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Original Article

Heart rate variability in elite hockey players of 11-13 years old and selection efficiency in professional youth hockey

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Abstract
The aim of this article is to study the peculiarities of heart rate variability (HRV) in elite hockey players aged 11-13 in terms of efficient selection in youth ice hockey. The study involved 37 elite hockey players aged 11-12 (n=17) and 13 (n=20) years. The standard methods of HRV assessment were used (statistical methods and spectral component). In addition, the method of variation pulsometry and the reactivity index of the parasympathetic nervous system (30:15) were applied. Selection efficiency in youth ice hockey was estimated using the youth league ranking, which is comprised of players in the first year after sport schools (aged 17-18).
In hockey players aged 11-12 there was no connection between the parameters of heart rate variability and the league rank, where young athletes played after sport schools. In 13-year hockey players there is a strong direct correlation between RMSSD (r=0.95), AMo% (-0.59) and vegetative rhythm index (VRI) (-0.64). Therefore, HRV regulation in hockey players aged 11-12 is characterized by the absence of stress because of the dominance of parasympathetic influence on sinus node, which corresponds to age-related changes. Heart rhythm regulation in 13-year hockey players is accompanied by stress as a result of the increased influence of central mechanisms regulation under specific physical loads. Such indicators as RMSSD, AMo%, and VRI are important at the beginning of adolescence (13 years) for the assessment of selection efficiency in 11-13-year hockey players.
Key Words: athletes, adolescence, ice hockey, sport selection

Introduction

Changes in heart rate occur under the influence of any exogenous or endogenous environmental factors, which provide sufficient impact to activate the hypothalamic-pituitary-adrenal axis and short-term adaptive responses (Baevsky, & Ivanov, 2000, Tonello, Rodrigues, &Souza, 2014). Heart rate variability is a method for evaluating the activity of various mechanisms regulating visceral systems of a human body(Szlajzel, Jung, &Sievert, 2008, Leti, &Bricout, 2013, Abad, do Nascimento, Gil, Kobal, Loturco, Nakamura, Mostarda, & Irigoyen, 2014, Koenig, Jarczok, Wasner, Hillecke, &Thayer, 2014, Plews, Laursen, Le Meur, Hausswirth, Kilding, &Buchheit, 2014, Cipryan, Laursen, &Plews, 2016). HRV changes occur prior to hemodynamic, metabolic and energy disturbances of the body making this method valuable for the assessment of functional condition (Ban', & Zagorodnyi, 2010). Methods of HRV assessment are used in sports physiology and medicine (Schmitt, Regnard, Desmarets, Mauny, Mourot, Fouillot, Coulmy, & Millet, 2013, Sandercock, & Brodie, 2006). However, the study of age-related HRV peculiarities showed ambiguous results (Gąsior, Sacha, Jeleń, Pawłowski, Werner, & Dąbrowski, 2015, Cayres, Vanderlei, Rodrigues, Silva, Codogno, Barbosa, & Fernandes, 2015, Jarrin, McGrath, Poirier, Séguin, Tremblay, Montplaisir, Paradis, & Séguin, 2015), which are possibly related to the samples studied. Interpretation and the choice of methods and HRV parameters also differ. In international practice, the parameters of time domain methods (Statistical methods) and spectral analysis (Spectral components) are considered to be the most informative. In the spectral analysis of short-term ECG recordings little attention is paid to very low frequency waves – VLF (≤0.04 Hz). High frequency and low frequency waves in absolute and relative values are used as the main parameters of the spectral analysis. Parameters of VLF-waves are totally excluded from HRV analysis when normalized values are used. At the same time, some authors think that VLF-waves are an essential component, which proves the activity of cerebral-ergotropic structures of the central nervous system (CNS) (Shlyk, 2009).
The period between 11 and 13 years is critical for ontogenesis as it comprises active neurohormonal changes of the body. Changes occur at all levels of body functioning from homeostatic to psychophysiological functional systems and influence the development of young hockey players (Surina-Marysheva; Erlikh; Korableva; Kantyukov; Svisheva; & Ermolaeva, 2017). There is a high risk of injury in young athletes because of the peculiarities of competition rules (Popkin, Schulz, Park, Bottiglieri, & Lynch, 2016, Linzmeier, & LaBella,

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2016). Due to the lack of attention to age-related body peculiarities in young athletes, inappropriate physical strain can be the reason for deceleration of a young athlete’s ontogenesis and the developing of maladjustment (overtraining).

Aerobic endurance is one of the most important criteria of functional fitness during sport selection in hockey players (Montgomery, 2006). Scientists established that there is a correlation between athlete’s aerobic capacities and HRV parameters (Gavrilova, & Churganov, 2012). Changes in young hockey players during the critical periods of ontogenesis should influence the parameters of HRV, while the level of regulatory strain can indirectly affect the efficiency of athlete’s career development after graduation from Olympic Reserve sport schools.

We anticipated that there is a correlation between HRV parameters in hockey players aged 11-13 and the efficiency of sports selection for professional youth hockey teams. There is a subpar amount of research in field considering the manner of studies in youth elite hockey schools. At the same time, information on age-related peculiarities in young hockey players is essential to control the conformity of physical loads to functional capacity of the body and to conduct sport selection in professional junior and youth hockey teams. The aim of this article is to study the qualities of heart rate variability in elite hockey players aged 11-13 in terms of the efficiency of sport selection for professional ice hockey.

Materials & Methods

The study was conducted in the specialized “Traktor” school of the Olympic reserve (Russia). Between 2009 and 2017 “Traktor” sport school was routinely ranked among the TOP 5 hockey schools of Russia, and the qualification of its hockey players was considered to be high (elite athletes). Results of sport selection in youth hockey teams prove the qualification of hockey players. According to official statistics, 64-79% of juniors aged 16-17 enter the teams of the youth hockey league and 5-6% are selected for American youth hockey leagues and KHL (Russian Hockey. – http://www.r-hockey.ru).

The study of HRV parameters was conducted among hockey players (forwards and defensemen) aged 11-13. The age of participants was identified as of the time of the study. This age range corresponds to 2 periods of development (prepubertal and pubertal). Hence, all hockey players were divided into 2 groups: 11-12-year old (average age 11.29±0.47; n = 17) and 13-year old (average age 13.31±0.48; n = 20) athletes. Before the study voluntary informed consent from the parents was obtained in order to conduct the experiment. In accordance with the Declaration of Helsinki, they were informed of aims, security measures, methods and research protocols. The study was approved by the university ethics commission.

The study of HRV qualities in hockey players aged 11-13 was carried out at the beginning of the preparation period in 2010/2011. ECG testing was conducted in the morning by the same researcher (standard conditions).

The efficiency of sport selection was established by the rank of the league where hockey players performed in the first year after a specialized ice hockey sport school.

The electrocardiogram (ECG) was taken for 6 minutes in supine (physiological rest, 5 minutes) and standing positions (active orthostatic test (AOT) – 1 minute). Conditions were standardized (morning, the same researcher). The experiment was carried out in accordance with international standards on electrocardiographic studies for HRV assessment by means of short-term ECG recordings[22].

ECG registration was performed using the computer hardware produced by VNS-MICRO (Neurosoft, Russia). All equipment has an international certificate of conformity. During active orthostatic test, ECG was taken only in the first minute of transition period after changing body position. Results were processed with VRS PolySpectr software (Neurosoft, Russia). Automatic arrangement of markers in QRS-complex was checked visually and, if necessary, adjusted manually.

HRV analysis was carried out using well-established time domain methods (standard deviation of the NN interval – SDNN; root mean square of the successive differences – RMSSD; coefficient of variation – CV%) and spectral analysis (total power – TP, high frequency – HF (0.15-0.40 Hz), low frequency – LF (0.04-0.15 Hz), very low frequency – VLF (≤0.04 Hz) (Heart rate variability. Standards of measurement, physiological interpretation, and clinical use, 1996, Mikhaylov, 2000). According to international standards on VLF waves interpretation, VLF waves obtained during short-term ECG recordings can be used for scientific purposes (Heart rate variability. Standards of measurement, physiological interpretation, and clinical use, 1996).

The method of variation pulsometry was also used. According to the literature, results of variation pulsometry are highly informative in HRV assessment (Gavrilova, 2015).

Regulatory process adequacy index (RPAI) reflects correspondence between the activity of the parasympathetic system and leading level of sinus node. It is determined from the following formula:

$$RPAI = \frac{\mathrm{AMo}}{\mathrm{Mo}} \quad (1)$$

Mo is a range of values for the most frequent RR intervals; AMo is a number of intervals within Mo range; RPAI is a regulatory process adequacy index;

Vegetative rhythm index (VRI) is an indication of vegetative balance in terms of the activity of the parasympathetic nervous system.

$$VRI = \frac{1}{(Mo*VR)} \quad (2)$$

VRI – vegetative rhythm index; Mo is a range of values for the most frequent RR intervals; VR is a difference between the length of the largest and the smallest intervals.
SI – stress index. It reflects the degree of centralization in heart rate regulation.

$$SI = \frac{AMo}{2VR*Mo} \quad (3).$$

The assessment of the reactivity of the parasympathetic nervous system during the transition period of AOT was performed using the Mikhailov's method (Mikhaylov, 2000). 30:15 coefficient was also used being the ratio of time (msec) of the longest RR interval (peak of the cardiogram) to the shortest RR interval. As a rule, for a healthy adult this coefficient equals 1.6-1.8.

The results of official statistics for 2014-2016 are used in the study (Russian Hockey. – http://www.r-hockey.ru). The efficiency of selection in youth hockey was established using the results of selection in professional teams of the youth hockey league. For hockey players aged 11-12 (at the time of HRV study) we used the selection results for 2014-2015, for 13-year hockey players we used the results for 2016. The rank of each league was determined in the following way: 1 rank – failed selection, athlete finishes his career; 2 rank – junior hockey league (JHL); 3 rank – youth hockey league, B division (YHL-B); 4 rank – youth hockey league (YHL); 5 rank – American hockey league (QMJHL, SMHL etc.). The results of individual statistics were not taken into account as the level of hockey leagues is different.

After checking the normality of distribution with the help of the Kolmogorov-Smirnov test, the significance of differences was defined between independent samples (athletes aged 11-12 and 13-year athletes) using a Mann-Whitney nonparametric criterion. Results are presented as means±SD.

To analyze correlations between HRV parameters and the results of sport selection during the transition period from the junior league to the youth league a Spearman's rank correlation coefficient was used. Data processing was performed with the help of Statistica 10.0 software package.

Results

Groups of hockey players differ in terms of certain HRV parameters depending on age (Table 1). In 13-year athletes a decrease in RMSSD ($p<0.05$) and AMo% ($p<0.05$) was registered. Parameters that reflect the total power of heart rate regulation (SDNN and TP) did not depend on the age of hockey players ($p>0.05$ in all cases). In 13-year athletes we saw redistribution in the ratio of waves of different frequency: we registered an increase in VLF% ($p<0.01$) and LF% (as a trend) and a decrease in HF and HF% ($p<0.001$). The vagosympathetic interaction index in this age group increased – LF/HF ($p<0.001$).

Table 1. Heart rate variability in young hockey players aged 11-12 and 13. Data are means (±SD)

Parameters	11-12 years M±SD	13 years M±SD	P
SDNN, ms	76.65±30.52	58.50±22.54	0.138
RMSSD, ms	88.18±48.35	51.00±27.70	0.036
CV,%	9.14±3.04	7.21 ±2.47	0.100
AMo%	32.65±9.53	40.76±11.93	0.045
RPAI, c.u.	40.91±15.27	51.86±18.10	0.149
VRI	3.44±1.97	4.03±1.46	0.230
Si, c.u.	62.72±51.02	85.66±49.98	0.128
TP, ms^2	6294.77±4013.39	4043.36±2964.73	0.118
VLF, ms^2	1495.47±1098.85	1482.37±907.75	0.891
LF, ms^2	1524.47±998.43	1322.57±1169.37	0.336
HF, ms^2	3274.77±2228.50	1238.57±1332.28	0.006
VLF,%	25.07±11.09	40.77±15.55	0.006
LF,%	25.47±8.15	30.96±9.71	0.092
HF,%	49.44±14.89	28.30±12.87	0.0003
LF/HF	0.66±0.56	1.34± 0.68	0.0004

Note: SDNN - standard deviation of the NN interval; RMSSD - root mean square of the successive differences; CV - coefficient of variation; AMo - number of intervals within Mo range; RPAI - regulatory process adequacy index; VRI - vegetative rhythm index; Si - stress index; TP - total power; VLF - very low frequency; LF - low frequency; HF - high frequency; LF/HF – sympatho-vagal balance index.

The reactivity of the parasympathetic nervous system decreased significantly in 13-year athletes (30:15; $p<0.001$) (Fig. 1).

Hockey players aged 11-12 and 13 years, who were selected in a professional Russian team for this age group, are distributed in the following way after a sport school: 8-12% of athletes finish their career; 23-33% enter JHL teams; 59% perform in the YHL-B and YHL. Selection to the American Hockey League (QMJHL, SMHL) mostly depends on scouts. No more than 6% of hockey players perform in North American youth hockey leagues after graduating from the sport schools of Olympic reserve.

Correlations between HRV parameters and career success (according to the rank of junior and youth leagues) in hockey players aged 11-12 were not established (Table 2). A strong direct correlation with RMSSD (r=0.95) was revealed in 13-year athletes.

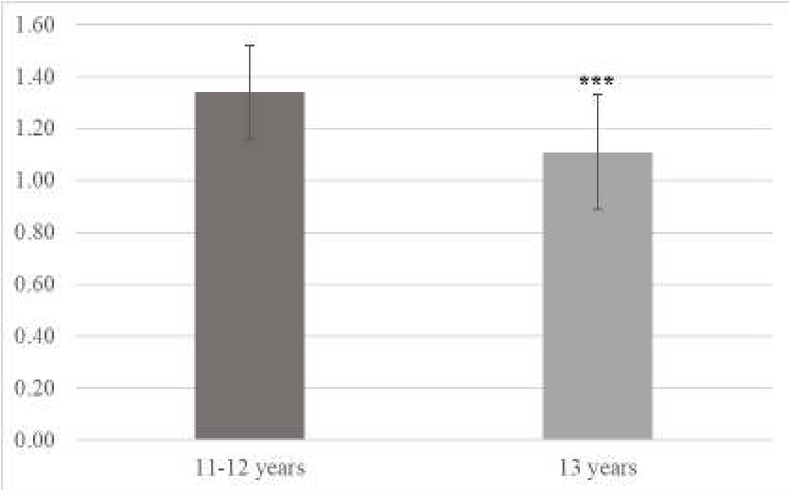

Fig.1. 30:15 coefficient in hockey players aged 11-12 and 13 years (*** – p<.001)

Table 2. Correlation coefficients between HRV parameters and hockey league at the beginning of the career in hockey players aged 11-12 and 13.

Parameter	11-12 years (n=17) r	p	13 years (n=20) r	p
SDNN	-0.08	□0.05	-0.37	□0.05
RMSSD	-0.22	□0.05	0.95	<0.001
CV%	0.07	□0.05	-0.12	□0.05
AMo%	0.001	□0.05	-0.59	<0.05
RPAI	-0.04	□0.05	-0.27	□0.05
VRI	0.11	□0.05	-0.64	<0.01
SI	0.14	□0.05	-0.35	□0.05
TP, ms^2	0.12	□0.05	0.33	□0.05
VLF, ms^2	0.21	□0.05	0.17	□0.05
LF, ms^2	0.21	□0.05	0.30	□0.05
HF, ms^2	0.01	□0.05	0.12	□0.05
VLF, %	0.15	□0.05	-0.20	□0.05
LF, %	0.44	□0.05	0.26	□0.05
HF, %	-0.36	□0.05	0.11	□0.05
LF/HF	0.47	□0.05	0.25	□0.05
K 30:15	0.25	□0.05	0.33	□0.05

Note: SDNN - standard deviation of the NN interval; RMSSD - root mean square of the successive differences; CV - coefficient of variation; AMo - number of intervals within Mo range; RPAI - regulatory process adequacy index; VRI - vegetative rhythm index; Si - stress index; TP - total power; VLF - very low frequency; LF - low frequency; HF - high frequency; LF/HF – sympatho-vagal balance index.

Discussion

According to prior research (Karpenko, 2010), we find dominance of the parasympathetic nervous system in heart rate regulation in non-athletic children aged 11-12. Autonomous patterns are also leading patterns of heart rate regulation in hockey players. The contribution of various heart rate regulation patterns in hockey players differs in comparison with non-athletic children. In children aged 11-12 and not involved in sports there is an increase in cerebral-ergotropic influence (VLF) in relation to the innervation of the vasomotor center (LF): HF>VLF>LF (Karpenko, 2010, Mamonova, Saburtsev, & Krylov, 2016). The balance between various regulatory mechanisms in hockey players aged 11-12 can be regarded as optimal: HF>LF>VLF. In prior research there have been different interpretations of the physiological significance of VLF-component. Some scientists establish a correlation between VLF-waves and metabolic processes of the body (Karpenko, 2010, Mamonova, Saburtsev, & Krylov, 2016). Others believe that VLF-waves characterize the activity of the sympathetic nervous system and the highest subcortical centers. Low-frequency waves describe the functional condition of the cerebral cortex and are sensitive indicators of energy and metabolic processes which show energy deficiency (Fleishman, 1999, Shlyk, 2009). Therefore, a significant increase in VLF values indirectly proves the emotional strain and stress in non-athletic children aged 11-12. The changes in the nervous centers of the limbic system are probably related to initial changes in the body due to the transition to a pubertal stage. At the same time, the body of hockey players aged 11-12 is more resistant to the influence of endogenous and exogenous stress factors of the environment. The parameter of the parasympathetic nervous system reactivity (30:15) during orthostasis does not depend on the type of activity. In non-athletic schoolchildren aged 11-12 (Lyutfullin, Almetova, 2014) it is 30:15, the same as in hockey players.

There are insignificant regional features in HRV parameters of elite hockey players from sport schools, which are probably related to competitiveness (sport selection). Hockey players of the Ural region do not differ in terms of the total power of heart rate regulation with respect to hockey players from elite ice hockey sport schools aged 11-12 (Lyutfullin, & Almetova, 2014, Reutskaya, Kuznetsova, & Antipova, 2014). However, hockey players from the Ural region demonstrate greater contribution of cerebral-ergotropic influence and smaller contribution of vagal influence to heart rate regulation, which result in the increase of the stress index (SI). In comparison with athletes of other specialization (football and basketball) (Shakhanova, Kuzmin, 2008), hockey players aged 11-12 demonstrate lesser autonomization and efficiency of heart rate regulation.

Age period between 11-12 and 13 years is related to neurohumoral shifts of the pubertal stage. The secretion of noradrenaline in 13-year old children decreases in comparison with 12-year old children, while the secretion of androgens increases (Shaykhelislamova, Dikopolskay, Valee, Sitdikov, Svyatova, & Zayneev, 2004). Based on the principle of the unity of neurohumoral regulation, hormonal shifts are accompanied by the shift of vegetative regulation, including the rhythmical activity of a cardiac muscle. However, in 13-year old children not involved in sport the data obtained during different studies differ. Some authors (Karpenko, 2010, Mamonova, Saburtsev, & Krylov, 2016) claim that the strain of the pubertal period appears later (from 14 to 15 years inclusive). Others think that in pupils not involved in sport the strain of regulatory processes appears exactly at 13 years (Eskov VM, Filatova, Eskov VV, Filatov, & Khadartseva, 2014). This data was obtained under adaptation to unfavorable climatic conditions. The development of strain in heart rate regulation is explained by the necessity of the adaptation to the combined influence of 2 strong stimuli – mental stress and physical stimuli (low temperature, short daylight, etc.). The combined influence of these stimuli is related to the development of the strain of heart rate regulation. During the period of active readjustment in 13-year old hockey players there is an antagonistic confrontation between sympathetic and parasympathetic influence of the nervous system, which shifts in favor of the strengthening of central mechanisms. At this age, there is a significant decrease of a vagal influence on heart rate regulation at rest, which results in the decrease of HF-waves power. There are changes in the distribution of the influence of various mechanisms on heart rate regulation. The influence of cerebral ergotropic structures of the central nervous system increases (increased VLF%). The balance of vagosympathetic interaction shifts in favor of the increase in the activity of the medullary vasomotor center (increased LF/HF). Distribution of heart rate regulation in favor of central mechanisms in 13-year hockey players in comparison with hockey players aged 11-12 is accompanied by the decrease in the reactivity of the parasympathetic nervous system. It is possibly connected with the increased tone of the vagus nerve at rest and confirms the decrease in adaptive reserves of the cardio-vascular system of the body.

The increase in the centralization of heart rate regulation in hockey players is made possible due to the increase in emotional loads in elite teams with a high level of competitiveness. This age period is characterized by the incomplete formation of hypothalamus connections. The strain in regulatory processes can also be the result of heterochrony in the development of morphofunctional systems, for example, the ratio between the speed of increase in the length of blood channels and the length of the body and extremities. At the same time, there are changes in the system of hemodynamics: there is an increase in the systolic blood pressure, mean pressure and peripheral vascular resistance (Shayhelislamova, Sitdikov, Zefirov, & Dikopolskaya. 2015). At the age of 13 cortisol secretion is activated in hockey players (stress hormone of the adrenal cortex) (Shaykhlislamova, Sitdikov, Dikopolskay, Bilalova, & Zotova, 2016). With respect to other team sports 13-year old hockey players differ from football players in terms of HRV parameters (Shakhanova, & Kuzmin, 2008), but are similar to basketball players. At this age period there is no strain in the heart rate regulation of football players. After pronounced sympathicotonia at the age of 12, the contribution of vagal innervation to the heart rate regulation of 13-year old footballers decreases, but still remains leading at a relative rest. The ratio of various regulatory mechanisms in 13-year old footballers corresponds to the following scheme: VLF<LF<HF. The biomechanical structure of the motor actions of basketball and hockey players has much in common. Movements with objects are performed by the upper extremities at a great speed and within a relatively small playground. Despite the fact that at the age of 12 the ratio of heart rate regulation mechanisms in football, basketball and hockey players was the same, at the age of 13, cerebral-ergotropic mechanisms (VLF-waves) and parasympathetic mechanisms became leading in basketball and hockey players. The increased strain in regulatory processes at the age of 13 in hockey and basketball players indicates the increased influence of specific physical loads on HRV parameters. Apart from speed-strength loads, emotional loads increase due to the increase in the number of competitions.

Sport preparation in Russia is organized in the following way: initial stage (ages of 8-10), sport preparation stage (ages of 11-17). After the sport school of Olympic reserve hockey players are selected into the teams of Junior and Youth hockey leagues. At the age of 11-12 we did not reveal any statistically significant correlations between the parameters of the cardiovascular system and the rank of the league, where athletes perform after the sport school of Olympic reserve. At the beginning of the pubertal stage (13 years old) there is a strain in heart rate regulation and a strong positive correlation between the activity of the nervous centers of the parasympathetic nervous system in heart rate regulation (RMSSD) and the level of the hockey league. According to literature, RMSSD is the most informative parameter among other indicators reflecting changes in regulatory activity under load testing (Al Haddad, Laursen, Chollet, Ahmaidi, & Buchheit, 2011). As a rule, RMSSD and SDNN change in the same way. The increase in the total influence of parasympathetic regulation (RMSSD) is accompanied with the unilateral change in total regulation (SDNN). Hence, the absence of correlations between SDNN and prospective results of sport selection in youth hockey proves the greater significance of the autonomization of regulatory processes under adaptation to physical loads in the critical period of onthogenesis. Athletes with the low VRI strain (negative correlation) and lower values of AMo% had better prospects to start professional career in youth hockey teams. It means that at the beginning of the pubertal stage hockey players with a greater influence of the parasympathetic nervous system on sinus node at rest have better prospective to enter professional youth hockey teams.

Conclusions

The parameters of heart rate regulation in hockey players aged 11-12 correspond to age-related peculiarities and are less influenced by environmental factors and specific physical loads. Heart rate regulation is characterized by the significant influence of the parasympathetic nervous system and the optimal balance between the central and autonomous regulatory mechanisms. The reactivity of the parasympathetic nervous system in hockey players aged 11-12 during the transition to orthostasis has not reached the level of a healthy man but corresponds to the age-related peculiarities of the cardio-vascular system.

At the age of 13 there is strain in heart rate regulation being the result of the increase in the influence of central regulatory mechanisms. The increase in the influence of cerebral-ergotropic brain structures occurs, which indirectly proves the increase in the activity of the limbic system. Strain in heart rate regulation in 13-year old hockey players is mostly connected with the peculiarities of adaptation to specific physical loads.

At the age of 11-12, HRV parameters are not informative to assess the selection efficiency in youth hockey. However, at the age of 13 (at the beginning of the pubertal period), the degree of autonomization in heart rate regulation reflected in RMSSD, AMo% and VRI is connected with the parameter of career success after a preparation in the specialized hockey school. These peculiarities should be taken into account by the coaches when scheduling physical loads of young hockey players aged 11-13 and by the experts in sports medicine to provide medical and biological support to young athletes.

Perspective Further research of age-related characteristics of HRV of hockey players in relation to predicting their level of success in professional development will be of valid interest for sports medicine professionals, coaches and professional hockey team scouts. It is also important to conduct additional longitudinal study of HRV dynamic in hockey players of various levels of qualification during the whole puberty period, as well as to uncover critical strain periods in the autonomic heart regulation patterns during its adaptation to varying physical stress. One of additional avenues of research is the establishment of connection between the HRV indicators and the professional development of young and adult ice hockey players.

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