Healthsaving Technologies for Young Cross Country Skiers
Cardiovascular System Testing for Sport Training Program Design

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Abstract: Training process in sport imposes high demands on athletes' cardiovascular system. Results of incremental treadmill test revealed that young athletes perform intensive physical work with cardio strain, i.e. at high HR. That is why training for cardiac adaptation should be foreground at the initial stages of sport specialization. Hemodynamic monitoring allows assessing cardiovascular system dynamics in training. The analysis of such indicators as HR, SV, EDV and inotropy (heart contractility) in 30 12-14 year-old cross-country skiers made it possible to divide them into 3 groups with different training orientation. Group 1 (low aerobic fitness: SV< 70 ml, EDV<110 ml) underwent aerobic training and general exercises. For group 2 (moderate fitness with high inotropy: RHR< 65 bpm, SV>70 ml, EDV >110, inotropy > 45) general and specific exercises were used on cross-country terrain under HR control (upper limit is 160 bpm). Group 3 (moderate fitness with normal inotropy less than 40%) underwent intermittent training as well. Regular hemodynamic monitoring (once per 3 months) helped individualize training, transferring athletes from one group to another according to the monitoring results obtained, thus avoiding inadequate cardiac adaptation. Incremental tests carried out twice a year proved the effectiveness of the selected health-saving technologies.

1 INTRODUCTION

Cross country skiing is a demanding sport. The skiing and running workouts take place in mounting terrain that increase demands on an athlete's cardio respiratory system. Modern adolescents differ from previous century teenagers. In the XXth century we had to do a lot of house and garden work, walked a lot instead of going by car and played outdoors rather than computer games, thus developing our endurance. Back in those times starting cross-country skiing at the age of 13 and even 18 might lead to being an Olympic champion because of routine background endurance and strength. Nowadays comfortable and physically inactive childhood limit the cardiovascular fitness at early ages. As a result the children start sport training with insufficient level of endurance. Therefore young athletes can hardly sustain a training load that is too intensive for a weak heart. Too intensive physical work at early ages disrupts the regulatory systems interaction and leads to irrational cardio adaptation.

An analysis of the scientific literature revealed that at present the typical planning of the training process does not take into account the young athlete's individual characteristics, morphological and functional development and current condition. Recommendations for planning training during the period of initial sport specialization contain approximate annual training loads and the ratio of loads of various intensity and specialities, and the coach is recommended to take into account the adolescents' individual characteristics judging by their appearance and level of their physical capabilities. No specific criteria are offered for assessing a child's morphofunctional development.

The situation is redoubled at puberty: the quick muscles development upsets the "heart-muscle balance" challenging their heart and cardiovascular system. So during the puberty period it is necessary to determine the volume and, what is more important, its intensity in order to save the heart muscle for the sport career in adulthood and for a happy life after abandoning the sport career. That is why the aim of our research was to determine the testing technologies that may serve as the basic for designing a training program.

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2 ORGANIZATION AND METHODS

Subjects. A group of 30 young cross-country skiers (19 males and 11 females) 12-14 years old who had 1-3 years of training experience in skiing participated in the study. The participants of the experiment had 14 hours of training a week.

Research Design. We assumed that there were subjects with different morphofunctional state. To divide them into different training groups with similar morphofunctions, the initial measurement of athletes' hemodynamics was taken in April, 2013. The current research was carried out from April 2013 to May 2015 with several experimental tests including athletes' hemodynamics measurements and incremental treadmill test (Table 1).

Incremental Test. The incremental test protocol was not less than 5 stages jogging. It was held without a preliminary warm-up on a treadmill (Technogym, Italy) whose design allows adjusting the running speed up to 25 km h^{-1}. The initial speed was 4 km h^{-1}. The duration of each stage was 2 minutes. The speed of the treadmill was increased by 2 km h^{-1} for each subsequent stage up to the last stage to exhaustion in order to determine the maximal running speed. Heart rate monitoring with Garmin Forerunner 305 (Garmin, USA) was used during the test and 5 minutes after it for recovery recording.

2.1 Heart Rate Monitoring during Incremental Test

The running incremental test is one of the most accessible and informative tests to assess physical fitness in cyclical kinds of sport (cross-country skiing, speed skating, cycling, track-and-field, etc). The idea of the incremental test is to match the changing athlete's heart rate with the intensity (speed or power) of physical load.

The heart rate monitoring was carried out with Garmin Forerunner 305 for recording current HR during the test and recovery. For rapid test results processing an interval workout was created in advance in Forerunner 305. The current values of HR, the duration of interval stage were demonstrated on the screen and saved in Forerunner 305 memory.

In an ideal athlete the "speed-heart rate" plot yields a straight line. But in real athletes this curve has a different form. The analysis of the peculiarities of the graph "jogging speed–HR" location and its trajectory (figure 1) allows you determining:

- $HR_{4km\ h^{-1}}$ which is the athlete's heart rate while jogging at a speed equal to 4 km h^{-1}, corresponds to the athlete's aerobic system development. There is a heart rate plateau on the graph the value of which is taken as the $HR_{4km\ h-1}$ indicator;
- the slope of the curve in the interval between the speed of 4 km h^{-1} and 6 km h^{-1} indicates the cardio-vascular system potential. The smaller the angular inclination of a line drawn through the point $HR_{4\ km\ h^{-1}}$ and $HR_{6\ km\ h^{-1}}$, the higher the heart potential to deliver oxygen to muscles is. The extrapolation of this line (when HR is within 90 and 120 beats min^{-1}) until the intersection with isoline HR = 190 beats/min shows the speed at which the athlete could run if for achieving high running speed he (she) used only their cardiovascular system (without muscles recruitment). This allows determining the potential capabilities of the heart to deliver oxygen to muscles;
- running speed at a heart rate 170 beats min^{-1}, km h^{-1} used as physical working capacity indicator similar to PWC_{170} (Belotserkovsky, 2005) or PWC 170 – Cycle test, the primary purpose of the which (Cambell et al., 2001) is to predict the power output at a projected heart rate of 170 beats per minute (bpm). For example, one athlete has 16 km h^{-1} at the HR =170 bpm while the other has only 13.5 km/h. The former is more physically fit than the latter;
- jogging time with HR below 170 bpm corresponds to the athlete's aerobic fitness: the longer an athlete has run with heart rate below 170 bpm the better is the current state of the athlete's aerobic system;
- time of physical work at HR above 180 bpm is used as an indicator of the development of the muscular system on cardiovascular system: the longer the athlete is able to perform high intensity workload the stronger is their muscular system;

Table 1: Experiment schedule design.

	April	July	October	January	April
Incremental treadmill test	*		*		*
Hemodynamic monitoring	*	*	*	*	*
The training focus selection	*	*	*	*	*

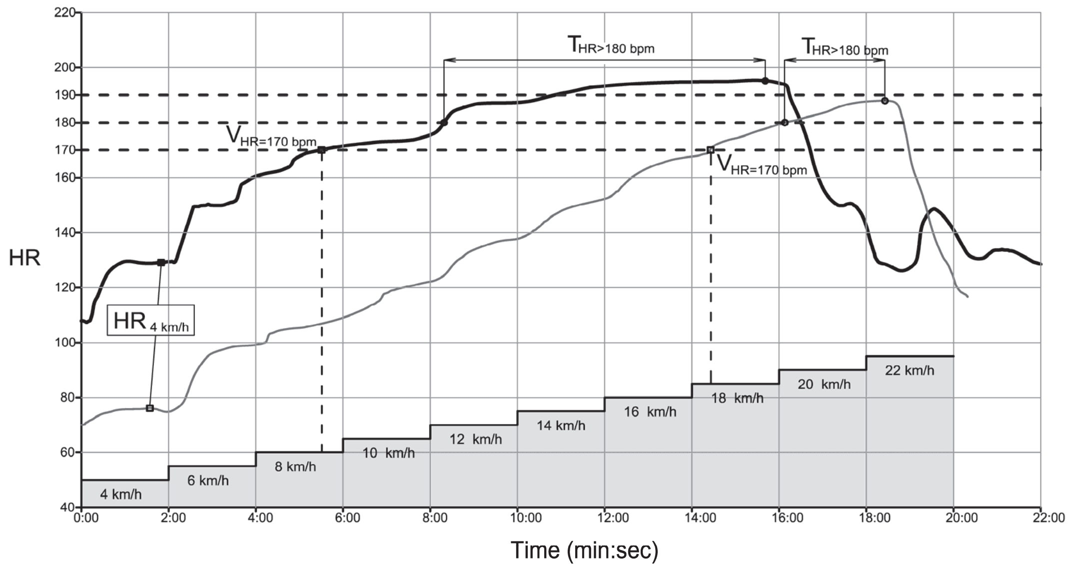

Figure 1: A young skier's, 13 years old, (thick line) and a skilled skier's, 24 years old, (thin line) pulsograms.

- V_{max} is the maximal speed the athlete could reach. It characterizes an athlete's integral readiness in jogging;
- HR_{max} is an indicator of the priority in the cardiovascular or muscle fitness: if HR_{max} is lower than 180 bpm, then there is cardiovascular priority. And there is a priority in the muscular system "heart-muscle balance" if HR_{max} is higher than 200 bpm.

The last three indicators allow us to determine the limiting factors of athletes' performance (Seluyanov, 2002). According to modern concepts in cyclic sports, physical performance qualifiers can be largely limited by either cardiorespiratory (cardiovascular) system or muscular system.

2.2 Hemodynamic Measurements

The hemodynamic monitor MARG 10-01 "MicroLux" (Chelyabinsk, Russia) is usually used in emergency and operation rooms. The device functioning is based on such noninvasive methods of hemodynamic monitoring as impedance cardiography and spectrophotometry, electrocardiogram monitoring (ECG), pulse oximetry monitoring, reography and central hemodynamics monitoring, blood pressure and temperature.

Measuring Methods. For the experiment a patient (athlete) was in supine position. Before recording all subjects were at rest in supine position during 10 minutes. All measured indicators of the central hemodynamics were automatically registered with 8 pregelled ECG electrodes Ag/AgC by MicroLux software with beat-to-beat record.

Hemodynamics is described by four general indicators: volemia, inotropy, vascular tone, chronotropy. The above-mentioned indicators are shown on the monitor as a percentage of normal values. The deviations of more than 25% are considered too high/low for adult.

Central hemodynamic indicators are presented in four groups: perfusion (stroke volume, cardiac output, stroke index, cardiac index), preload (end-diastolic volume, end-diastolic index), afterload (the index of total peripheral resistance, stroke index of total peripheral resistance), contractility and left ventricular activity (contractility index, ejection fraction; index of left ventricle activity, stroke index of left ventricle activity).

To investigate the young athletes' functional state we chose the most informative for cross-country skiing hemodynamic indicators.

Heart rate (HR) is the most accessible and informative indicator of the athletes' cardiorespiratory system development.

The stroke volume (SV) values should be a reference point in examining athletes in endurance sport.

Cardiac output (CO) is the indicator of cardiac systolic function and is equal to HR multiplied by SV. Increasing SV and CO during long term exercise is one of the main effects of endurance training. At the same time the growth of CO should occur due to SV rise, but not due to heart rate rise.

End diastolic volume provides sufficient stroke volume and cardiac output and is the guarantor of good tolerance for high-intensity work load in training and competitive activities.

*An ejection fracti*on changes from 57 to 65 and serves as an indicator of fitness level as well as the intensity of the previous training process.

3 RESULTS

The graphical displays of research subjects' heart rate values showed that all research participants have insufficient development of the cardiovascular system to perform intense workouts. Figure 3 features the HR graphical displays of one of the participants in the experiment (13 years old) and skilled skier (24 years old). It shows the difference in the development of the cardiovascular system and the dynamics of HR during the incremental treadmill test. According to the graphs, the same physical load (jogging speed) generates different response in the athletes, and they performed in different zones of intensity (figure 1, table 2). In this case higher values of HR during intensive load are explained by higher initial heart rate of the younger skier (table 2).

Table 2: Incremental treadmill test indicators in young (1) and experienced (2) cross-country skiers.

Indicator	1	2
HR at rest, bpm	69 ± 5	55 ± 3
$HR_{4km\ h\text{-}1}$	128	76
$V_{170\ bpm,}$ km h^{-1}	8	18
T $_{HR<170\ bpm}$, min:sec	5:10	13:40
T $_{HR>180\ bpm}$, min:sec	7:50	2:05
V_{max}, km h^{-1}	18	22
HR_{max}, bmp	196	187

Initial measurement and evaluation of athletes' hemodynamic indicators showed that the values of hemodynamic indicators in the participants were within age norms (Baranov and Scheplyagina, 2006; Diatlov et al., 2005; Zotova et al., 2012) or better (higher or lower than normal, depending on trends in age-related changes in endurance training), with the exception of inotropy. Namely, it was revealed that:

- HR indicators were within the age limits in 10 subjects and below normal in 20 subjects;
- SV indicators were within the age limits in 21 subjects and above normal in 9 subjects;
- EDV indicators were within the age limits in 19 subjects and above normal in 11 of them;
- inotropy exceeded adult norm (25%) by more than 20 % in 22 young subjects, less than 20% in 8 subjects.

Inotropy is described as the force of heart contraction and it varies depending on the training process intensity: the more intensive work in the training cycle is, the higher the inotropy value. Inotropy in research participants varies from 30 to 60% (the age norm is 30%). High values of inotropy are usually the result of exposure to a high intensity load that can lead to irrational adaptation of a child's heart (without an end-diastolic volume and ejection fraction increase) and overstrain. Young 12-13 year-old skiers have little sport training experience and, as a rule, increased resting heart rate (RHR). Therefore any workout of cross-country training is intense for them.

The initial hemodynamic research in April 2013 and the analysis of such indicators as HR, SV, EDV and inotropy (heart contractility) in 30 young cross-country skiers 12-14 years old made it possible to divide them into 3 groups (table 3):

- Group №1 included athletes who had low aerobic fitness levels: SV < 70 ml, EDV < 110 ml, high RHR and inotropy;
- Group №2 was composed of moderately trained young skiers (RHR < 65 bpm, SV > 70 ml, EDV > 110) with high inotropy (inotropy > 45%);
- Group №3 also had moderate fitness level athletes with normal inotropy (not more than 40%).

Different training groups had various focuses in further training taking into account the results of initial hemodynamics research (table 4).

For athletes of group №1 it was recommended to limit physical work causing HR rise higher than 160 bpm. For adolescences with resting HR about 80 bpm it is not difficult to overcome this heart rate limit. That is why uphill terrain skiing and jogging were excluded from their workouts. Aerobic training was essential for group №1 in order to improve cardiovascular fitness.

We called subjects "moderately trained" meaning "moderate" in comparison with skilled athletes but they had very good hemodynamic indicators and fitness level for 12-14 year-old adolescents. The only problem in hemodynamics in group №2 and 3 is high values of inotropy.

For cross country skiers from group №2 general and specific exercises were used on cross-country terrain under HR control (upper limit is 160 bpm). This was done to avoid excess strain in cardiovascular system.

Group №3 underwent interval training along with aerobic training. The volume of training load for all groups was selected according to age, sex and period of training.

After 3 months of training the second hemodynamic research was carried out. According to the results of hemodynamics monitoring, the groups

Table 3: Hemodynamics criteria for 12-14 year-old cross-country skiers group forming (in supine at rest).

Training groups	HR, beats/min	SV, ml	EDV, ml	Inotropy, %
Age norm	72-82	60-80	80-120	30-40
Group №1 (10 people)	70±5 lower limit of norm	65±6 norm	105±9 norm	55±10 above norm
Group №2 (12 people)	62±4 below norm	76±8 upper limit of norm	115±8 norm	54±9 more than 20% above norm
Group №3 (8 people)	60±5 below norm	85±6 above norm	132±11 above norm	35±7 norm

Table 4: The focus of the training in groups.

Training group	Training focus	Basic exercises	Basic methods
Group №1	Aerobic	Overall physical training (total body strength training), sport walking, cycling, sport games, skiing on flat terrain	game like method, uniform (steady)
Group №2	Aerobic	Running, skiing simulations, skiing on uphill terrain	Uniform
Group №3	Aerobic and anaerobic	Running, skiing simulations, roller skiing, cross-country skiing	Uniform, repeated

were reformed within group criteria (table 3). If group №3 athlete's inotropy is high, the athlete is transferred to training group № 2. The training focus was readjusted for him (her). With the inotropy value decreasing below 40% and the growth of EDV an athlete from group №2 was enrolled into training group № 3. Thus, such process of hemodynamic monitoring took place regularly (once in 3 months) and resulted in changing the group number and training focus correspondingly.

An example of the experiment participant's hemodynamics changes during the year is shown in table 5.

The incremental treadmill test with heart rate monitoring conducted twice a year determined positive training effects of the experimental training focus selection. Figure 2 shows pulsograms of a cross country skier at the beginning and at the end of the experiment.

Table 5: Year changes of an athlete's hemodynamic indicators.

Indicators	April 2014	July 2014	October 2014	January 2015	April 2015
EDV, ml	100	109	112	115	125
HR, beats/min	68	66	62	65	63
SV, ml	64	66	70	78	81
Inotropy, %	51	40	38	45	41
Training group	№ 2	№ 3	№ 3	№ 2	№ 2

The data presented in figure 2 show that the physical work performed in the course of the experiment, led to a heart rate decrease at a speed of 4 km h-1, an increase in running speed at heart rate 170 bpm, an increase in the maximum running speed (table 6), thus indicating the growth of aerobic and muscular fitness.

Table 6: Incremental treadmill test indicators in young cross-country skier before (1) and after (2) the experiment.

Indicator	1	2
HR at rest, bpm	70 ± 3	61 ± 2
$HR_{4km\ h\text{-}1}$	135	113
$V_{170\ bpm}$, km h^{-1}	12	14
$T_{HR<170\ bpm}$, min:sec	8:15	10:50
$T_{HR>180\ bpm}$, min:sec	4:50	2:15
V_{max}, km h^{-1}	18	20
HR_{max}, bmp	193	187

All the measured indicators of the young athlete became close to those of the experienced cross-country skier (table 2).

The analysis of the experiment results shows that at the stage of initial sports specialization the focus of the training process, as well as the means and methods of training, were properly selected and adjusted. As a result, the projected adaptation processes occurred in the athlete's body. The experimental planning focused on proper adaptation of athletes' cardiovascular system at the stage of initial sports specialization allowed:

1. Reducing inotropy to below 40% (i.e. by 10-15%).
2. Increasing SV by 15-30 ml by means of EDV increase by 20-30 ml.
3. Reducing resting heart rate by 5-15 bpm.

Thus, at end of the experiment there were no athletes in group №1: all cross-country skiers with low aerobic fitness improved their fitness and skiing performance. These results suggest purposeful car-

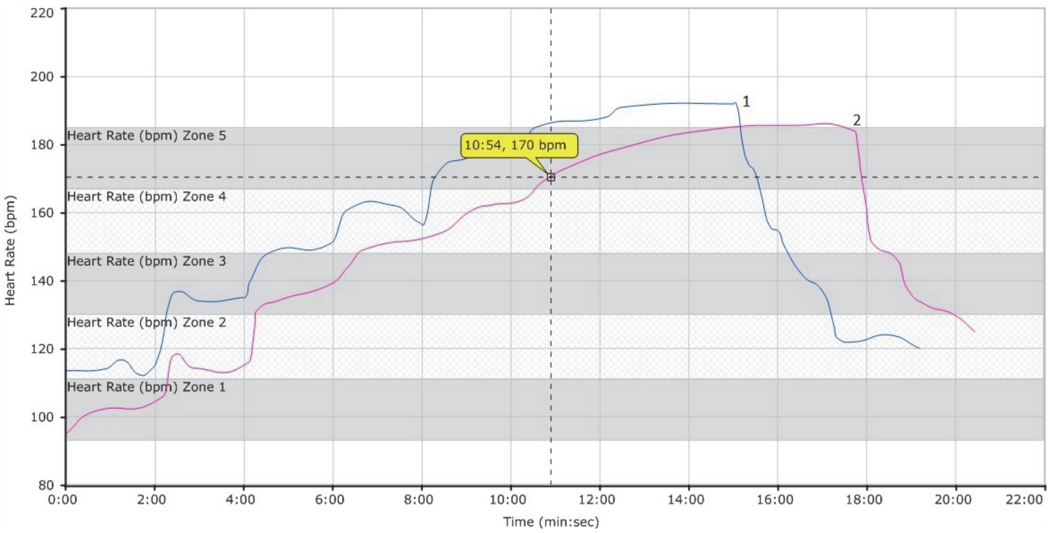

Figure 2: Pulsograms before (line 1) and after (line 2) the research.

diovascular development of 12-14 year-old cross-country skiers thanks to experimental planning of the training.

Such individualization of the training process at the stage of initial sports specialization is a health-saving technology that can be widely applied in youth sport. The data obtained can be used to optimize the development of athletes' cardiovascular system and will prevent overtraining and the disruption of adaptation processes in athletes. The knowledge of the relationship between HR, SV, EDV and inotropy allows providing health savings and successful preparation of sports resources.

4 CONCLUSIONS

1. Hemodynamic monitoring reveals the indicators of athlete's cardiovascular development (HR, SV, EDV, inotropy) and their readiness to perform demanding physical work in sport.
2. The account of hemodynamic indicators serves as the theoretical basic for differentiated training in youth sport. It allows influencing the cardiac development purposely and selectively, thus ensuring the athletes' health, performance improvement, especially in adolescence.

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