Journal of Physical Education and Sport ® (JPES), 18 Supplement issue 2, Art 145, pp. 980 - 987, 2018
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Influence of skier speed on the diagonal stride motion

KOLUMBET A.N.[1], NATROSHVILI S.G.[2], BABINA N.A.[3], BABINA T.G.[4]
[1,2,3,4]Kiev National University of Technologies & Design, UKRAINE

Published online: July 31, 2018
(Accepted for publication June 12, 2018)
DOI:10.7752/jpes.2018.s2145

Abstract:

The aim of the work: to determine the impact of skier speed on the structure of diagonal stride motion at the distance segments. *Material and methods*. The study included 12 racing skiers (first-class athletes). The subjects covered short (up to 50 m) distance segments of various steepness with different speed under standard conditions of sliding. *Results.* Assessment of the changes in technique general characteristics does not reveal the character of these changes. Peculiarities of skating step phase structure reflect the inscape and the direction of these changes. Increase of speed at flat segment is accompanied with the reduction of step time. It occurs at the expense of significant decrease of the duration of the II phase and the time of taking-off (phases IV and V) along with unchanged length of these phases. The speed of the I and the III phase is gained at the expense of their length increase along with unchanged duration. The dynamics of general center of gravity speed in the cycle of skating stroke explains the change of phase content during skier speed increase. The greatest decrease of general center of gravity speed occurs during the II phase. It is conditioned by its duration reduction along with the increase of general racing speed. The phase speed is increased at the expense of its duration reduction along with constant length. Another way is possible: phase length increase along with unchanged duration, which is peculiar for the I and the III phases. This way, however, is not suitable for the foot pushing-off phases. Their length cannot be increased significantly (period of ski stand). Therefore, only the first variant of their speed increase is possible – at the expense of phase time reduction. This is confirmed practically: as the speed of motion increases, the time of taking-off decreases. *Conclusions.* An increase of speed of skiing by diagonal stride at 4-12° steepness of distance occurs at the expense of proportional increase of stride length and frequency. Rhythm is an integral index of athlete motion technical level. The technique should be mastered at high speed in order to form proper rhythmic structure of skating stroke. The simplest control for technical preparation of skiers may be realized according to general characteristics of technique (stride length and frequency), knowing the regularities of their changes depending on racing speed and steepness of slope.

Key words: ski sports, biomechanical indices, technique, diagonal stride motion.

Introduction

Nowadays a rapid development of skiing is observed caused by improvement of equipment, new methods of skiing runs preparation, introduction of sprint races in the competition program (Novikova & Sergeev, 2016; Sandbakk et al., 2011). Increase of competitive speeds has resulted in changes of skating step biomechanical parameters and motivated the scientists to analysis technique and search for the optimum variants of covering different competitive distances in ski races and biathlon.

Racing skiers utilize various skating steps for efficient covering different distance segments. No other sports event has such a wide range of various motion patterns used in one race.

There are two major skiing styles: skate and classic (Koriagina, 2015). Efficient selection of skating step depends on path profile and speed of skier (Baumann, 1985; Grasaas at al., 2014; Ramenskaya, 2001). The frequency of skating step alternating during competition complicates the motion. E. Anderson et al. (2010) reported that during 1,43 km race the average number of skating step changes constituted 29,1. More skilled skiers tend to use higher portion of speed skating steps (Sandbakk at al., 2015), besides, faster athletes have increased length of motion cycle (Stoggl et al., 2011).

Technical preparation of a skier represents a process of purposeful training and mastering of skiing techniques. A high level of sports results requires constant and in-depth work on improving the technique throughout the entire period of active skiing (Stoggl et al., 2013). In the plans for the preparation of skiers from novice to qualified athlete, continuity of mastering and improving technical skills must be foreseen. Even the achievement of the highest results does not mean that technical excellence has been achieved. The skier should continue to improve the technique of the various elements of movements, eliminate individual inaccuracies and errors even in this case (Lindinger & Holmberg, 2011; Marsland at al., 2012).

Corresponding Author KOLUMBET A.N, E-mail: re_play@3g.ua

The main factor in the development and improvement of skating step techniques is the correct mastering of the biomechanical structure of movements (Bilodeau at al., 1996). While designing sports preparation at all stages of the annual macrocycle (especially at the stage of direct preparation for the competition), technical training of skiers is of tremendous importance.

The technique of the best racing skiers of today is changing drastically, which is connected with the improvement of ski equipment, ski lubricants, preparation of ski runs and other variables. Analysis of changes that occur in the technique of skiers allows identifying their peculiarities and determining the optimal parameters of the most technical preparation (Holmberg at al., 2005; Lindinger at al., 2009).

Continuous work on improving the technique of skiing with usage of a variety of video materials and films not only significantly complements the information that comes to the athlete, but also contributes to the creation of a real image of the correct technique and errors that arise during the movement and, in the same way, greatly facilitates the process of technical improvement (Myklebust at al., 2014). Within the framework of the biomechanical analysis, the calculation of optimal kinematic and angular parameters, the determination of technical skill efficiency indices and the identification of differences in the technique of racing skiers of leading ski countries are made.

The modern technique of skating steps, especially the sprint technique is highly efficient, but extremely energy-consuming and requires excellent physical fitness. The rational usage of various technique variants for competitive distance covering contributes to economy of efforts, energy and increase of overall performance (Stoggl at al., 2008).

Clear definition, explanation and reinforcement of the factors ensuring sports achievements in this field, and first of all, the study of qualitative aspects and their importance for provision of the economy of movement (ease and energy economy due to technical skills), speed of movement i.e. the final result in the competition are the prerequisites for elaboration of an efficient concept and methods of technique mastering (Smith, 1990).

The range of training speeds in ski races is relatively small. If the athlete's average competitive speed is taken as 100%, then all training loads are performed by him within the range of 80-110%. However, the questions of the change in the structure of the skating step in the speed range (75-115% of the competitive) remain unanswered. There is no clear information in the differences in the technique of skiing at speeds below the competitive ones.

The aim of the work - determining the influence of skier speed on the structure of diagonal stride motion on the distance sections.

Materials and methods

Participants. Twelve racing skiers (I class athletes) participated in the study.

Methods of study. 3D-video analysis allowed to reveal the kinematic characteristics of the examined types of motion technique (Mössner, 1992). The dynamic structure (support reaction forces directed perpendicular to the skis and the point of force application) was investigated by means of the soles of the *Mobil-Pedar-System* (Novel GmbH company), which allow measuring the pressure distribution. Kinematic and dynamic measurement systems were used for detailed biomechanical analysis of the main two-step diagonal during skiing. Frame by frame shooting with two synchronized video cameras (50Hz) was used to determine 3D coordinates of all selected conditional points of the system "athlete-implement". To process the image and evaluate the video recordings, the video analysis system of *Peak Performance Technologies-Englewood*, Colorado (USA) was used with *SoftwarePeak 5 Software* (version 5.2). Vertical and horizontal pointing the video cameras and adjusting the focal length necessitated the *Peak 5-Standard-Software* increment at the expense of the so-called *PanningProgramm* (Drenk, 1993). To measure the distribution of pressure, or more precisely the support reaction forces on the sole (50 Hz) being perpendicular to the surface of the skis, the *Pedar-Mobile-System* of *Novel GmbH Company* (Munich, Germany) was used. The system consisted of two soles with sensors for measuring pressure, and a memory unit.

The system of *Ernst Company* (Germany) and ski pole embedded dynamometric sensors (the Hottinger-Baldwin tensometry principle) allowed to measure the force of pushing-off (200 Hz) that arose while moving by diagonal stride motion.

Organization. The subjects covered short (up to 50 m) distance segments of various steepness (from 4° to 12°) with different speed under standard conditions of sliding.

Results and analysis

When the slope steepness is changed (from 4° to 12°), the general indices of technique (speed and its components) have characteristic dependencies. These dependencies are described quite accurately by equation of linear regression. An increase in the speed of movement in the given interval at a section of a certain steepness is due to proportional increase of stride length ($\boldsymbol{l}$) (Table 1) and frequency ($\boldsymbol{\tau}$) (Table 2).

An exception is the flat segments, where the increase in speed is caused mainly by an increase of stride frequency during stabilization and even a slight decrease of their length at competitive and supercompetitive speeds (100-110%).

Table 1. Change of stride length (***l***) depending on speed of skiing (***V***) at segments of different steepness (***α***)

V, %	α, m							
	0°		4°		8°		12°	
	X	σ	X	σ	X	σ	X	σ
75	-	-	-	-	1,31	0,10	1,05	0,12
80	2,71	0,17	2,00	0,15	1,33	0,10	1,07	0,11
85	2,75	0,17	2,06	0,17	1,36	0,11	1,09	0,11
90	2,81	0,18	2,09	0,13	1,40	0,13	1,11	0,14
95	2,89	0,20	2,10	0,11	1,44	0,16	1,13	0,11
100	2,91	0,20	2,13	0,18	1,48	0,16	1,15	0,13
105	2,92	0,17	2,15	0,18	1,50	0,13	1,17	0,13
110	2,80	0,19	2,20	0,19	1,52	0,11	1,20	0,17
115	-	-	-	-	-	-	1,30	0,17

This is a consequence of insufficient development of speed-strength capacities of athletes, which prevents them from exerting maximum efforts within a critically short period of foot taking-off (0.12-0.14 s). Similar phenomenon is observed during uphill skiing at very high speed (120% and more) that is hardly used in training. Changes of skating step harmonicity coefficient (ratio of stride length to frequency) with increased intensity of skiing confirm the revealed tendency (Table 3). On flat segment (***α=0°***) harmonicity coefficient (***H***) significantly decreases, i. e., increase of stride frequency outstrips that of length. On uphill segment (***α=8°***) these indices demonstrate similar increase, which is expressed in constant value of skating step harmonicity.

Table 2. Change of stride frequency (***τ***) depending on skiing speed (***V***) at segments of different steepness (***α***)

V, %	α, m							
	0°		4°		8°		12°	
	X	σ	X	σ	X	σ	X	σ
75	-	-	-	-	1,92	0,11	-	-
80	1,41	0,10	1,64	0,11	1,95	0,11	2,05	0,11
85	1,45	0,12	1,66	0,09	1,97	0,14	2,09	0,14
90	1,50	0,09	1,72	0,12	2,02	0,14	2,12	0,12
95	1,55	0,10	1,77	0,12	2,05	0,12	2,16	0,12
100	1,58	0,11	1,82	0,14	2,07	0,15	2,20	0,12
105	1,65	0,13	1,87	0,14	2,10	0,17	2,25	0,17
110	1,72	0,14	1,90	0,13	2,13	0,11	2,30	0,11
115	1,81	0,16	1,95	0,15	2,16	0,13	2,33	0,17

The set of two types of dependencies — $l(\alpha)$, $l(V)$ and $\tau(\alpha)$, $\tau(V)$ is correctly given by equations:

$$l = 2{,}04 + 0{,}0076V - 0{,}143\alpha,$$

$$\tau = 0{,}52 + 0{,}0112V + 0{,}043\alpha,$$

where l — stride length (m), τ — stride frequency (s), V — speed (% of competitive), α — slope steepness (degrees).

Table 3. Change of harmonicity coefficient (***H***) depending on speed of skiing (***V***) at segments of different steepness (***α***)

V, %	α, m					
	0^O		4^O		8^O	
	X	σ	X	σ	X	σ
75	-	-	-	-	-	-
80	1,85	0,09	1,30	0,10	0,63	0,09
85	1,83	0,09	1,24	0,11	0,66	0,08
90	1,83	0.11	1,20	0,12	0,72	0,08
95	1,82	0,11	1,18	0,11	0,74	0,09
100	1,73	0,11	1,17	0,09	0,70	0,07
105	1,60	0,13	1,16	0,11	0,69	0,12
110	1,55	0,10	1,12	0,11	0,71	0,06
115	1,52	0,11	1,10	0,09	0,70	0,07

Equations allow evaluating both the competitive and training activity of a skier according to the value of the main biomechanical parameters. With these data, the coach may efficiently manage technical preparation of racing skier taking into account the changes in the general characteristics of technique, depending on the lay of the land and individual speed of the athlete.

However, a quantitative assessment of changes in the general characteristics of technique does not reveal their character, that is, their qualitative aspect. The peculiarities of skating step phase structure reflect the internal content and direction of these changes. Speed increase at flat segments (Table 4) is accompanied with stride time reduction. It occurs at the expense of significant decrease in duration of the II phase and time of foot taking-off (phases IV and V) along with unchanged length of these phases.

The length of phases was determined according to displacement of selected point on the hip joint. The speed of the I and the III phases is increased at the expense of their length increase along with unchanged duration. The dynamics of general center of gravity speed in the cycle of skating stroke explains the change of the phase composition as the speed of the skier's movement increases.

The greatest drop in speed of general center of gravity takes place during the second phase. This is due to the reduction of its duration with increased total speed of skating step. The speed of the phase is increased at the expense of its duration reduction at a constant length. Another way is possible: increase of phase length with the same duration. In our example it is typical for the I and the III phases. However, such a way is not suitable for the phases of foot taking-off. Their length can not be significantly increased (the period of ski stand). Therefore, only the first variant of their speed increase is possible – at the expense of the reduction of phase time. This is confirmed practically: as the speed of movement increases, the time of taking-off decreases. Similar trends can be easily traced during uphill skiing (Table 5).

Table 4. Speed of skier general center of gravity in the cycle of diagonal stride motion during different intensity of skiing on flat segment

Speed of general center of gravity (***t***), s	Speed of skating step (***V***), ms^{-1}			*Phase*
	5.35	*4.75*	*3.75*	
0.05	5.60	5.00	4.15	I – free sliding with absorption
0.06	5.61	5.01	4.14	
0.07	5.62	4.99	4.13	
0.08	5.61	4.98	4.12	
0.09	5.60	4.97	4.11	
0.10	5.58	4.96	4.10	
0.15	5.50	4.90	4.05	
0.18	5.45	4.81	3.93	
0.20	5.40	4.75	3.91	II – sliding with foot extension
0.30	5.20	4.60	3.60	
0.35	5.15	4.55	3.50	
0.40	5.10	4.52	3.46	
0.45	5.08	4.50	3.50	
0.50	5.18	4.55	3.55	III – sliding with squatting
0.53	5.30	4.61	3.69	
0.55	5.40	4.70	3.80	IV – lunge with take-off foot flexion in knee joint
0.60	5.50	4.86	4.00	
0.65	5.60	4.97	4.10	V – taking-off with take-off foot extension
0.70	5.65	5.10	4.15	

The following regularity was observed: increase of skiing speed was associated with reduced fluctuations of skier general center of gravity speed (or, rather his hip joint). Fluctuations of skier general center of gravity speed are determined according to formula:

$$\frac{V_{max}-V_{min}}{V},$$

where $V_{max}-V_{min}$ – the difference between extreme values of general center of gravity speed in the cycle of skating step, V — average speed of skating step.

Table 5. Speed of skier general center of gravity in the cycle of skating stroke during different intensity of uphill 8° skiing

Speed of general center of gravity (***t***), s	Speed of skating step (***V***), ms^{-1}		*Phase*
	2.95	*3.80*	
0.01	2.93	3.80	I – free sliding with absorption
0.02	2.92	3.78	
0.04	2.90	3.75	
0.05	2.87	3.68	III – sliding with squatting
0.10	2.82	3.60	
0.13	2.68	3.50	III – sliding with squatting
0.16	2.64	3.40	
0.25	2.31	3.20	IV – lunge with take-off foot flexion in knee joint
0.30	2.33	3.30	
0.34	2.45	3.44	
0.40	2.70	3.70	V – taking-off with take-off foot extension
0.45	2.90	3.80	
0.50	3.00	3.84	

Table 6 presents percentages of this value.

At distance segments of different steepness, the relative fluctuations of general center of gravity speed are not the same. The direction of their changes with increase of skiing speed is traced clearly. The decrease of ΔV is associated with reduction of the time of the "fastest" (where V_{max} takes place) and the "slowest" (V_{min}) phases with their constant length. In our example (Tables 4 and 5), these are the II and the V phases for the flat segment and the IV and the V phases for 8° uphill. Total step time is reduced, whereas its speed is increased at the expense of these phases duration reduction. An increase of step speed diminishes the degree of deviations from the uniform speed of skiing. This is the index of utilized technique efficiency.

Table 6. Fluctuations of skier speed of general center of gravity (%)

Slope steepness (α), %	*Speed of skiing (**V**), %*		
	80	*100*	*110*
0°	27	27	16
4°	35	34	28
8°	23	20	17
12°	27	21	20

Changes in the phase composition of skating step with increase of skiing speed at any segments occur at the expense of two phases - IV, V (for flat areas and gentle uphill the II phase is included). These are the periods when the ski is stationary. To characterize the structure of skating stroke, it is advisable to introduce a rhythmic index - the ratio of ski sliding time to that of its standing. Dependences of the rhythm time coefficient on the speed of movement for distance segments of different steepness are presented in Table 7. Distinctive sharp decrease in linear growth at certain values of the speed is noted. This peculiar "threshold" is in the range from 85 to 90%. Improvement of the technique of skating steps should be conducted at a speed not lower than 85% of the average competitive one. The internal structure of the step determined by the rhythm of movements at low speeds, is significantly different from the competitive one.

Table 7. Change of rhythm time coefficient (***I***) depending on speed of skiing (***V***) at segments of different steepness (***α***)

V, %	***α***, m							
	0°		*4°*		*8°*		*12°*	
	X	*σ*	*X*	*σ*	*X*	*σ*	*X*	*σ*
70	2,12	0,11	-	-	-	-	-	-
75	2,31	0,11	0,91	0,11	-	-	-	-
80	2,52	0,09	1,25	0,09	0,25	0,06	0,14	0,06
85	2,69	0,13	1,47	0,11	0,42	0,05	0,25	0,06
90	2,84	0,11	1,60	0,09	0,56	0,07	0,35	0,11
95	2,90	0,21	1,65	0,17	0,61	0,09	0,39	0,03
100	2,92	0,22	1,70	0,15	0,66	0,09	0,43	0,08
105	2,89	0,17	1,72	0,09	0,69	0,11	0,41	0,13
110	2,73	0,13	1,77	0,12	0,71	0,11	0,38	0,11
115	-	-	-	-	0,73	0,12	0,37	0,09

Changes of skating step external structure with an increase in skiing intensity at a segment of a certain steepness are quantitatively small. Of thirty considered kinematic and angular indices of skating stroke, only six changed significantly. The ratios of the lunge speed, the maximum velocities of foot and hand to the speed of skating step became lower. This was due to faster increase of skiing speed relative to that of maximum velocity of extremity motions. However, it is not the evidence of a decrease in the vigor of performing these motions. The duration of pushing-off (both absolute and relative values) tends to decrease. Along with speed increase, the ski pole is placed closer to the boot tip. The angle of hip inclination of swing-up leg decreases after the end of the lunge. The skier uses slightly lower posture. The external "picture" of skating step remains even at a speed below 80% of the competitive. The technique should be mastered at high speeds (over 85%) so that to form the correct rhythmic structure of skating stroke. The rhythm of motions represents an integral index of the technical level of athlete motions.

An increase of skiing speed is accompanied by decreased fluctuations of general center of gravity speed at the expense of reduction in the time of those phases, the speed of which is maximally higher or lower than the average speed of skating step. This is manifested in a more uniform movement of the skier in the cycle of skating stroke without noticeable speed drops in the period of sliding and without accelerations during pushing-off.

Discussion

The modern technique of skating steps, especially the sprint technique is highly efficient, but extremely energy-consuming, and requires excellent physical fitness. The rational use of various variants of techniques during covering competitive distances contributes to economy of efforts, energy and increase of overall performance (Eisenmann at al., 1989; Losnegard at al., 2012).

Diagonal stride motion, despite the common cross-coordination (like walking without skis) is rather complicated and requires a considerable amount of time for its mastering. The presence of a sliding phase makes it necessary to coordinate the work of hands and feet with respect to time. The change of motion rhythm while skiing uphill creates certain difficulties in mastering this skating step. The study of the diagonal stride motion begins after repetition and refreshment of skills in skating stroke skiing (Houdijk at al., 2000; Kamaeva & Kamaev, 2011).

Today, scientists around the world conduct studies of the kinematics of various skating steps using state-of-the-art equipment (Macintosh & Chapman, 2012; Schenau at al., 1990). The studies allow to isolate separate phases of motions, general, as well as individual peculiarities of skiing techniques, which are associated with anthropometric characteristics.A detailed analysis of data of skating step technique represents one of the most promising directions of studies. It may be now obtained by means of special microsensors fixed on the athlete, which collect information on the displacement of body parts and accelerations (Nilsson at al., 2004; Stoggl at al., 2007). In this case, however, the influence of such variables as speed, state of snowpack and peculiarities of skiing run profile should be thoroughly controlled.

Scientific literature dealing with skiing is almost lacking a qualitative biomechanical analysis of skating step techniques. Until now, there is an apparent deficiency of clear, modern principle based methods of skating steps. The basic elements of the effective technique of each type of skating steps are still unrevealed. Discussions and assumptions on this issue fill the leisure time of coaches and athletes (Kvamme at al., 2005; Millet at al., 2003; Sandbakk at al., 2012; Stoggl at al., 2013). The basis of "ideal" technique is formed by the so-called "target technique". It rests upon the individual abilities and capacities of athletes, sets the major parameters and determines the content of training sessions.

Clear definition, explanation and consolidation of the factors that ensure sports achievements are the prerequisites for development of efficient concept and methods of technique development and mastering. And, first of all, it is the study of qualitative aspects and their importance for providing the economy of movement (easiness and energy economy due to technical skills), speed of movement, i.e. the final result at the competitions.

One of the concepts of improving the quality of training sessions that has not yet found its way into international training practice is the enhanced development of skiing technique in the direction of energy economy (Sandbakk at al., 2010; Stoggl at al., 2010), including in combination with specific strength endurance in all its forms.

The importance and the highest priority of fundamental biomechanical studies of the types of skating steps as the basis for the development of further ideas is quite obvious for the authors.

Conclusions

An increase in the speed of skiing diagonal stride motion at 4-12° steepness of distance occurs at the expense of proportional increase of stride length and frequency. The rhythm of motions represents an integral index of the technical level of athlete motions. The technique should be mastered at high speeds so that to form the correct rhythmic structure of skating stroke. The simplest control for the technical preparation of skiers can be exercised according to general characteristics of the technique (stride length and frequency), knowing the regularities of their changes, depending on skiing speed and slope steepness.

Funding

The authors received no financial support for the research, authorship and publication of this article.

Conflict of interest

The authors declare no conflict of interest.

References

Andersson, E. (2010) Analysis of sprint cross-country skiing using a differential global navigation satellite system. *European Journal of Applied Physiology*, *110*, 585-595.

Baumann, W. (1985) The Mechanics of the Roller Ski and its Influence on Technique in Cross Country Skiing. *Biomechanics*: *Current Interdisciplinary Research*, *12*, 711-716.

Bilodeau, B., Rundell, K.W., Roy, B., Boulay, R.M. (1996) Kinematics of cross-country ski racing. *Medicine and Science in Sports and Exercise*, *28*, 1, 128-138.

Chikov, A.E., Chikova, S.N. (2013) Indicators of Mechanical Power of cross-country skiers in classic and skate skiing. *European Journal of Natural History*, *1*, 27.

Drenk, V. (1993) *Panning. Dokumentation zum zusatzprogramm zur behandlung schw enkimd neigbarer und in ihrer brennweite variierbarer kameras in peak 3D*.

Eisenmann, P.A., Johnson, S.C., Bain-Bridge, C.N., Zupan, M.F. (1989) Applied Physiology of Cross-Country Skiing. *Sports Medicine*, *8*, 2, 67-79.

Grasaas, C.A., Ettema, G., Hegge, A.M., Skovereng, K., Sandbakk, O. (2014) Changes in technique and efficiency after high-intensity exercise in cross-country skiers. *International Journal of Sports Physiology and Performance*, *9*, 1, 19-24.

Holmberg, HC, Lindinger, S, Stoggl, T, Eitzimair, E, Muller, E. (2005) Biomechanical analysis of double poling in elite cross-country skiers. *Medicine and Science in Sports and Exercise*, *37*, 807-818.

Houdijk, H., Koning, J.J., Groot, G., Bobbert, M.F., Van Ingen, Schenau, G.J. (2000) Push-off mechanics in speed skating with conventional skates and klapskates. *Medicine and Science in Sports and Exercise*, 32, 635–639.

Kamaeva, E.K., Kamaev, V.O. (2011) Features of educating of students to the technique of ski motions on the basis of innovative technologies. *Physical Education of Student*, *3*, 46-48.

Koriagina, Y.V. (2015) Ski equipment moves: modern foreign classification and terminology. *Athletic formation of Siberia*, *1(33)*, 100-104.

Kvamme, B., Jakobsen, B., Hetland, S., Smith, G. (2005) Ski skating technique and physiological responses across slopes and speeds. *European Journal of Applied Physiology*, *95*, 2, 205-212.

Lindinger, S.J., Stoggl, T., Muller E., Holmberg H.C. (2009) Control of speed during the double poling technique perfonned by elite crosscountry skiers. *Medicine and Science in Sports and Exercise*, *4L*, 210-220.

Lindinger, S.J., Holmberg, H.C. (2011) How do elite cross-country skiers adapt to different double poling frequencies at low to high speeds? *European Journal of Applied Physiology*, *111*, 1103-1119.

Losnegard, T.T., Myklebust, H., Hallen, J. (2012) Anaerobic capacity as a determinant of performance in sprint skiing. *Medicine and Science in Sports and Exercise*, *44*, 4, 673-681.

Macintosh, D., Chapman, D. (2012) *Sensors*, 12, 5047-5066; doi:10.3390/s120405047.

Marsland, F., Lyons, K., Anson, J., Waddinglon, G., Macintosh, D., Chapman, D. (2012) Identification of Gross-Country Skiing Movement Patterns Using Micro-Sensors. *Sensors*, *12*, 5047-5066; doi: 10.3390/s120405047.

Millet, G.P., Boissiere, D., Candau, R. (2003) Energy cost of different skating techniques in cross-country skiing. *Journal of Sports Sciences*, *21*, 1, 3-11.

Mössner, M. (1992) *3D-filmauswertung bei mitgeschwenkter und gezoomter kamera. Institutsbericht am institut für mathematik und geometrie der universität innsbruck*.

Myklebust, H., Losnegard, T., Hallen, J. (2014) Differences in V1 and V2 ski skating techniques described by accelerometers. *Scandinavian Journal of Medicine and Science in Sports*, *24*, 6, 882-893.

Nilsson, J., Tveit, P., Eikrehagen, O. (2004) Effects of speed on temporal patterns in classical style and freestyle cross-country skiing. *Sports Biomechanics*, *3*, 85-107.

Novikova, NB, Sergeev GA. (2016) Diagonal stride technique features of world's best long distance cross-country skiers. *Uchenye zapiski universiteta imeni P. F. Lesgafta*, *135*, 5, 177-184.

Ramenskaya, T.I. (2001) *Special training of the skier.*

Sandbakk, O., Holmberg, H.C., Leirdal, S., Ettema, G. (2010) Metabolic rate and gross efficiency at high work rates in world class and national level sprint skiers. *European Journal of Applied Physiology*, *110*, 3, 473-481.

Sandbakk, O., Ettema G., Leirdal, S., Holmberg, H.C. (2011) Analysis of a sprint ski race and associated laboratory determinants of world-class performance. *European Journal of Applied Physiology*, *111*, 947-957.

Sandbakk, O., Ettema, G., Leirdal, S., Holmberg, H.C. (2012) Gender differences in the physiological responses and kinematic behavior of elite sprint cross-country skiers. *European Journal of Applied Physiology*, *112*, 3, 1087-1094.

Sandbakk, O., Leirdal, S., Ettema, G. (2015) The physiological and biomechanical differences between double poling and G3 skating in world class cross-country skiers. *European Journal of Applied Physiology*, *112*, 3, 483-487.

Schenau, G.J., Van Ingen, Cavanagh, P.R. (1990) Power equations in endurance sports. *Journal of Biomechanics*, *23*, 9, 865-881.

Smith, G.A. (1990) Biomechanics of Cross-country Skiing. *Sports Medicine*, *9*, 5, 273-285.

Stoggl, T., Lindinger, S., Muller, E. (2007) Analysis of a simulated sprint competition in classical cross country skiing. *Scandinavian Journal of Medicine and Science in Sports*, *17*, 362-372.

Stoggl, T., Müller, E., Lindinger, S. (2008) Biomechanical comparison of the double-push technique and the conventional skate skiing technique in cross-country spruit siding. *Journal of Sports Science*, *26*, 1225-1233.

Stoggl, T., Kampel, W., Müller, E., Lindinger, S. (2010) Double-push skating versus V2 and V1 skating on uphill terrain in cross-country siding. *Medicine and Science in Sports and Exercise*, *42(1)*, 187-196.

Stoggl, T., Muller, E., Ainegren, M., Holmberg, H.C. (2011) General strength and kinetics: fundamental to sprinting faster in cross country skiing? *Scandinavian Journal of Medicine and Science in Sports*, *21*, 6, 791-803.

Stoggl, T., Hebert-Losier, K., Holmberg, H.C. (2013) Do anthropometries, biomechanics, and laterality explain VI side preference in skiers. *Medicine and Science in Sports and Exercise*, *45(8)*, 1569-1576.