DOI 10.26773/smj.220212

SportMont

ORIGINAL SCIENTIFIC PAPER

The Method for Enhancing Statokinetic Stability in Alpine Skiers Based on the Use of Normobaric Hypoxia in Combination with Cervical Spine Muscle Exercises

Alexander Bolotin[1] and Vladislav Bakayev[1]

[1]Peter the Great St. Petersburg Polytechnic University, Institute of Physical Education, Sports and Tourism, St. Petersburg, Russia

Abstract

Lately, the improved outfitting and sports alpine skiing equipment have brought about significantly increased speed of their motion on the mountain slope. At the same time, alpine skiers' psychological and physiological reserves remain practically unchanged. In order to enhance the statokinetic stability level of the alpine skiers included in the experimental group, normobaric hypoxia training in combination with cervical spine muscle exercises were used for a month during a preparatory period before competitions. The subjects of the control group used conventional exercises to enhance the statokinetic stability level. The results of the studies showed that the alpine skiers from the experimental group demonstrated a confidently increased tolerance time of continuous cumulation of Coriolis accelerations (versus initial measurements). We also observed the lowered intensity of negative vestibulosensory, vestibulovegetative and vestibulosomatic reactions. This showed their improved tolerance of continuous cumulation of Coriolis accelerations. Besides that, the alpine skiers of the experimental group showed positive changes in the static stabilometric test in the integrated functional computer stabilography. The open eyes test showed a confidently significant reduction in the rate of increase of the statokinesiogram length and area, oscillation amplitude of the projection of the common center of gravity in the frontal and sagittal planes, and also the coefficient of asymmetry in the frontal and sagittal directions. The obtained results can justify recommendation of normobaric hypoxia course to be used in combination with cervical spine muscle exercises as means to improve statokinetic stability in alpine skiers.

Keywords: *alpine skiers, statokinetic stability, normobaric hypoxia, cervical spine muscle exercises*

Introduction

At present, the most important and mandatory conditions for achieving high results in professional sports are the athlete's sufficient psychophysiologic capacity, good functional state and high physical performance (Bakayev, 2015; Hébert-Losier, Supej, & Holmberg, 2014; Wrigley, 2015; Bubanja, Milasinovic, & Bojanic, 2016).

The optimum state of the above psychophysiologic characteristics is of special importance for alpine skiers whose competitive activities are associated with high tension of the organism psychophysiologic functions during the movement along a piste at high speed. The movement speed can exceed 200 km/h along the giant slalom piste during competitions of alpine skiers. Alpine skiers experience intensive

Correspondence:

V. Bakayev
Peter the Great St. Petersburg Polytechnic University, Institute of Physical Education, Sports and Tourism, 29 Polytechnicheskaya st., St. Petersburg, 195251, Russia
E-mail: vlad.bakaev@gmail.com

overstresses and simultaneously they should make correct decisions within a minimum interval of time in order to select the right trajectory of going along a piste and at the same time not to allow technical mistakes. Such activity places high demands on alpine skiers' organism psychophysiologic systems.

Lately, the considerably improved alpine skiing equipment, betterment of sports equipment technical data result in significantly increased speed of their movement along a piste. At the same time, athletes' psychophysiological reserves remain practically unchanged. This non-compliance resulted, in its turn, in the situation, when during the excessive impact of dynamic factors associated with going along a piste the sportsman's organism is influenced by the forces, which worsen the functional state of his/her vestibular system and have a negative effect on the efficiency of competitive activities (Bakayev, Bolotin, & You, 2018; Nemec, Petric, Babic, & Supej, 2014). This is associated with the fact that the high-speed movement and maneuvering along a piste are accompanied by the influence of angular, linear and centipetal accelerations on the athletes' organisms, which can lead to development of stable vestibulosomatic (vestibular somatic reactions are based on changes in the tone of the striated muscles of the eye, limbs, trunk and neck, which is realized in the form of nystagmus, a motor reaction of the limbs, head and trunk), vestibulovegetative (vestibular-vegetative effects are based on changes in the function of the organs innervated by the vegetative nervous system, which is manifested by haemodynamic, vascular reactions, nausea, vomiting, sweating, changes in the colour of the skin, etc.) and vestibulosensory (vestibulosensory (imaginative) reactions are associated with cortical stimulation and are realised by the appearance of a sense of movement, reflecting its direction and speed, which is characterised as vertigo) reactions. The duration and significant intensity of these reactions have a negative effect not only on alpine skiers' well-being but also on the quality of going along a piste at competitions (Supej, Kugovnik, & Nemec, 2004).

The studies performed by many scientists provide evidence that excessive exposure to dynamic factors negatively influences the bioelectric cerebral cortex activity and conditioned reflexes, memory, attention, emotional responses and also orientation in space. Meanwhile, the time on a piste, as well as the number of mistakes, including gross mistakes, affecting the safety of the athletes' downhill movement, increase. This circumstance dictates the need to search for new effective means and methods for training alpine skiers aimed at improvement of the functional state of their vestibular system and the level of their physical performance (Bakayev et al., 2018; Hadzic, Bjelica, Vujovic, & Popovic, 2015; Mao, Chen, Li, & Huang, 2014; Vaverka, & Vodickova, 2010). This is related to a high degree of manifestation of sensory, vegetative and somatic components of statokinetic reactions in alpine skiers.

The methods currently used for improvement of the functional state and physical performance of athletes, as a rule, directly influence various physiologic systems of alpine skiers. These methods include the method of normobaric hypoxic training as well, which is used to enhance the athletes' organisms resistance to unfavorable influence of several factors associated with going along a piste (Wrigley, 2015; Naeije, 2014; Mekjavic, Amon, Kölegård et.al., 2016; Gonggalanzi, Labasangzhu, Bjertness, Wu, Stigum & Nafstad, 2017). Besides that, this method is aimed at improvement of adaptive reserves of the alpine skiers' vestibular systems.

Currently, despite the availability of a detailed description of mechanisms of negative impact exerted by hypoxia on organs and tissues, in certain conditions it can also be regarded as a driver for expansion of physiologic ranges of functional systems. This can favor the enhancement of the athletes' organism psychophysiologic reserves. The use of normobaric hypoxic training in combination with exercises for certain muscle groups can result in optimization of the athletes' functional state and enhancement of their physical performance (Bakayev, 2015; Bakayev et al., 2018; Gorshova et al., 2017; Vogiatzis et.al., 2007).

The objective of the study was to develop a method for the use of normobaric hypoxia in combination with special cervical muscle exercises of alpine skiers to enhance their statokinetic stability, improve the adaptive resources of the vestibular system for competitive activities.

Methods

The study was performed at the Department of Medical and Valeological Specialties at the Herzen State Pedagogical University of Russia, Institute of Physical Education, Sport and Tourism at the Peter the Great Saint Petersburg Polytechnic University. The alpine skiers aged 18–20 years, whose tolerance time of continuous cumulation test of Coriolis accelerations (hereinafter referred to as CCCA) was less than 2 minutes, performed as the subjects.

At the initial stage of the experiment, all the subjects were presented the plan and protocol of the forthcoming study, and the methods used. All subjects provided voluntary written consent to participate in the experiment (in accordance with the Declaration of Helsinki on Ethical Principles for Medical Research). Next, random sampling was used to form two groups of subjects: the experimental group (n-12) and the control group (n-12). Subsequently, the subjects of the experimental group were engaged in a month course of normobaric hypoxia training (hereinafter referred to as NBHT) in combination with dedicated cervical muscle exercises (hereinafter – DCME). The subjects of the control group received "false" NBHT courses and they did not perform DCME at all.

All subjects underwent a repeated investigation in the initial extent after a month experiment. Then the investigation in the initial extent was repeated 1, 2 and 3 months after the completion of the experiment.

In the course of the experiment, the CCCA test tolerance time was determined using the procedure and evaluation according to the traditional R. Barany chair method (Pearce, 2007; Lewkowicz, & Kowaleczko, 2019). The degree of manifestation of sensory, vegetative and somatic components of statokinetic reactions was also assessed. It was determined using a point rating system developed by us: 0 – absence of sensations; 1 – mildly manifested sensations; 2 – intense sensations.

In the experimental group (EG), we used the "Bionova-Nova-204, AF" system (Russia) for NBHT. NBHT was performed in a course of 14 sessions. The duration of each session was 30 minutes. During the first session, the subjects were administered hypoxic gas mix with 18.0 % oxygen content. During the following four sessions, oxygen content was reduced by 1.0–1.5 %. Starting from the fifth session to the end of the NBHT course, oxygen content in the hypoxic gas mix was maintained at the level of 11.0–12.0 %.

The DCME method included two exercises in the supine position. In Exercise No. 1, the subject was supine on a gymnastic bench, with the head poised (earphone helmet loaded with 500 g weight prevented engagement of muscles adducting the head to the chest). In Exercise No. 2, a rubber band, secured around the head with the loose end protracting from the back of the head, was fixed 0.8 meters higher than the bench level, preventing engagement of muscles extending the head. In both exercises the subjects of EG evenly tilted the head upward and downward, making one movement in two seconds, with the tilt angle of 30.0°, the duration of each exercise was 5 minutes, and the interval between exercises was also 5 minutes.

Immediately after CCCA, the ST-02 stabilograph was used for the subjects to perform a static stabilometric test in the integrated functional computer stabilography (hereinafter – SST IFCS), consisting of two tests: test No. 1 was performed with the eyes open and the subject's gaze fixed on the remote (5 m) object; test No. 2 was performed with the eyes closed. The duration of tests amounted to 20 seconds, with the 1-minute interval between them. During the study we recorded the parameters of the mean rate of increase of the statokinesiogram length and area, oscillation amplitude (hereinafter referred to as OA). Besides that, the coefficient of asymmetry (hereinafter referred to as CA) of the projection of the common center of gravity (hereinafter referred to as PCCG) in the sagittal and also frontal planes was also assessed.

Statistical processing of the obtained data was performed using Microsoft Excel software package according to the adopted standards. Numerical distribution characteristics were calculated for each sample of parameters. The statistical significance of difference between the compared samples was evaluated using the parametric Student's t-test.

Results

Results obtained in the course of the studies justify a conclusion that a month of combined use of NBHT and DCME confidently improved CCCA tolerance in the subjects of the experimental group. This was accompanied by a reduced degree of manifestation of sensory, vegetative and somatic components of statokinetic reactions (Table 1).

Table 1. Tested functional parameters for subjects "Before" and "After" a month of NBHT use in combination with DCME (M±SD)

No.	Studied parameters	Experimental group		Control group	
		Before	After	Before	After
1	CCCA tolerance time (sec)	97.1±8.3	190.1±7.1*	98.3±7.6	99.7±7.3
2	Heat sensation (points)	0.57±0.05	0.31±0.04*	0.4±0.06	0.4±0.07
3	Head heaviness sensation (points)	0.53±0.07	0.32±0.05*	0.5±0.06	0.4±0.08
4	Vertigo sensation (points)	0.48±0.04	0.21±0.03*	0.4±0.05	0.5±0.04
5	Stomach discomfort (points)	0.47±0.06	0.23±0.05*	0.4±0.07	0.3±0.08
6	Hypersalivation degree (points)	0.64±0.05	0.32±0.04*	0.5±0.07	0.4±0.08
7	Hyperhidrosis degree (points)	0.43±0.03	0.21±0.04	0.4±0.06	0.5±0.07
8	Protective movements (points)	0.78±0.09	0.43±0.07*	0.6±0.07	0.5±0.08
9	Nystagmus duration (sec)	21.2±3.2	17.1±3.4*	21.1±3.3	20.9±3.8
10	Number of subjects	12	12	12	12

Legend: reliability of differences: * – p<0.05 versus initial parameter values; NBHT - normobaric hypoxia training; DCME - dedicatedcervical muscle exercises; CCCA - continuous cumulation of Coriolis acceleration

The CCCA test tolerance time was improved by 95.8 % in comparison with the initial measurements. Moreover, there was a 47.8 % reduction in parameters descriptive of heat sensation, 48.7 % reduction in head heaviness sensation, 59.3 % reduction in vertigo sensations, and 58.1 % reduction in stomach discomfort. Besides, there was a reduction in hypersalivation by 58.3 %, hyperhidrosis by 59.7 %, manifestation degree of protective movements by 49.3 %, and time of post-rotation nystagmus by 18.1 %.

The open eyes test there was a confident decrease in the parameters descriptive of the rate of increase in the length (by 11.8 %) and area (by 12.7 %) of the statokinesiogram, OA PCCG in the frontal (by 14.7 %) and sagittal (by 12.9 %) planes, CA in the frontal (by 14.8 %) and sagittal (by 12.9 %) directions. At the same time, confident changes between parameter values before and after the course of NBHT and DCME use in the closed eyes test were not revealed.

Overall, the observed positive dynamics in the above-listed parameters indicates that the experimental group test subjects could tolerate CCCA loads on the R. Barany chair longer and easier.

The obtained dynamics is concordant with the nature of change in parameters obtained during SST IFCS which the subjects underwent after the CCCA test (Table 2).

One of the tasks we intended to solve by the experiment was to determine the duration of the achieved effect from the combined use of NBHT and DCME for a fortnight. To this end, the subjects were investigated repeatedly also in one, two and three months after the NBHT and DCME course.

The analysis of the obtained data shows that the highest value of CCCA tolerance time in the experimental group subjects was reached immediately after the NBHT and DCME course; later its values started to gradually decrease and were back nearly to the initial level by the end of the third month (Figure 1).

Table 2. SST IFCS parameters for subjects "Before" and "After" a fortnight of NBHT use in combination with DCME (M±SD)

No.	Studied parameters	Experimental group		Control group	
		Before	After	Before	After
	Open eyes test				
1	Length increase rate (mm/s)	43.2±1.9	37.1±1.7*	42.5±2.3	39.9±2.1
2	Area increase rate (mm^2/s)	63.4±3.9	60.3±3.3*	62.9±4.1	61.8±3.8
3	OA PCCG, frontal plane (mm)	6.7±0.3	5.8±0.3*	6.5±0.4	6.4±0.5
4	OA PCCG, sagittal plane (mm)	7.2±0.4	6.2±0.3*	6.9±0.4	6.7±0.5
5	CA, frontal direction (%)	7.7±0.4	6.4±0.5*	7.6±0.5	6.9±0.8
6	CA, sagittal direction (%)	7.6±0.4	6.7±0.3*	7.5±0.5	7.2±0.7
	Closed eyes test				
1	Length increase rate (mm/s)	46.3±4.3	44.1±4.5	46.4±4.1	44.6±4.7
2	Area increase rate (mm^2/s)	69.3±5.3	62.1±4.9	69.8±5.2	62.3±5.0
3	OA PCCG, frontal plane (mm)	8.1±0.8	8.0±0.9	7.8±0.8	7.7±0.7
4	OA PCCG, sagittal plane (mm)	7.4±0.7	7.4±0.8	7.2±0.7	7.3±0.8
5	CA, frontal direction (%)	7.4±0.9	7.3±0.8	7.5±0.8	7.8±0.7
6	CA, sagittal direction (%)	8.2±0.8	7.1±0.9	8.1±0.9	8.0±0.7

Legend: reliability of differences: * – p<0.05 versus initial parameter values; SST IFCS - static stabilometric test in the integrated functional computer stabilography; CA – coefficient of asymmetry; OA - oscillation amplitude; PCCG - projection of the common centre of gravity

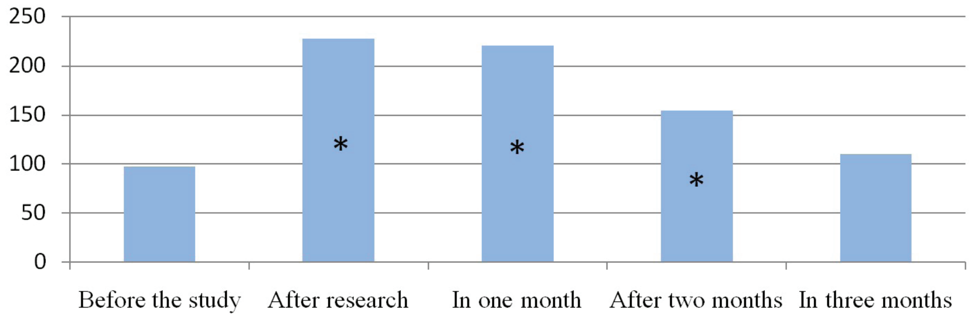

FIGURE 1. The CCCA (continuous cumulation of Coriolis acceleration) test tolerance time in the experimental group subjects "Before", "After", and in 1, 2, 3 months following the course of NBHT (normobaric hypoxia training) use in combination with DCME (dedicated cervical muscle exercises) in seconds

Discussion

It has been found that the effect of any training factor causes a response in a whole range of systems in the alpine skiers' organism. At the same time, it was noted that all homeostasis regulating systems were activated along with exercising an individual functional system enabling increased tolerance to a certain factor. As a result, general tolerance increases not only to the factor of exposure, but also to other stimuli (Hackett, & Rennie, 2016; Luks, Swenson & Bärtsch, 2017). In our study we took into account that in order to improve the stress resistance of the organism it is necessary to use a wide variety of means, methods and their combinations, which can activate the adaptation process and enhance capacity of the stress-limiting systems, both at the level of central regulatory mechanisms and at the tissue level (Gonggalanzi, Labasangzhu, Bjertness, Wu, Stigum & Nafstad, 2017; Hackett, & Rennie, 2016).

It has been found that with the use of normobaric hypoxia training, the process of adaptation to hypoxia caused 53.7 % RNA concentration increase in brain structures. Another response was an increase of the weight of lungs and growth of the quantity of alveoli. There was an increase in the number of red blood cells and hemoglobin, concentration of myoglobin in myocardium and skeletal muscles. In alpine skiers, we observed improvement in the functional capability of the cardiovascular and muscular systems in the course of preparation to competitive activities. There was a marked increase of the quantity of prostaglandin E and opioid peptides reducing adverse effects of stressors on the athletes' organism, etc. (Luks, Swenson, & Bärtsch, 2017).

On the cellular level, the organism responded by enhancing the capacity of the energy supply system due to the increase of mitochondria count and activation of the respiratory chain ferments. Simultaneously there was a reduction of basic metabolism and more economical use of oxygen by tissues. These changes helped expand reserve capabilities of the organism's functional systems and increase physical performance of athletes.

Therefore, improvement of non-specific resistance of the organism is characterized by a wide range of physiologic changes in alpine skiers' organisms. This results from alpine skiers' adaptation to normobaric hypoxia in combination with cervical muscle exercises. These changes play an important role in correction of the athletes' functional state and optimization of capabilities of organs and systems in athletes (Mao, Chen, Li & Huang, 2014). Finally, this mechanism plays the role of a critical link in the chain of adaptation changes and facilitates improvement of tolerance to statokinetic exposures and reduction of the manifestation degree of sensory, vegetative and somatic reactions (Gonggalanzi, Labasangzhu, Bjertness, Wu, Stigum & Nafstad, 2017).

In their turn, physical exercises in the form of regular and adequately selected types of loads assist enhancement of the vascular tone, improve the cardiovascular and external respiratory function. They optimize gas exchange, redox and rehabilitation processes, thereby improving bioelectric activity and reinforcing excitatory processes in the structures of the central nervous system, facilitating overall enhancement of the stamina and physical performance of the alpine skiers' organisms.

It has been established that the increase of statokinetic stability under the influence of DCME is caused by the change in the sensitivity threshold of the vestibular, visual, interoceptive, tactile and proprioceptive analyzers (Wrigley, 2015). In turn, this improves tolerance to statokinetic loads through faster and more adequate buildup of a single statokinetic stability system in athletes when going along a piste.

Conclusion

1. A month regimen of NBHT in combination with DCME confidently increases the CCCA test tolerance time, simultaneously reducing the degree of manifestation of sensory, vegetative and somatic components of statokinetic reactions in alpine skiers.

2. The highest CCCA tolerance time was registered immediately after a month of NBHT use in combination with DCME. The achieved effect is preserved for 2 months, then it is gradually reduced to the initial level. This shows the need to use such training for alpine skiers at the final stage of preparation to competitive activities.

Acknowledgements
There are no acknowledgements.

Conflict of Interest
The authors declare that there is no conflict of interest.

Received: 13 March 2021 | **Accepted:** 03 May 2021 | **Published:** 01 February 2022

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