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Original Article

SKI-ERG training for enhancing anaerobic glycolysis in cross-country skiers

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Abstract.
The aim of the study was to determine the effectiveness of the cross-country ski training method based on the development of anaerobic glycolysis. **Materials and methods.** The study involved a highly skilled skier (27 years old). To assess the effectiveness of training for the development of anaerobic glycolysis, the subject was asked to perform two training sessions on the SkiErg ski ergometer with double pole technique with an interval of 16 days. The training protocol consisted of 8 sets of 30 seconds after a 5-minute rest. The first set was performed as a warm up, the rest were performed at a power of about 70-80% of the maximum alactate power (MAP). The power of physical activity was set and regulated by the PerfPro computer program developed to work simultaneously with ergometers according to the ANT + system (Fig. 1). After each set, at the end of the first minute of rest, the concentration of lactate was measured using the LACTATE PLUS portable device (USA). According to the results of the study, the indicators of power, capacity and efficiency of anaerobic glycolysis were calculated. Power was evaluated by the rate of lactate accumulation (La (mmol/L/30 s). The capacity of anaerobic glycolysis was assessed by the maximum accumulation of lactate in the blood. The efficiency of anaerobic glycolysis was assessed by the ratio of lactate concentration to the length of the distance (La/S, (mmol / m)). The study was carried out at the pre-competitive stage. **Results:** The training method on the ski ergometer, which comprises 8 sets of 30 seconds after a 5-minute rest, was a local work for the development of anaerobic glycolysis. Power indicators increased by 50.16% ($p < 0.05$), efficiency - 48.25% ($p < 0.05$), capacity - 32.32% ($p < 0.05$). **Conclusion:** The method proposed can be considered as a specific work for the development of speed endurance and anaerobic glycolysis, the inclusion of which is possible only under the condition of a formed “aerobic base.” It aims to avoid excessive accumulation of metabolites due to local work, which allows to control the power drop. The efficiency of glycolytic performance 8x30 sec consists in the following protocol: the number of sets is not more than 8; stop criterion is a drop in average power by 5-7%, rest between sets for at least 5 minutes; determining blood lactate from finger blood, the difference between earlobe blood is about 1.5 mmol; the first set is warming up, the rest should be conducted at a power of about 70-80% of the MAP (maximum alactate power).
Keywords: anaerobic glycolysis, lactate, power, cross-country skiers

Introduction

Aim. Development of aerobic energy supply is the main task for cross-country skiers. Aerobic performance allows to increase the activity of oxidative enzymes in the muscles up to 230%. Studies show that competitive performance in cross-country skiing depends on the activation of aerobic and anaerobic processes that provide ATP resynthesis. Analysis of foreign literature shows that the ratio of aerobic and anaerobic contributions in sprint is equal to 75% and 25%, and in distance skiing - 90% and 10%, respectively. When skiing uphill, anaerobic contributions in sprinters reach up to 40% and in long-distance skiers - up to 10 - 20% (Andersson E.P., Noordhof D.A., Logdal N., 2020; Losnegard T., 2019; Bakhareva, A., Cherepanov, V., Bykov, E., & Budanov, G., 2020). Therefore, aerobic metabolism alone is not enough to ensure energy needs because the maximum power of anaerobic glycolysis is about 2.50 kJ/min, which is 2-3 times higher than the power of the aerobic process (Solovev V.B., Volodin R.N., 2016).

Anaerobic training comprises exercise of supramaximal intensity and is aimed at stimulating the production of anaerobic energy. The overall goal of anaerobic training is to increase the athlete's potential for high-intensity exercise, as well as the ability to perform at peak efficiency over a relatively short period of time (Bangsbo J., 2015; Iaia F. M., Bangsbo J., 2010; Iaia F.M., Bangsbo J., 2009).

The complexity of energy supply mechanisms and the development of motor qualities, such as strength, speed and endurance, restrain the development of speed endurance (Zakirov M.M., 2018; Nutsialov N.N., Samsonov A.N., Rutman A.B., 2018; Fomin D.A., 2018; Khaupshev M.K., Kirzhinov M.M., Atabiev A.M., Tsagov S.Z., Soblirov A.M., Perkhichev T.A., 2016; Yatsyk V.Z., Vasilchenko O.S., Podgornaya A.S., 2018).

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Large volume of glycolytic anaerobic performance leads to a noticeable decrease in aerobic capacity, while increased aerobic performance in the annual cycle reduces anaerobic capacity (oxygen debt) (Gussakov I.V., Nurmukhanbetova D.K., Kudashova L.R., Afzalova A.N., Kydyrbaeva D.B., 2020; Solonshchikova V.S., Mavliev F.A., Manina A.Z., 2019; Golovachev, A., Kolykhmatov, V., & Shirokova, S., 2019).

It turns out that in the case of the maximum development of one of these components, the progress of the others is inhibited. Consequently, the relevance of developing a methodology for improving speed endurance in cross-country skiers with respect to their sports disciplines increases.

Materials and methods

To assess the effectiveness of training for the development of anaerobic glycolysis, the subject was asked to perform two training sessions with an interval of 16 days on the SkiErg ski ergometer with double pole technique. The training protocol consisted of 8 sets of 30 seconds after a 5-minute rest.

The first set was performed as a warm up, the rest were performed at a power of about 70-80% of the maximum alactate power (MAP). The power of physical activity was set and regulated by the PerfPro computer program developed to work simultaneously with ergometers according to the ANT + system (Fig. 1). The data obtained were processed by using the SPSS 15 Statistica software package.

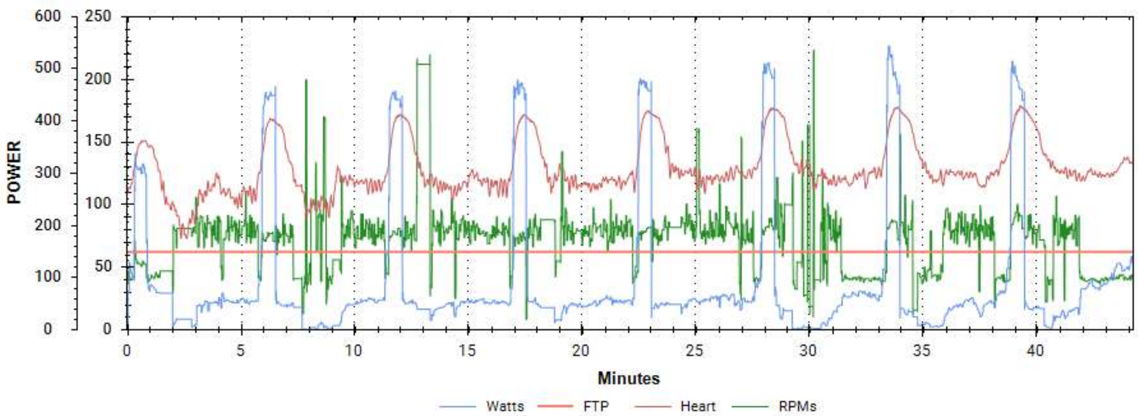

Fig.1. Training protocol in the PerfPro program

After each set, at the end of the first minute of rest, the concentration of lactate was measured using the LACTATE PLUS portable device (USA). According to the results of the study, the indicators of power, capacity and efficiency of anaerobic glycolysis were calculated. Power was evaluated by the rate of lactate accumulation (La (mmol/L/30 s).

The capacity of anaerobic glycolysis was assessed by the maximum accumulation of lactate in the blood. The efficiency of anaerobic glycolysis was assessed by the ratio of lactate concentration to the length of the distance (La/S, (mmol / m)).

Results

The data obtained during the training sessions were recorded in the protocols (Tables 1, 2).

Table 1. Protocol of the 1st training session

Set	La, mmol	S, m	W_{mean}, W	W max, W	HR_{mean}, bpm	HR max, bpm	HR bpm	Δ HR
1	1.5	139	260	336	140	151	100	51
2	3.6	156	374	456	153	168	115	53
3	4.5	154	384	457	154	171	121	50
4	5.8	160	393	478	154	171	118	53
5	5.8	157	394	481	155	174	131	43
6	8.0	165	428	512	162	177	132	45
7	9.7	163	425	543	163	177	136	41
8	9.9	156	415	514	165	179	135	44

Table 2. Protocol of the 2nd training session

Set	La, mmol	S, m	W_{mean}, W	W max, W	HR_{mean}, bpm	HR max, bpm	HR bpm	Δ HR
1	5.8	152	432	470	154	160	103	57
2	6.3	157	445	492	159	169	111	58
3	7.4	154	439	507	155	170	114	56
4	7.9	162	473	521	165	175	131	44
5	9.5	161	487	518	169	177	133	44
6	10.8	163	484	521	168	177	134	43
7	12.5	161	500	534	168	176	134	42
8	13.1	156	484	539	172	177	139	38

Table 3 shows that in the second training session, the lactate level increased by 50.16% ($p < 0.05$). The increase in lactate is observed against the background of an increase in the power of work, the average values of which increased by 21.83%, the maximum values - by 8.60%, and the frequency of hand movements (cadence) - in 16.75 times. At the same time, in the second training session, with increasing power, an increase in average heart rate by 8 bpm was observed. The maximum heart rate values both at the first and at the second training session did not have significant differences and were within the limits of 4-5 intensity zones.

Table 3. Dynamic of indicators at training sessions (M±m)

Training session	La, mmol	S, m	W_{mean}, W	W max, W	HR_{mean}, bpm	HR max, bpm	HR bpm	Δ HR
1	6.10± 2.26	156.25± 7.92	384.13± 53.77	472.13± 62.68	155.75± 7.92	171.00± 8.90	123.50± 12.41	47.50± 4.78
2	9.16± 2.77	158.25± 4.06	468.00± 25.60	512.75± 22.66	163.75± 6.84	172.63± 6.02	124.88± 13.41	47.75± 7.91

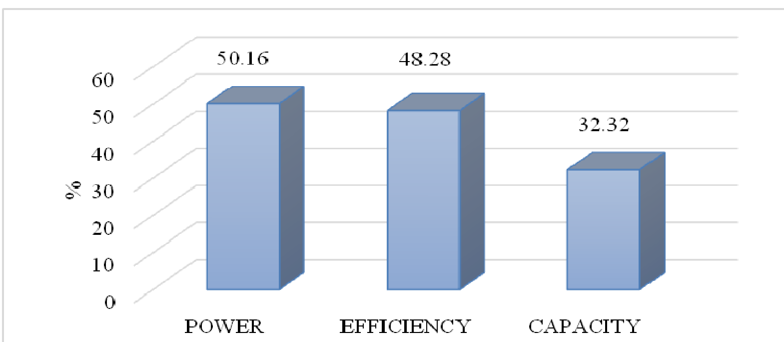

Fig 2. Anaerobic (glycolytic) performance

Figure 2 shows that speed endurance training leads to an increase in anaerobic (glycolytic) metbolism. Power, which was assessed by the rate of lactate accumulation, increased by 50.16% ($p < 0.05$); the capacity of anaerobic glycolysis - by 32.32% ($p < 0.05$); the efficiency of anaerobic glycolysis increased by 48.25% ($p < 0.05$).

Discussion

High-intensity exercises for more than 10 seconds lead to a pronounced accumulation of H + and lactate, which determines the development of fatigue. Moreover, K + and Na + are accumulated outside and inside of muscle cells, causing changes in membrane potential and sarcoma resistance (Sejersted O.M., Sjqgaard G., 2000). Consequently, the Na +/K + pump plays a crucial role in maintaining membrane excitability and skeletal muscle function, that is, slowing down the time of fatigue during exercise at a given intensity. Early studies found that speed endurance training in athletes increased the expression of the α1 or α2 subunits of the Na +/K + pump, while there was no significant increase in the β1 subunit. The enhanced α-subunits of the Na +/K + pump lead to a large number of functional pumps and enhance performance during intensive short-term exercise. Higher peak Na +/K + pump activity has been shown to reduce net K + loss from contracting muscles, while maintaining cell excitability and force production. This is supported by the fact that in studies showing increased expression of α-subunits after speed endurance training, the accumulation of K + in venous plasma was reduced and performance during repeated supramaximal exercise improved (Hansen A.K., Clausen T., Nielsen O.B., 2005). Other studies show that after speed endurance training, the expression of the first isoform of the Na + / H + exchanger (NHE1) is increased. This results in the uptake of Na + within the muscle cell and thus results in a higher stimulation of the Na +/K + pump, causing hyperpolarization of the membrane potential. This mechanism leads to a decrease in intracellular pH and contributes to the delayed onset of fatigue and enhanced performance during intensive exercise. It was also found that speed endurance training creates conditions for a higher expression of monocarboxylate transporters (MCTs) (Mohr M., Krustrup P., Nielsen J.J., Nybo L., Rasmussen M.K., Jue C., Bangsbo J., 2006). which are involved in lactate transport. According to the authors, the increase in the total release of lactate from the muscle, both under normoxic and hypoxic conditions, is mainly regulated by the activation of the sympatho-adrenal system (Guliyev Yu.N., Bagirova R.M., 2013; Chinkin A.S., 2014; Vincenzo de Paoli F., Overgaard K., Pedersen T.H., Nielsen O.B., 2007). This is confirmed by the similar dynamics of arterial norepinephrine concentration and the total release of lactate from the working muscle (Duclos M., Tabarin A., 2016). With the release of catecholamines as a result of hypoxic stress, the hypothalamic-pituitary-adrenal system is activated through the secretion of glucocorticoids (Hill E. E., Zack E., Battaglini C., Viru M., Viru A., Hackney A. C., 2014). Glucocorticoids have a powerful effect on carbohydrate, lipid and protein metabolism. Their effect on protein and lipid metabolism in tissues and organs (except for the liver) is predominantly catabolic. The effect of glucocorticoids on carbohydrate metabolism is expressed in the stimulation of gluconeogenesis. The main effect of glucocorticoids on protein metabolism is the mobilization of amino acid resources and the induction (in particular, in the liver) of the synthesis of a number of enzymes. Through the synthesis of the corresponding enzymes, glucocorticoids enhance the transamination of amino acids. Thus, glucocorticoids not only mobilize "building materials" for protein synthesis but also prepare them for their intended use. Anaerobic training increases the activity of glycolytic enzymes and ATP synthase, which leads to an increase in the rate of glycolysis and muscle contraction.

According to available data, during short-term (from 25 to 40 seconds) glycolytic performance to failure, CRF concentration in human skeletal muscle drops to almost zero, while the decrease in ATP does not exceed 30–40% of the initial total content in the muscle (Biryukova I.V., 2014). Due to the degradation of creatine phosphate in the muscle, there is a pronounced increase in creatine, a slight decrease in adenosine triphosphate and a pronounced increase in the level of adenosine monophosphate, which activates 5' AMP-activated protein kinase (AMPK), which is involved in the regulation of muscle energy metabolism and adaptation (Witczak C. A., Sharoff C. G., Goodyear L. J., 2008). As a result of AMPK activation, the cell goes into an energy-saving state, blocks the synthesis of fatty acids, activates their oxidation, and participates in cholesterol metabolism. At the same time, AMPK can phosphorylate and activate Na +, K + -ATPase, which leads to an increase in Na + transport from muscle cells (Shenkman B.S., Vilchinskaya N.A., 2018). AMPK is involved in the regulation of mitochondrial gene expression and mitochondrial biogenesis by phosphorylation of the PGC-1a protein, which is involved in the coordination of many metabolic reactions in skeletal muscles (Fiorenza M. , Gunnarsson T.P., Hostrup M., Iaia F.M., Schena F., Pilegaard H., Bangsbo J., 2018). Phosphorylation of PGC-1a by AMPK leads to the activation of a variety of transcription factors, such as peroxisome proliferator-activated receptors (PRAR) factors; nuclear respiratory factors (NRF-1.2); mitochondrial transcription factor A (TFAM), MEF factors, and others (Sergej Pirkmajer S., Metka Petric M., Chibalin A.V., 2021).

Conclusion

The use of speed endurance training in the training process of cross-country skiers leads to effective adaptation, as well as an increase in metabolism and performance of skeletal muscles. The increase of power and efficiency of anaerobic glycolysis was found. This is manifested in an increase in maximum oxygen consumption (VO2max), muscle substrate levels, activity of glycolytic, oxidative and hydrolase enzymes, as well as membrane transport proteins involved in pH regulation. This leads to a decrease in energy expenditure when performing submaximal exercises and to an increase in the expression of muscle Na (+)/K (+) pump α-subunits, which, due to the higher activity of the Na +/K+ pump during exercise, delay the onset of fatigue. The local mode of operation on the Ski-Erg ski ergometer kept maximum power throughout the training session and minimized stress on the heart.

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