When skiing on an uphill, which is a more demanding terrain for performing of skiing technique, some differences were found in group A for important absolute and relative time parameters. For absolute values of selected temporal parameters, a longer gliding time was found on skin skis with large-sized effect (d = 0.80) and the take-off was performed in a shorter time on skin skis with a large effect (d = 1.0). The step cycle time was longer on skin skis with a medium-sized effect (d = 0.68). For relative values, were found out a large effect for the gliding and take-off (d = 0.91 and d = 2.00, respectively). The swing was found to have a small effect (d = 0.4). The differences for the mean and maximum values of the take-off pressure were minimal, (d = 0.01, d = 0.03, respectively). The gliding phase was found longer on skin skis with a medium-sized effect (d = 0.57).

For the skiers in group B, only small effects were found for the absolute time parameters of all observed variables (d = 0.00 - 0.45). However, in relative values, this meant a large effect for the swing (d = 1.07), which lasted longer on the grip skis, and the gliding phase was longer on the skin skis (d = 0.75). For take-off was found a large effect (d =1.11) with longer time on grip skis . The difference in the pressure for group B during gliding and the mean pressure during take-off had a medium-sized effect (d = 0.78 and d = 0.77 respectively) with a larger value always being found on the skin skis. A small effect size was found for maximum take-off pressure (d = 0.27).

Comparison of the studied parameters between our groups when skiing on grip and skin skis

When comparing our two groups, a large effect can be observed for almost all parameters on the flat and on the uphill on both grip and skin skis. This means that the kinematic and kinetic characteristics of both groups are different on both grip and skin skis. All kinematic parameters were better in group A, a longer movement cycle and a longer glide and take-off, which are essential for good skiing technique. The differences between the two groups are shown in Tables 6 - 9.

Table 6. Cohen coefficient d for selected variables of skiing on flat on grip skis between Gr. A and Gr. B.

Absolute time values of step cycle		**Relative values of step cycle**		**Pressure values**	
Cohen d	Phase	Cohen d	Phase	Cohen d	Phase
2.21	Swing	2.15	Swing	1.1	Gliding
3.46	Gliding	2.55	Gliding	0.66	Mean take off
0.8	Take off	17.26	Take off	0.6	Max take off
4.54	Step cycle				

Table 7. Cohen coefficient d for selected variables of skiing on flat on skin skis between Gr. A and Gr. B.

Absolute time values of step cycle		**Relative values of step cycle**		**Pressure values**	
Cohen d	Phase	Cohen d	Phase	Cohen d	Phase
3.12	Swing	2.39	Swing	0.94	Gliding
2.35	Gliding	1.17	Gliding	0.82	Mean take off
0.83	Take off	4.95	Take off	6.63	Max take off
0.83	Step cycle				

The values for selected kinematic and kinetic parameters indicate mostly large differences in the time of all step cycle phases on the flat. Medium-sized effect was found between the groups when running on the grip skis for both mean and maximum pressure during take-off (d = 0.66; d = 0.60, respectively). In both cases, the recreational skiers generated less pressure during take-off than the skiers with better technique.

In the uphill skiing, mostly large effects were found between groups. The with two exceptions. For absolute time of take-off on the grip skis was found to have a small effect (d = 0.14). In absolute values, we found a medium effect size for the take-off time on the skin skis on uphill (d = 0.63), which was longer for the recreational skiers. All remaining kinematic and kinetic differences between the groups on both the grip and skin skis when skiing on flat or uphill were found to have large effects (d = 0.82 - 17.26).

Table 8. Cohen coefficient d for selected variables of skiing on uphill on grip skis between Gr. A and Gr. B.

Absolute time values of step cycle		**Relative values of step cycle**		**Pressure values**	
Cohen d	Phase	Cohen d	Phase	Cohen d	Phase
2.73	Swing	1.61	Swing	1.72	Gliding
2.99	Gliding	2.91	Gliding	1.31	Mean take off
0.14	Take off	9.96	Take off	0.82	Max take off
6.00	Step cycle				

Table 9. Cohen coefficient d for selected variables of skiing on uphill on skin skis between Gr. A and Gr. B.

Absolute time values of step cycle		**Relative values of step cycle**		**Pressure values**	
Cohen d	Phase	Cohen d	Phase	Cohen d	Phase
9.21	Swing	2.68	Swing	2.36	Gliding
3.72	Gliding	3.33	Gliding	1.00	Mean take off
0.63	Take off	8.62	Take off	0.87	Max take off
7.57	Step cycle				

DISCUSSION

The constant development of technology and new materials have enabled improvements to the construction of the ski, the quality of the means for preparing the ski (waxes, structures) and also the preparation of the tracks. All of these variables influences the performance of skiers (Hottenrot and Urban, 2004), and the biomechanical parameters by which we can characterize the quality of their movement (Rusko, 2003; Breitschädel et al., 2010; Budde and Himes, 2017; Pellegrini et al., 2018). If we compare the results of our groups on grip skis with other studies, the kinematic parameters for group A are similar to studies with high-quality skiers (e.g., Nillson et al., 2004; Lindinger et al., 2009; Pellegrini et al., 2020, 2022). Also, the take-off pressure values for this group after converting to force are similar to results which presented Komi (1987), Moxes and Hausken (2009), or Anderson et al. (2014). This confirms the possibility of objectively comparing the effect of the new technology in the group of higher-quality skiers (gr. A) and then comparing their results with the group of recreational skiers (gr. B). When comparing the results of selected kinematic parameters from the above-mentioned studies as well as the results of group A with the results of poorly skilled skiers (gr. B), a longer time of the take-off on the flat and on the uphill was found in our group B, which we consider to be important findings.

The remaining variables in group B had a higher variability in the results, but it was possible to prove, they too have large differences in technique compared to the better skiers, and we can conclude that they don't have a stable technique and automation of movement. It was assumed that quality movement skills would be evident in both kinematic and kinetic parameters. The differences between groups had large effects for skiing on wax and skin skis, with some exceptions on both flat ground and uphill. The small or medium-sized effect of take-off on the uphill on both wax and skin skis is more likely a result of low speed, at which skiers with good technique don't dynamically perform a take-off that is slow. During take-off on the flat, both groups generate a more similar pressure at the same speed (medium-sized effect). This is a consequence of the technically easier take-off. When skiing on the flat, group B takes more advantage of the skin ski during take-off, whereas for group A at low speed prevail automated movements without the need to adapt skills to new technology.

On the uphill, the differences between the groups again mostly had a large effect, but on both types of skis the absolute take-off time was more similar for both groups. This is a consequence of the need to reduce take-off time to be efficient. On the uphill, the skills of group B are also supported by technology that can compensate for the low quality of take-off and allow the skier to perform the necessary movement structure with a higher quality than the skier is capable of on grip skis.

In the intra-individual group evaluation of skiing on the grip and skin ski, the smallest differences were found for skiing in the flat, which is a technically and physically less demanding terrain, on which, at a low movement speed, even technically less capable skiers are closer to the movement structure performed by better skiers. When skiing on flat terrain, this is a moderately difficult movement structure with less force needed to influence spatiotemporal parameters. When comparing the results of skiing on grip and skin skis for both groups, we find the greatest number of small differences (similar, non-significant results) in absolute values of the time parameters when skiing on flat terrain, i.e., on simple, easy terrain, at low skiing speeds, and therefore at low load intensity. Here we did not find many significant kinematic or kinetic differences.

On flat ground, both groups had similar time for the step cycle on both skis, and also the proportion of each phase within the step cycle was similar for group A, with no significant differences, but no for gliding, what is logical. For group B, there was only a large difference in the take-off time, which was longer on the skin skis both in absolute and relative values. This is clearly a consequence of the effect of the new technology, which allows a longer take-off without technical problems such as the ski slipping backwards on grip skis and technology compensates the lack of take-off skills. We think this is logical, since in this case recreational skiers can perform a longer take-off without worrying about the ski slipping. This is a sought-after change in the movement pattern of the cycle, which is caused by the new technology, which allows technically less skilled skiers to perform the take-off more confidently. The skier can perform take-off for a longer time and more efficiently, and this change is reflected in the kinematic movement structure of the individual, because at the same time the swing phase of the second lower limb responds to this change and is significantly extended.

Time of take-off is an important variable that influences the quality of the skiers' technique, and on grip skis this corresponds to the quality of the snow conditions and the ability to produce a sufficient pressure for the resistance between the ski base and the snow track so that the ski does not slip backwards. Both groups performed a shorter take-off on the flat than on the uphill (absolute and relative time values) because there was no need to generate as much propulsive force at the lower speed and the take-off could be shorter, thus confirming both groups' ability to adapt their technique to the conditions created by the type of ski used for the take-off. The difference in gliding is of course due to the greater resistance of the skin skis, on which the skier covers a shorter distance during the step cycle on the skin skis and also in shorter time. However, quantifying the distance covered during the step cycle was not the aim of this study.

Advanced skiers with good technique apply more automated movement patterns when skiing on the flat on both types of skis, so from a kinematic point of view, the different ski type only has a minor effect on the step cycle. For technically better skiers, there is no difference on the flat when skiing on grip and skin skis, nor is there a difference in the value of pressure on the insoles, which is again consequence of low speed and low intensity of movement. In group B, when evaluating the values of take-off pressures, we already find a difference, which shows that even skiers with imperfect take-off on the grip skis can increase the pressure on the skin skis and perform a reliable and more dynamic take-off.

In uphill skiing, we already found more significant differences (medium-sized and large effects) for the different groups. Skiing in more challenging terrain is also more technically demanding, especially in terms of the correct execution of the take-off phase, where it is especially important to adapt the length and dynamics of the take-off to the angle of incline and the quality of the snow track (Rusko, 2003). On the uphill, there was a similarity in some absolute values of the time indicators for both groups (swing, gliding, step cycle). A logical justification can be found for the gliding and step cycle in group A, which are affected by the worse slipperiness of the ski. The shorter swing in group B is usually due to poorer technique, balance, longer gliding on both skis after putting the ski on the snow to early, these are a common deficiency of this kind of skiers. On the uphill, both groups already showed significant differences in relative values for the take-off time, which was shorter on the skin skis than on the wax skis. On the uphill, the correct technique is physically and technically more difficult. This was confirmed by the simpler and more confident carry out of the take-off on the skin skis. What we somewhat expected here is a longer time of take-off on grip skis for group B, with more variability and less quality of take-off. But this was not confirmed, these skiers performed the take-off both absolutely and relatively in a similar time. It means, they took advantage of the skin skis to perform a faster and more reliable take-off on the uphill.

On the uphill, the differences were also found in the group with better ski technique, and it is clear that there is also some effect of the new technology on the movement pattern in the take-off of the diagonal stride, but also subsequently in the gliding, which is affected by the worse mechanical properties of the skin ski base. In the take-off, this is a logical adaptation to speed and conditions, and if a firm take-off is made, it can result in a longer gliding. A medium effect size was found for longer absolute gliding time and a large effect for shorter take-off time on skin skis. These are logical differences, especially for gliding, which is influenced by the mechanical principles of the ski gliding on snow. Shortening of the take-off is also a result of experience based on a good feel for the ski's properties and adapting the take-off to the conditions. This suggests that under more technically demanding conditions, skiers with good technique will adapt the take-off to the new technology and take advantage of it to perform a fast dynamic take-off.

For group B, we found more differences in the take-off when skiing on the uphill. This is a group that has not yet automated the correct movement structures well. The relatively shorter take-off time suggests the advantages of a skin ski for this group under conditions that are problematic for the use of an appropriate grip wax. Group B skiers are therefore more confident on skin skis when performing a take-off on the uphill that can be more dynamic and faster. Extending the gliding was not anticipated but is possible when performing a firm take-off that generates more propulsive forces for longer gliding. It may also be the result of placing the ski on the snow too early at the end of the swing phase and performing a long glide on both skis, which is a common mistake in technically less skilled skiers. Of course, the take-off is also influenced by some other factors that negatively affect the technique of the run, such as changes in the position of the body and quality of movement coordination in changing terrain, changing snow and track quality, lower ability to quickly and accurately transfer the centre of gravity over the gliding ski, i.e. precise and dynamic movement in the medio-lateral direction, and also a lower level of specific strength, which are always found in less skilled skiers (e.g. Rusko, 2003, Hottenrot and Urban, 2004, Ilavský et al., 2023).

For both groups, there is a change in the temporal characteristics of the take-off on the uphill due to technology that facilitates the generation of propulsive forces in the direction of motion. This gives greater confidence to perform fast, dynamic motion, especially under problematic wax and take-off conditions. The shorter take-off time also corresponds with the better ability of skiers to use the ski's take-off properties, even in technically superior skiers, which is shorter in skin skis. The skier does not have to think more about the correctness and do the take-off dynamically in a shorter time. Thus, it is clear that more changes occur in more challenging terrain, where it is more difficult to apply a take-off technique that is appropriate to the needs of the moment.

When evaluating the pressures generated during gliding and take-off on grip skis in recreational skiers, we observe lower values than in higher quality skiers (gr. A) or even in other studies (e.g. Komi, 1987, Anderson et al., 2014). This is usually due to insufficient weight transfer to the loaded ski, gliding on both skis, poor take-off execution (length, dynamics), poorer quadrupedal coordination, lower levels of specific force required for a quality take-off, and the interplay of agonists and antagonists.

The differences in the values of pressure do not support the assumption that its value would change significantly during take-off on flat in group A. This change only occurred in the technically weaker skiers, who also took advantage of the reliable take-off to increase the take-off pressure, and thus to a more reliable take-off and creating greater propulsive force in the direction of movement. The differences in the values on the pressure insoles for both groups when skiing on the flat between the two types of skis were found to mostly have small effects, which is also a result of the low intensity of the movement due to the low speed in the test. We found a medium effect size for the difference in mean take-off pressure for group B, which indicates the ability to produce more pressure on the skin skis while ensuring a firm and secure take-off.

More differences were found for both take-off and gliding on the uphill, and these differences were mostly a medium-sized effect for both groups. With gliding, this is also due to the higher resistance of the ski when moving on the snow. More interesting were the differences that indicate changes in the pressure on the insole during take-off. These were only evident in group B with lower pressure values on the sensor on skin skis on flat and also on uphill skiing, while in group A the values for take-off were similar on both types of skis on terrain. This confirms the use of automated movement patterns in better skilled skiers and, on the other hand, the ability to take advantage of the new technology in group B, which manifests itself in a greater pressure on the skin ski during take-off on uphill skiing and lower than on grip skis on flat, where is take-off easier to perform. Thus, under standard snow conditions, skiing on both types of skis from the point of view of take-off pressure is more comparable in group A. In group B, there is a medium-sized difference in effect size for this parameter, which clearly confirms the simplification of take-off on the flat, which makes it possible to take-off with lower pressure without the ski slipping backwards. However, this should be taken into account in training, and practicing technique on skin skis should only be used under conditions where waxing is problematic. The consequence of inadequate use of skin skis can be in poor movement pattern of take-off on the grip skis.

CONCLUSIONS

Group A demonstrated similar kinematic values to skiers in other studies (Komi, 1987, Lindinger, 2009, etc.) for skiing on grip skis. On skin skis, they showed a somewhat steady movement pattern, although there were some differences, especially for the gliding and also on the uphill for the take-off.

For skiers with good technique, differences in selected kinematic and pressure parameters were minimal when comparing skiing on both types of skis on the flat. This was due to the quality of the automated movement skills/technique, which varies minimally on different types of skis under the same snow conditions, but they are able to adapt to the conditions. Only in relative gliding values are there logical differences due to the increased resistance of the ski. On the uphill, it is already possible to find differences in take-off, which is the main variable observed in skin skis, and it is clear that even the A group uses a firm take-off for its faster and more dynamic performance.

For the group of recreational skiers, we found out differences of medium and large effect size for kinematic variables on the flat and on the uphill, especially for take-off. For the pressure parameters, the effect of the new ski types is medium in size. This suggests an advantage to using a firmer take-off than on grip skis, which can be a technical problem for recreational skiers.

The differences between the groups were significant in almost all parameters, both on the flat and on the uphill. The differences between the groups were logical, and it is clear that the ability to use the existing skills of each skier, and their adaptation with respect to external conditions and ski type, is decisive.

From the results of group B, we conclude that from a methodological point of view, the use of skin skis in training should be approached with discretion and only under specific climatic and snow conditions, so as to develop a feel for both take-off and gliding as an important part of the XC skiing technique under different climatic and snow conditions.

AUTHOR CONTRIBUTIONS

The contribution of the authors has been as follows in each of the sections: P. Korvas 40 %; T. Goldschmidt 20 %; O. Jaroš 20 %; J. Štastný 20 %.

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