Informativeness of biomechanical criteria in assessing the competitive efficiency of highly qualified cross-country skiers

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Abstract

Objective of the study was to assessment of the influence of competitive conditions on the biomechanical characteristics of the technique of simultaneous single-step skating skiing (SSS).

Methods and structure of the study. The biomechanical indicators of the OSH technique of highly qualified cross-country skiers were determined using Dartfish Pro 10 software based on video footage of the athletes' movements on the flat sections of the sprint, 10 km race and in the roller ski test. The free development environment «RStudio» was used for data analysis and visualization.

Results and conclusions. A statistically significant negative correlation was found between the speed on the first lap and the angles in the knee and hip joints at the time of placing the poles (-0.552 (<0.05) and -0.573 (<0.05)) in men. In sprinting, skiers' speed was associated with the magnitude of the hip angle (-0.558 (<0.05)). In all other cases, there was no relationship between the values of joint angles and the speed of movement in competitions. The absolute values of the joint angles in the key phases of GSHP depend on the exerted effort and change as a result of a controlled change in the intensity of movement or an unintentional decrease in speed as a result of fatigue, which makes it possible to use these indicators to assess the level of preparedness in races and intensive training. The amplitude of movements in the ankle, knee and hip joints during the push-off in the GSHS is not related to the speed of movement under competition conditions.

Keywords: *cross-country skiing, biomechanical characteristics, simultaneous one-step skating, highly qualified ski racers, assessment of competitive activity.*

Introduction. In cross-country skiing, competitions and training are held on trails with varied terrain and lap lengths, in changing snow and weather conditions, and athletes adapt the technique of multiple modes of movement to external conditions and their own capabilities with varying degrees of efficiency. All these factors complicate the objective assessment of the technical and physical preparedness of athletes, preventing the establishment of accurate model indicators of special preparedness. In skiing, there are no absolute criteria that allow comparison between athletes who do not participate in the same competitions, which creates problems for predicting the performance of cross-country skiers. Studies of the factors that determine the result in competitions are carried out in laboratory conditions, which makes it possible to increase the validity and reliability of tests for assessing the performance and functional state of athletes [3]. The development and use of skiers' readiness indicators in the field is necessary to assess the ability to demonstrate functional capabilities in real conditions. In particular, attempts are being made to standardize the conditions for testing the technical readiness of athletes in skiing, using for this purpose the measurement of kinematic indicators of the technique of simultaneous one-step skating when moving on the plain [1]. The use of 2D video recordings for subsequent measurement of kinematic characteristics, including joint angles, has significant limitations. Firstly, only the analysis of the positions of body links located parallel to the plane of the video camera matrix can be correct. Secondly, measuring angles and dis-

tances in video analysis programs is a labor-intensive and time-consuming process, and the data obtained does not always justify the effort expended. Electrogoniometers are often used to measure angles [4], but this requires intervention in the training process and is not possible in competitions.

It seems obvious that factors such as the length of the distance and sliding conditions, skill level, morphological structure, level of preparedness and degree of fatigue of athletes, the location of the flat area where video shooting is carried out, and the tactics of its passage significantly influence the parameters of the technique. We hypothesized that studying the relationship between the biomechanical indicators of cross-country skiers and the speed of movement on flat sections of competitive distances and in a standard test will allow us to assess the specific influence of competitive conditions on technique and identify informative criteria of preparedness.

Objective of the study was to assessment of the influence of competitive conditions on the biomechanical characteristics of the technique of simultaneous single-step skating skiing (SSS).

Methods and structure of the study. Video recording of the movement of ski racers at the Russian Cup distances of the 2023-24 season. was carried out during the sprint qualification on November 25, 2023 and at a distance of 10 km freestyle on December 1, 2023 as part of scientific and methodological support for the Russian national cross-country skiing team. In both cases, a flat section of the route was chosen, the video camera was installed motionless, perpendicular to the movement, so that at least two cycles of movements were captured in the frame. At the sprint distance, filming was carried out at the beginning of the lap after the starting acceleration, the air and snow temperature was -2°. At a distance of 10 km, a flat section was chosen after an ascent, shooting was carried out on both circles, the weather conditions were stable, air temperature -7-8°, snow temperature -6°. The biomechanical indicators of the 20 best athletes in the sprint and the 18 best athletes at 10 km distances among men and women were calculated in the DartfishPro 10 program. The «stride length» indicator characterizes the athlete's movement in one cycle of movements (from the beginning of pushing off with poles until the next moment of placing the poles). Squat time is the time from the moment the poles are placed until maximum bending of the leg at the knee joint. Take-off time is the time from the moment the knee of the swing leg moves forward of the knee of the supporting leg until the ski lifts off the snow. Statistical processing of the research results was carried out in the RStudio program [5]. For comparison, similar indicators of athletes (6 men, 5 women) were calculated when performing a standard test on roller skis, conducted in September 2023 as part of scientific and methodological support for the Russian national cross-country skiing team.

Results of the study and discussion. High speed in sprint qualifying for men and women was ensured by a larger step length and frequency of movements (Tables 1, 2). However, if the speed of female skiers in the sprint depended to a large extent on the frequency of movements, then for men, the speed of movement was positively related to the length of the step in the sprint (ρ=0,801) and on the first lap of the race (ρ=0,585, p<0,01). The increase in the frequency of movements in sprints in women occurred due to a decrease in the time of repulsion and the time of free

Table 1. Biomechanical indicators of female cross-country skiers' technique at the Russian Cup distances

Biomechanical indicators		Sprint, n=20	1 lap race, n=18	2 lap race, n=18	p
Speed, m/s		7,03±0,35	4,90±0,29	4,90±0,20	<0,0001
Step length, m		5,44±0,35	4,46±0,31	4,43±0,30	<0,0001
Movement frequency, cycle/min		77,88±0,06	65,99±3,59	66,71±4,78	<0,0001
Foot push-off time, s		0,23±0,02	0,28±0,03	0,27±0,03	<0,0001
Sit-down time, s		0,15±0,03	0,16±0,02	0,16±0,04	>0,05
Push-off time with sticks, s		0,23±0,02	0,30±0,02	0,31±0,02	<0,0001
Free sliding time, s		0,39±0,05	0,47±0,04	0,47±0,05	<0,001
The angles at the moment of placing the poles, degrees.	Shin tilt	71,54±4,39	71,09±2,88	72,31±3,74	>0,05
	Knee	136,75±7,71	141,18±7,12	142,69±7,09	>0,05
	Hip	**113,67±4,30**	**118,34±5,96**	119,12±8,36	<0,05
The magnitude of the angles at the moment of sitting down, degrees.	Shin tilt	68,85±3,10	67,08±3,67	67,25±2,76	>0,05
	Knee	120,2±4,83	123,42±4,08	124,15±4,99	>0,05
	Hip	91,97±3,97	95,25±5,68	96,10±8,03	>0,05

Table 2. Biomechanical indicators of the GS technique of cross-country skiers at Russian Cup distances

Biomechanical indicators		Sprint, n=20	1 lap race, n=18	2 lap race, n=18	p
Speed, m/s		8,01±0,28	5,63±0,17	5,50±0,22	<0,0001
Step length, m		6,76±0,46	5,44±0,27	5,30±0,26	<0,0001
Movement frequency, cycle/min		71,34±3,15	62,14±2,45	62,31±3,60	<0,0001
Foot push-off time, s		0,23±0,02	0,26±0,03	0,27±0,03	<0,01
Sit-down time, s		0,14±0,02	0,19±0,03	0,18±0,02	<0,001
Push-off time with sticks, s		0,22±0,01	0,29±0,01	0,30±0,02	<0,0001
Free sliding time, s		0,47±0,04	0,51±0,02	0,52±0,04	<0,01
The angles at the moment of placing the poles, degrees.	Shin tilt	68,62±2,74	68,69±4,65	67,02±3,56	>0,05
	Knee	138,12±6,59	139,70±7,13	138,36±6,91	>0,05
	Hip	114,88±6,92	117,29±6,59	115,85±9,62	>0,05
The magnitude of the angles at the moment of sitting down, degrees.	Shin tilt	67,06±2,54	66,61±3,21	66,05±2,85	>0,05
	Knee	118,60±5,13	120,91±5,71	118,98±5,09	>0,05
	Hip	91,06±6,79	91,45±7,00	90,22±7,63	>0,05

sliding. In men, in addition, the duration of sit-ups was significantly reduced.

The speed of movement on the plain, step length and all time indicators remained stable over two laps of the distance in both men and women, despite progressive fatigue.

At the moment of placing the poles, the angles in the hip joint were significantly different in the sprint and on the first lap of the race for women. In other cases, significant differences were identified between the performance in the sprint and in each of the two laps of the distance for men and women.

In women, at the time of placing the poles in the sprint, the average values of the angles in the knee and hip joints were less than at a distance of 10 km. This may be due to the high frequency of movements and advanced bending of the legs before placing the poles. On the second lap of the distance, there is a tendency for the angles in the knee and hip joints of skiers to increase, which apparently reflects the accumulated fatigue of some athletes.

When comparing average values, changes in individual values can be leveled out, therefore, to identify the relationship between angular indicators and movement speed, a linear Pearson correlation was determined on all segments. A statistically significant negative correlation of medium strength was found between the speed on the first lap of the distance and the angles in the knee and hip joints at the time of placing the poles (-0,552 (<0,05) and -0,573 (<0,05)) in men. In sprinting, high speed of skiers was associated with the magnitude of the angle in the hip joint (-0,558 (<0,05)). Interpretation of the data in Figure 1 shows that in all other cases there is no relationship between the values of joint angles and the speed of movement (middle and bottom rows of diagrams).

The speed of movement of athletes can be influenced not by the absolute values of joint angles in key phases of the skiing cycle, but by the amplitude of movement in the knee and hip joints [1].

The parameters of the simultaneous one-step technique, determined in competitive conditions, differ significantly from similar indicators recorded in the standard test on roller skis. According to the conditions of the test, conducted in accordance with the technical specifications of the Analytical Directorate of the Center for Sports Teams of the Russian Federation sports teams, athletes were asked to overcome a flat area five times with a simultaneous one-step skating stroke, increasing the speed to maximum, but maintaining the structure of movements. In Fig. Figure 2 clearly illustrates that such a targeted and controlled increase in speed was accompanied in men and women by a decrease in the angle of the hip joint at the time of placing the poles and a decrease in the angles in the knee and hip joints during the squat. The range of motion in all three joints remained stable and did not depend on the speed of movement.

The data obtained indicate that the values of the joint angles in the key phases of the joint movement change as a result of a controlled change in the intensity of movement or an unintentional decrease in speed as a result of fatigue, that is, they do not depend on the speed of movement, but on the exerted effort. This allows us to consider the dynamics of individual kinematic parameters of highly qualified skiers during competitions or intense loads as an indicator characterizing the level of physical fitness and current performance, but not technical skill. An effective tool for

visual assessment of technique and an effective way of technical improvement remains the automated construction of kinematic diagrams based on the angular characteristics of athletes at key moments of skiing [2]. Visualization of key skiing positions in the form of simplified diagrams contributes to a better awareness of technical errors and understanding of the coach's requirements.

C**onclusions.** An increase in the speed of simultaneous one-step walking over a short distance was ensured by an increase in step length and frequency of movements; in men, a correlation between step length and movement speed in the sprint and on the first lap of the distance was determined.

A statistically significant negative correlation was found between the speed on the first lap of the distance and the angles in the knee and hip joints at the time of placing the poles (-0,552 (<0,05) and -0,573 (<0,05)) in men. In sprinting, high speed of skiers was associated with the magnitude of the angle in the hip joint (-0,558 (<0,05)). In all other cases, there was no relationship between the values of joint angles and the speed of movement under competition conditions. Visualization of the angular characteristics of the joint angles during competitions and during a standard test made it possible to identify a tendency towards a decrease in the absolute values of joint angles in the case of a controlled increase in intensity. The amplitude of movements in the ankle, knee and hip joints during the push-off in a simultaneous one-step skating stroke was not related to the speed of movement in any case.

Correct kinematic analysis of skating skiing techniques requires strict adherence to video recording conditions and high labor costs. A promising direction of research may be the automation of determination of kinematic characteristics by using computer vision methods. The information content of biomechanical indicators can be improved by studying relationships with the individual anthropometric characteristics of athletes, since, according to observations, it is this factor that can explain the large scatter of indicators and deviations from the general tendencies of the technique of individual successful athletes.

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