

Effectiveness of normobaric hypoxia course use in combination with cervical muscle exercise as a means to improve statokinetic stability in alpine skiers


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ABSTRACT

Russian and international research on optimization of functional state and physical performance of athletes is one of the focus areas in current sports studies. The aim of this research was to study the effectiveness of normobaric hypoxia course use in combination with cervical muscle exercise as a means to improve statokinetic stability in alpine skiers. The research involved 35 alpine skiing athletes aged 18–20 (21 subjects – experimental group, 14 subjects – control group) from the representative team of Peter the Great St. Petersburg Polytechnic University. Continuous cumulation of Coriolis acceleration (CCCA) method was used as a stimulus for the vestibular analyser. To improve statokinetic stability of the experimental group subjects, a two-week normobaric hypoxia training course in combination with cervical muscle exercises was used. The control group subjects were given “fake” normobaric hypoxia courses and performed no dedicated cervical muscle exercise. The results of the study showed that the experimental group subjects who received normobaric hypoxia in combination with cervical muscle exercise demonstrated a reliably improved CCCA tolerance time (versus initial measurements). Besides, there was a decrease in the manifestation degree of vestibulosensory, vestibulovegetative, and vestibulosomatic reactions, which generally indicates improvement of CCCA tolerance in this group of subjects. Positive dynamics of test parameters in the experimental group subjects has also been confirmed by the data of the static stabilometric test in the

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integrated functional computer stabilography. For instance, the open eyes test showed a reliably significant reduction in the rate of increase of the statokinesiogram length and area, oscillation amplitude of the projection of the common centre of gravity in the frontal and sagittal planes, and coefficient of asymmetry in the frontal and sagittal directions. The obtained results can justify recommendation of normobaric hypoxia course use in combination with cervical muscle exercise as a means to improve statokinetic stability in alpine skiers. **Keywords:** Speed sports; Equilibrium function; Statokinetic stability; Normobaric hypoxia; Cervical muscle exercise.

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INTRODUCTION

An important and mandatory condition for achieving significant results in professional sports is the athlete's functional state, high physical performance and sufficient psychophysiology capacity (Bakaev, Bolotin, & Vasil'eva, 2015; Bakayev, et al., 2018; Bolotin, & Bakayev, 2016; Bolotin, & Bakayev, 2017a; Dong, 2016; Gorshova, et al., 2017; Gonggalanzi, et al., 2017; Malcata, & Hopkins, 2014; Mekjavic, et al., 2016; Naeije, 2014; Wrigley, 2015; Bakaev, Bolotin, & Aganov, 2016; Luks, Swenson, & Bärtsch, 2017).

An optimum condition of the above-mentioned psychophysiology characteristics is especially important for alpine skiing athletes engaged in high-speed downhill skiing.

Relevance of this issue is caused by the fact that over the recent years, in the context of significant improvement of ski equipment and increase in the alpine skiers' speed of movement, the psychophysiologic capabilities of the athletes have remained virtually unchanged. This incongruity, in its turn, resulted in the situation when excessive dynamic influences and speed of movement on the mountain slope expose the athlete's body to the forces which negatively impact his or her functional state and scores (Mao, 2014; Hopkins, et al., 2009; Hackett, & Rennie, 2016).

This is because high-speed movement and manoeuvring in space is accompanied by exposure of the alpine skier's body to angular, linear and centripetal accelerations potentially leading to emergence of pronounced vestibulosomatic, vestibulovegetative and vestibulosensory reactions which, depending on the duration and degree of manifestation, adversely influence the well-being and quality of the athletes' competitive activity (Bakaev, Bolotin, & Vasil'eva, 2015; Ivashchenko, et al., 2017; Pieralisi, et al., 2017; Bolotin, & Bakayev, 2017c).

Russian and international research provides evidence that excessive exposure to dynamic loads negatively influences the bioelectric cerebral cortex activity and conditioned reflexes, memory and attention, emotional responses and orientation in space. Meanwhile, the time on the piste, as well as the number of mistakes, including gross mistakes, affecting the safety of the athlete's downhill movement, increases.

This circumstance dictates the need to search for new effective means and methods for training of alpine skiers directed at improvement of their functional state and the level of their physical performance (Bolotin, & Bakayev, 2017b; Dong, 2016; Malcata, & Hopkins, 2014). This is related to a high degree of manifestation of sensory, vegetative and somatic components of statokinetic reactions in alpine skiers.

The physiologic 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. Such methods include, inter alia, the method of normobaric hypoxia training which, apart from improving athletes' tolerance to a lack of oxygen, is used to enhance their bodies' resistive and adaptive capability to adverse effects of a number of other agents (Bolotin, & Bakayev, 2018; Naeije, 2014).

Currently, despite availability of a detailed description of mechanisms of negative impact of hypoxia on organs and tissues, in certain conditions it can also be regarded as a driver of expansion of physiologic ranges of functional systems and facilitate improvement of athletes' psychophysiologic capabilities. Thus, it can help optimize functional state of athletes and improve their physical performance (Wrigley, 2015; Bakaev, Bolotin, & Aganov, 2016).

The aim of this research was to study the effectiveness of the normobaric hypoxia course use in combination with dedicated cervical muscle exercise as a means to improve statokinetic stability in alpine skiers.

MATERIAL AND METHODS

The research was performed at the Department of Medical and Valeological Specialties in Herzen State Pedagogical University of Russia and the Institute of Physical Culture, Sports and Tourism in Peter the Great St. Petersburg Polytechnic University. Its subjects were alpine skiers aged 18–20 in whom the continuous cumulation of Coriolis acceleration (hereinafter “CCCA”) test tolerance time amounted to less than two minutes.

At the initial stage of the experiment, all the subjects were introduced to the plan and procedure of the forthcoming research, and the methods it used. All subjects provided voluntary written consent to participate in the experiment.

Next, random sampling was used to form two groups of subjects: the experimental group (n-21) and the control group (n-14). Subsequently the experimental group subject were engaged in a two-week course of normobaric hypoxia training (hereinafter “NBHT”) in combination with dedicated cervical muscle exercises (hereinafter “DCME”). The control group subjects received “fake” courses of NBHT and performed no DCME.

All subjects were retested according to the initial program after a two-week performance of NBHT in combination with DCME, and in one, two and three months afterwards.

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. Another parameter of evaluation was the manifestation degree of sensory, vegetative and somatic components of statokinetic reactions determined on the basis of our earlier developed point scoring system: 0 – absence of sensations; 1 – mildly manifested sensations; 2 – intense sensations.

For the NBHT we used the *Bionova-Nova-204*, AF system (Russia). The NBHT was performed in a course of 14 sessions. Duration of each session was 30 minutes. During the first session, the subjects were administered hypoxic gas mix with 17.0% oxygen content. During the following four sessions, oxygen content was reduced to 1.0–2.0%. 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 12.0–14.0%.

The DCME method included two exercises in the supine position. In Exercise No.1, the subject was supine on the 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 subject evenly tilted the head upward and downward, making one movement in two seconds, with the tilt angle of 30.0°, duration of each exercise 5 minutes, and break between exercises 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 gaze of the subject 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 break of 1 minute between them. The following parameters were captured: the average rate of increase of the statokinesiogram length and area, oscillation amplitude (hereinafter "OA"), coefficient of asymmetry (hereinafter "CA") of the projection of the common centre of gravity (hereinafter "PCCG") in the frontal and sagittal planes and directions.

Statistical processing of the obtained data was performed using Microsoft Excel software kit according to GOST R8.736-2011. For each sample of parameters, numerical distribution characteristics were calculated. The statistical significance of difference between the compared samples was evaluated using the parametric Student's t-test.

RESULTS AND DISCUSSION

The results obtained in the course of the experiment justify a conclusion that the two-week combined use of NBHT and DCME reliably 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" two-week use of NBHT in combination with DCME ($\bar{x} \pm \delta$)

Test parameters	Experimental group		Control group	
	Before	After	Before	After
CCCA tolerance time (seconds)	109.7 \pm 5.7	213.4 \pm 9.7*	98.5 \pm 6.6	98.9 \pm 7.5
Heat sensation (points)	0.5 \pm 0.05	0.3 \pm 0.04*	0.4 \pm 0.06	0.4 \pm 0.05
Head heaviness sensation (points)	0.5 \pm 0.06	0.3 \pm 0.07*	0.5 \pm 0.06	0.5 \pm 0.07
Vertigo sensation (points)	0.4 \pm 0.06	0.2 \pm 0.05*	0.4 \pm 0.05	0.4 \pm 0.06
Stomach discomfort (points)	0.4 \pm 0.05	0.2 \pm 0.06*	0.4 \pm 0.07	0.4 \pm 0.08
Hypersalivation degree (points)	0.6 \pm 0.05	0.3 \pm 0.06*	0.5 \pm 0.07	0.5 \pm 0.08
Hyperhidrosis degree (points)	0.4 \pm 0.04	0.2 \pm 0.05	0.4 \pm 0.06	0.4 \pm 0.07
Protective movements (points)	0.7 \pm 0.08	0.4 \pm 0.06*	0.6 \pm 0.07	0.6 \pm 0.08
Nystagmus duration (seconds)	21.0 \pm 3.3	17.3 \pm 3.5*	20.1 \pm 3.5	20.0 \pm 3.7
Number of subjects	21	21	14	14

Note: - reliability of differences: * - $p < 0.05$ versus initial parameter values. NBHT - normobaric hypoxia training, DCME - dedicated cervical muscle exercises, CCCA - continuous cumulation of Coriolis acceleration.

Thus, in comparison with the initial measurements, the CCCA test tolerance time was improved by 94.5%. Moreover, there was a 40.3% reduction in parameters descriptive of heat sensation, 40.9% reduction in head heaviness sensation, 50.2% reduction in vertigo sensations, and 50.7% reduction in stomach discomfort. Besides, there was a reduction in hypersalivation by 50.3%, hyperhidrosis by 50.7%, manifestation degree of protective movements by 42.9%, and time of post-rotation nystagmus by 17.6%.

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.

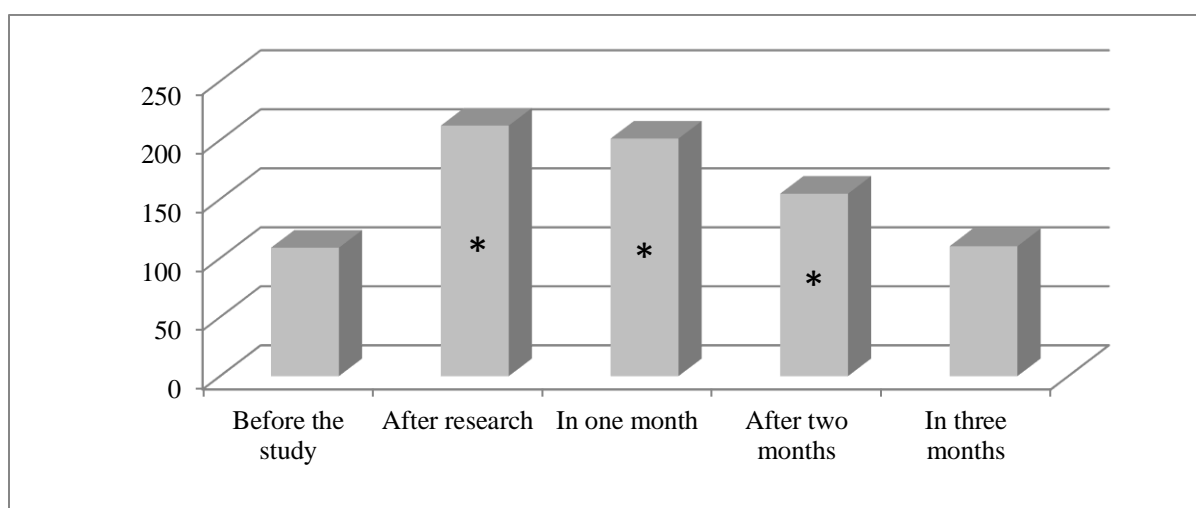
The obtained dynamics is concordant with the nature of change in parameters obtained during SST IFCS which the subjects underwent after the CCCA test (see Table 2).

Table 2. SST IFCS parameters for subjects "Before" and "After" two-week use of NBHT in combination with DCME ($\bar{X} \pm \delta$)

Test Parameters	Experimental group		Control Group	
	Before	After	Before	After
<i>Open eyes test</i>				
Length increase rate (mm/s)	41.2 \pm 1.8	37.4 \pm 1.7*	38.5 \pm 2.3	39.0 \pm 2.0
Area increase rate (mm ² /s)	68.4 \pm 3.4	61.3 \pm 3.3*	62.4 \pm 4.1	61.3 \pm 4.8
OA PCCG, frontal plane (mm)	6.8 \pm 0.4	5.9 \pm 0.3*	6.3 \pm 0.6	6.4 \pm 0.5
OA PCCG, sagittal plane (mm)	7.1 \pm 0.3	6.3 \pm 0.4*	6.4 \pm 0.7	6.6 \pm 0.8
CA, frontal direction (%)	7.4 \pm 0.4	6.4 \pm 0.5*	6.6 \pm 0.6	6.8 \pm 0.7
CA, sagittal direction (%)	7.6 \pm 0.3	6.7 \pm 0.4*	7.3 \pm 0.6	7.2 \pm 0.7
<i>Closed eyes test</i>				
Length increase rate (mm/s)	46.2 \pm 4.5	44.3 \pm 4.6	44.4 \pm 5.1	43.6 \pm 4.9
Area increase rate (mm ² /s)	64.3 \pm 5.5	62.0 \pm 4.8	69.8 \pm 5.4	60.1 \pm 5.0
OA PCCG, frontal plane (mm)	8.0 \pm 0.8	8.0 \pm 0.9	7.7 \pm 0.8	7.5 \pm 0.8
OA PCCG, sagittal plane (mm)	7.5 \pm 0.7	7.4 \pm 0.8	8.2 \pm 0.7	8.1 \pm 0.8
CA, frontal direction (%)	7.4 \pm 0.9	7.3 \pm 0.8	7.8 \pm 0.8	7.9 \pm 0.7
CA, sagittal direction (%)	7.2 \pm 0.8	7.1 \pm 0.9	8.1 \pm 0.9	8.0 \pm 0.8

Note: Reliability of differences: * $p < 0.05$ versus initial parameter values. NBHT - normobaric hypoxia training, DCME - dedicated cervical muscle exercises, 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.

Thus, in the open eyes test there was a reliable decrease in the parameters descriptive of the rate of increase in the length (by 9.3%) and area (by 10.4%) of the statokinesiogram, OA PCCG in the frontal (by 13.3%) and sagittal (by 11.3%) planes, CA in the frontal (by 13.6%) and sagittal (by 11.9%) directions. At the same time, in the closed eyes test there was no statistically significant difference between the parameter values before and after course use of NBHT and DCME.



Note: Reliability of differences: * - $p < 0,05$ versus initial parameter values.

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

One of the tasks we intended to solve by the experiment was to determine the duration of the achieved effect from the two-week combined use of NBHT and DCME. To this end, after the course performance of NBHT and DCME, the subjects were retested in one, two and three months.

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

Currently there is a common belief that the effect of any training factor causes a response in a whole range of alpine skier bodies. It was noted that along with exercising of an individual functional system enabling increased tolerance to a certain factor, all homeostasis regulating systems were activated. As a result, tolerance increases not only to the factor of exposure, but also to other stimuli (Pieralisi, et al., 2017; Wrigley, 2015).

Based on the understanding of this phenomenon, researchers could use a wide variety of means, methods and their combinations to improve the stress resistance of the body, trigger the process of adaptation and enhance capacity of stress-limiting systems, both at the level of central regulatory mechanisms and at the tissue level (Mao, 2014; Naeije, 2014).

So, with the use of normobaric hypoxia training, the process of adaptation to hypoxia caused 52.3% RNA concentration increase in brain structures. Another response was an increase of the weight of lungs and the quantity of alveoli. There was an increase in the number of red blood cells and haemoglobin, 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 the competition. There was a marked increase of the quantity of prostaglandin E and opioid peptides reducing adverse effects of stressors etc.

On the cellular level, the body 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 basal metabolism and more economical use of oxygen by tissues. These changes helped expand reserve capabilities of the body's functional systems and increase physical performance of athletes.

Therefore, improvement of non-specific resistance of the body emerging as a result of adaptation to normobaric hypoxia induces a whole array of physiologic changes in alpine skiers. These changes play an important role in correction of the athletes' functional state and optimization of capabilities of organs and systems in athletes (Luks, Swenson, & Bärtsch, 2017; Hackett, & Rennie, 2016).

Finally, this mechanism plays a role of a critical link in the chain of adaptation changes and ultimately facilitates improvement of tolerance to statokinetic exposures and reduction of the manifestation degree of sensory, vegetative and somatic reactions (Mekjavic, et al., 2016).

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 and redox 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 body.

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 analysers.

In turn, this improves tolerance to statokinetic loads through faster and more adequate build-up of a single statokinetic stability system in athletes.

CONCLUSIONS

- 1) A two-week regimen of NBHT in combination with DCME reliably 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 two-week use of NBHT in combination with DCME. The obtained effect persisted over two months and then gradually subsided to the initial levels.

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