Peculiarities of Adaptation to Training Loads in Paralympian Cross-country Skiers with Visual Impairment versus Able-bodied Athletes based on Analysis of Heart Rate Variability Data

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Abstract: An increasing number of people with impaired vision who engage in skiing sports dictates a pressing need to study the athlete's physiologic functioning in conditions of sensory insufficiency. In the course of the adaptation to training and competition conditions, unlike able-bodied athletes, blind and visually impaired people use compensatory mechanisms to replace the lost visual function. This fact contributes to the development of the structural trace of adaptation to loads and has to be considered in training of this category of athletes. The study involved 42 skiers. The experimental group (EG) comprised Paralympians with visual organ impairment (n=23), whereas the control group (EG) comprised athletes from the Russian Federation national cross-country skiing team (n=19). The research included an examination of the heart rate variability using Kardiometr-MT computer analyzer by TOO Mikard Lana at rest, immediately following the training, and before competition, and an examination using FirstBeat SPORT computer system for determining the training effect and overnight recovery on a daily basis during 7 days of the training camp. The obtained results are indicative of higher "price" of adaptation to the conditions of sports practice in Paralympic skiers with visual function impairment versus able-bodied athletes.

1 INTRODUCTION

Sports activities of Paralympian cross-country skiers with visual impairment, being one of the aspects of physical activity in people with disabilities, are related to high physical and psychological loads, which contribute to specific adaptive responses of the persons with disabilities to training loads they encounter (Bakaev et al., 2015, Bernardi et al., 2010, Bernardi et al., 2012, Tweedy, 2011, Laaksonen et al., 2018). Optimization of visually impaired Paralympian skiers' performance in competitions requires studying the peculiarities of their psychomotor function, psychophysical stamina, central nervous system throughput and functional asymmetry of the athlete's body.

Training practice of visually impaired Paralympian skiers is based on the diagnosis of the athletes' condition for management of various aspects of their fitness according to model characteristics. Such an approach to the training process requires development of novel methods of training and recovery after a physical performance, as well as for objective monitoring of impact training loads have on the athlete's physiology (Bakaev et al., 2016, Bakayev et al., 2018, Bolotin, 2017a, Bolotin, 2017b, Edmonds et al., 2014, Malcata and Hopkins, 2014, Sanz-Quintoet al., 2018). Therefore, it is necessary to find specific optimal loads as a background for developing the most appropriate specific physiological structure for visually impaired Paralympian skiers ensuring their achievement of highest possible results. Another issue to be considered in this relation is reciprocal limitation of certain motor capabilities in athletes, when progress in one capability reduces the level of the other (Bolotin and Bakayev, 2017c, Ivashchenko et al., 2017, Hopkins et al., 2009, Hynynen et al., 2006).

It is common knowledge that the stages of adaptation are inextricably interconnected and coordinated in the framework of the single adaptive physiological response in visually impaired Paralympian skiers. Adaptation includes shaping of

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a certain dominant functional system (Hoffman and Street, 1992). This thesis is critical for adaptation to the training and competitive stress in blind Paralympian skiers. In the process of adaptation, a visually disabled person forms new functional links and dominant functions, which help the athlete, master a qualitatively new sports skill. Thus, long-term adaptation allows athletes to perform the earlier impossible work in conditions of visual deprivation. Forming new links is a decisive factor in the process of expansion of bodily reserves, leading to economical functioning of the systems responsible for the process of adaptation.

In the course of long-term adaptation, reserve exhaustion and (over)recovery cycles must be taken into account for training sessions planning (Gorshova et al., 2017). One of the major tasks is to avoid (or delay as much as possible) the fourth stage, i.e. the adaptation collapse.

The adaptation collapse in athletes manifests in overstraining various systems and organs, and in the overtraining syndrome (Sattlecker et al., 2009, Malcata, 2014). In most cases, visually impaired Paralympian skiers overstrain their central nervous, immune, cardiovascular, and musculoskeletal systems. One of the modern theories explaining development of overtraining in athletes is the vegetative disorder theory. Pronounced activation of the sympathetic nervous system under the influence of training and competition can result in its exhaustion. Decrease in sympathetic activation and reciprocal domination of parasympathetic activation can cause inhibition of a number of bodily systems, fatigue and depression. Presently the most affordable method of vegetative nervous system functioning analysis is heart rate variability (HRV) with the examination using the method of rhythmocardiography (RCG). Overtraining manifests by reduced HRV on the rhythmogram (Bolotin, Bakayev, and You, 2018).

The rhythmocardiography method is currently being widely used for evaluation of training effectiveness in athletes practicing various sports disciplines, and it is difficult to overestimate its role in assessing adaptation to the conditions of sports practice and training process management (Bolotin, Bakayev, and Bochkovskaya, 2018). Nevertheless, to date virtually no research describes the peculiarities of heart rate variability in visually impaired athletes, which complicates the process of instructional support of their training and assessment of their current physiological condition.

The purpose of this work is to study the peculiarities of visually impaired skiers' adaptation to training loads in conditions of sports practice.

2 ORGANIZATION AND METHODS

The research was performed at the Institute of Physical Culture, Sports and Tourism in Peter the Great St. Petersburg Polytechnic University. The study involved 42 skiers. The experimental group (EG) comprised Paralympians with visual organ impairment (n=23), whereas the control group (EG) comprised athletes from the Russian Federation national cross-country skiing team (n=19).

The research included an examination of the heart rate variability using Kardiometr-MT computer analyzer by TOO Mikard Lana at rest, immediately following the training, and before competition, and an examination using FirstBeat SPORT computer system for determining the training effect and overnight recovery on a daily basis during 7 days of the training camp.

The analysis was performed on short 5-minute and long 7-day heart rate variability records of the athletes taken during the periods of their training camps and competitions.

The research used the following RCG parameters, which were found to be most applicable in sports studies:

- RRav. - an average interval between cardiac cycles in ms;
- RRmin and RRmax - minimum and maximum intervals between cardiac cycles in ms;
- dX - variation range - the difference between the longest and shortest RR intervals (cardiac cycle) in milliseconds (ms);
- SDNN - the standard deviation of the NN interval from the average value in ms. It is calculated as a square root of the RR intervals spread. The SDNN reflects all cyclic components responsible for variability during the recording period;
- CV (%) (the coefficient of variation) does not differ from the SDNN in terms of physiology but is normalized by heart rate;
- RMSSD - square root of the mean squared differences of successive RR intervals in ms.
- Mo - mode (ms) - the range of the most frequently occurring values of cardiac intervals - the peak of the histogram. It shows the most likely (dominant) level of functioning of the

sinus node. This is the highest RR interval - peak of the histogram.

- AMo (%) amplitude mode - the percentage of cardiac intervals that fall into the range of the mode, in relation to all cardiac intervals. The mode amplitude depends on the influence of the sympathetic part of the VNS and reflects the degree of centralization of the heart rhythm regulation.
- The heart rhythm wave structure analysis was performed:
- TP - total power (area of waves on the RCG) of the RCG wave spectrum in ms^2;
- HF - fast or high-frequency oscillations of the RCG wave spectrum reflecting the work of the parasympathetic nervous system and the autonomous circuit for regulating the heart rhythm (frequency range from 0.15 to 0.4 Hz) in ms^2;
- LF - slow or low-frequency oscillations of the RCG wave spectrum reflecting the work of the sympathetic nervous system and the central rhythm regulation circuit (frequency range from 0.04 to 0.15 Hz) ms^2;
- VLF - very slow or very low-frequency oscillations of the wave spectrum of the RCG reflecting the work of the central and humoral channels of heart rhythm regulation (frequency range from 0.04 to 0.015 Hz) ms^2.
- Indices according to Baevsky:
- VRI (vegetative rhythm index) AMo/Mo × dX. The smaller the VRI, the higher the activity of the parasympathetic part and the autonomous circuit.
- RPAI (regulatory processes adequacy indicator) AMo/Mo to identify the relationship between the level of functioning of the sinus node and sympathetic activity. This is the indicator reflecting the interaction between the autonomous circuit and the humoral regulation channel.
- SI (regulatory systems strain index) AMo/2dX × Mo reflects the degree of centralization of heart rhythm regulation.

In the pedagogic experiment, the training was monitored using FirstBeat SPORT software and hardware incorporating the dedicated BodyGuard sensor, which enables recording of the athlete's cardio signal for up to 7 days continuously, and FirstBeat BodyGuard software, by FirstBeat (Finland).

The research comprised an analysis of the training process using pulsometry and heart rate variability, including remote analysis, and monitoring of recovery after the training load. The software converted pulsometry and heart rate variability data into a unique digital model in accordance with advanced methods of mathematical data processing, and produced dedicated reports.

The FirstBeat SPORT system (www.firstbeat.com) is a single-channel electrocardiograph with large built-in memory capacity that enables recording a pulsogram continuously for up to 7 days.

The hardware was used to collect data on heart rhythm regulation circuit condition in skiers on round-the-clock basis. Simultaneously the parameters of the training load and post-load recovery were measured. Thus the design of the research enabled presentation of the results in the graphic and digital form to reflect the quality of training, daily activity and overnight recovery. The software calculates and generates a digital model of a specific individual, which describes the main physiological processes of the body, such as: maximum oxygen consumption, energy consumption, oxygen debt, strain and recovery of physiological processes.

In athletes who were recovering poorly or slowly, a decrease in heart rate variability and an increase in the sympathetic excitation of the autonomic nervous system were registered upon awakening. Firstbeat technology enabled measurement of the so-called “recovery coefficient”. An increase in this indicator was characteristic of a better quality of recovery. In contrast, its decline indicated accumulation of insufficient degree of recovery in skiers. The data was processed on a personal computer using Firstbeat SPORT software. The analysis of the RCG records was performed in accordance with the International Standard of 1996 and FirstBeat's recommendations. The statistical significance of difference between the compared samples was evaluated using the parametric Student's t-test.

3 RESULTS AND DISCUSSION

The results obtained in the course of the experiment justify a conclusion that the process of adaptation to training loads in experimental group subjects and control group subjects differed. The pedagogic experiment involved 42 skiers of superior sportsmanship, out of whom 23 were Paralympians with impaired vision, and 19 were athletes from the national team of the Russian Federation constituting the control group.

Table 1: At-rest rhythmocardiography in two groups of skiers on the first day of the training camp.

Parameters	quartile 1		Median		quartile 3		P-value
	EG	CG	EG	CG	EG	CG	
Mode Mo, ms	875.1	900.2	1000.0	1050.1	1100.5	1200.1	>0.05
Mode amplitude AMo, %	33.2	19.1	36.1	24.6	44.8	32.5	<0.05
Minimum value RR min., ms	784.3	686.2	863.4	772.1	930.5	826.9	>0.05
Maximum value RR max., ms	982.6	1148.5	1121.7	1352.3	1247.8	1446.1	>0.05
Difference between RR max and min RR dX, ms	198.6	462.0	258.5	580.4	316.5	620.0	<0.05
Coefficient of variation CV, %	4.9	5.4	5.7	7.5	6.3	11.4	<0.05
SDNN, ms	48.7	61.0	56.1	81.0	64.8	127.5	<0.01
RMSSD, ms	30,5	54.4	53.0	77.0	61.2	111.0	0.02
Vegetative rhythm index VRI (c.u.)	5.1	2.3	5.5	2.6	5.9	2.9	<0.01
Regulatory processes adequacy index RPAI (c.u.)	34,8	21.1	39.7	24.9	42.7	27.1	<0.05
Strain index SI (c.u.)	95.8	23.3	101.2	47.7	112.8	68.4	0.02
High frequency spectrum HF, ms^2	468.5	1215.0	1126.4	2138.8	1504.4	3348.5	>0.05
Low frequency spectrum LF, ms^2	835.8	863.5	1531.6	1962.6	2264.1	4506.5	<0.01
Very low frequency spectrum VLF,ms2	365.9	701.0	552.6	1566.1	1416.5	2879.6	0.04
Total power of spectrum TP, ms^2	1670.2	2779.5	3210.6	5,666.7	5,185.0	10,734.1	<0.01
LF/HF (c.u.)	1.8	0.7	1.4	0.9	1.5	1.3	>0.05
LF, %	50.0	31.1	47.7	34.6	43.7	42.0	>0.05
HF, %	28.1	43.7	35.1	37.7	29.0	31.2	>0.05

The HRV analysis was performed using 5-minute RCG records at rest in the morning on the first day of the training camp before breakfast in Paralympians (EG) versus the control group (CG).

Results of the 5-minute rhythmocardiogram records at rest in the morning on the first day of the training camp, before breakfast and training, are shown in Table 1.

As seen from Table 1, at-rest rhythmograms of visually impaired Paralympian skiers differ from the rhythmograms of the control group of able-bodied athletes by many parameters.

A general distribution of parameters corresponds to the classical distribution of quartile values: quartile 1 is less than quartile 2; median is less than quartile 3. These circumstances serve as evidence of objectiveness and statistical representativeness of the detected trends.

Variability parameters differed in the groups of athletes in *AMo* by 33.5 %.

The mode amplitude value depends on the influence of the sympathetic part of the VNS; its growth reflects the degree of centralization of heart rhythm regulation. Thus, based on *AM*o data, the strain of regulatory systems in Paralympians at the camp was reliably higher ($p<0.05$) than in the control group of skiers.

One of the most easily obtained parameters of heart rate variability *dX*- the difference between maximum and minimum RR-intervals on the electrocardiogram in Paralympians was 55.5 % less than in the control group ($p<0.05$).

The median *dX* value in blind athletes amounted to 258.0 vs. 580.0 ms in the control group ($p<0.05$). The research findings indicate that in ski sports the *dX* value closely correlates with the aerobic capability, whereas MOC (maximum oxygen consumption) values exceeding 60 ml/min/kg had reliably higher occurrence in skiers with *dX* equal to 489.6 ms and more. Thus, based on the data obtained in this ascertaining experiment, Paralympians tend to have lower aerobic capabilities than the subjects in the control group.

Medians of the coefficient of variation (*CV*) amounted to 5.7 % in the Paralympians' group versus 7.5 % in the control group and differed less than *d*X values, however also reliably ($p<0.05$), mainly due to quartile 2.

Reliable *CV* differences were discovered between low-skilled and high-skilled athletes. Improved sports skills and, respectively, adaptation of athletes, correlated to the decrease in the *CV* value.

In the Paralympians group, *SDNN* parameters were less than in the control group by 44.3 % ($p<0.01$), *RMSSD* – by 45.3 % ($p<0.02$).

SDNN - the integral parameter for presence of the heart rhythm wave structure, indicating at the cumulative effect of impact of both sympathetic and parasympathetic VNS divisions on the sinus node. This parameter is being very widely used in sports.

RMSSD - one of the most insightful parameters for assessment of the athlete's functional condition as it reflects both variability and autonomy of the heart rhythm and correlates to the highest number of other heart rhythm wave structure characteristics.

Thus, variability of Paralympians at rest appeared to be reliably lower than in the control group in absence of statistically reliable difference by a number of other parameters.

The total power of spectrum (*TP*) in Paralympians was 76.5 % lower than in the control group (3210.6 versus 5666.0 ms^2, $p<0.01$) due to the contribution from all spectral parameters.

Thus, all spectral parameters in Paralympians appeared to be lower than in the control group, with reliable difference in the parameters of the central regulation circuit *LF* ($p<0.01$) and *VLF* ($p=0.04$). This can be seen as evidence of lower adaptive capabilities in Paralympians versus the control group. Statistically reliable differences between the groups was also established by all integrated parameters.

VRI medians amounted to 5.5 in Paralympians versus 2.6 c.u. in the control group ($p<0.01$). *The VRI* is one of the most insightful integrated parameters in terms of assessment of aerobic capabilities of athletes in ski sports.

It is a well-known fact that the best functional condition in athletes at rest is high autonomy and variability of functioning, along with reduction of sympathetic regulation and of centralization of the function's regulation. This is achieved by structural and functional rearrangement of physiological regulation in athletes under the influence of the training process. However, as shown above, during the preparation period of the training cycle, variability of heart rhythm in Paralympian skiers with the impaired visual function was reliably lower in comparison to Olympic athletes, whereas centralization of physiological functions regulation was reliably higher.

Apparently, "variability is a property of all biological processes related to the necessity for the body to adapt to the changing conditions of the environment". It reflects input from regulatory signals readjusting the cells of the body to maintain the homeostasis or to adapt the body to new conditions. Heart rate variability is variability of time intervals between heart beats, which can reflect the ability for adaptation both in the present moment (tolerance to the existing loads) and in prospect (assessment of adaptation reserve).

4 CONCLUSIONS

The obtained results are indicative of higher "price" of adaptation to the conditions of sports practice in Paralympic skiers with visual function impairment versus able-bodied athletes. The former exhibit a more pronounced strain of adaptive mechanisms and physiological regulatory systems at rest.

In athletes with visual deprivation at rest, heart rate variability parameters appeared to be reliably lower, whereas the dominant central type of regulation was encountered four times more often than in high-skilled skiers with healthy vision. With the same pulse cost of the training load, there was a reliably lower functional mobilization of regulatory systems in response to the load and overnight recovery degree in Paralympians versus the control group.

Adaptation of Paralympians with the impaired visual function to the conditions of sports practice has certain peculiarities in terms of both regulatory and psychological aspects that should be considered during the selection of training programs and methods of psychological and pedagogical intervention in sports for the blind.

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