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Hemodynamic Status of Prepubertal and Pubertal Hockey Players

M. V. Shayhelislamova, F. G. Sitdikov, T. L. Zefirov, and N. B. Dikopolskaya
Kazan Federal University, Kazan, Tatarstan, Russia
e-mail: bettydn@mail.ru

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Abstract—The study of the properties of hemodynamics in 11- to 15-year-old hockey players depending on their age and puberty stages and comparison of its parameters with the parameters of non-athletes of the same age has made it possible to ascertain that regular muscle training has the dominant effect on the functional state of the cardiovascular system (CVS) in prepuberty and puberty. It has been shown that in hockey players a decrease in heart rate (HR) and an increase in the stroke volume (SV) with age result in a significant increase in systolic blood pressure (BP_s) at the age of 11–14 years and a progressive increase in total peripheral vascular resistance (TPVR), in contrast to significantly lower values in the control group. Quick adaptation of the CVS to graded physical activities at the age of 11–13 years leads to an enhancement of vascular spasmodic reactions, while SV remains constant. Adolescent hockey players have been found to have steadily high values of SV and BP_s; at the same time, maximal values of HR, cardiac output (CO), and diastolic blood pressure (BP_d) were observed at puberty stages 1 and 2, and; by stage 3, these parameters decreased, in contrast to the adolescents who did not do go in for sport, in whom the dynamics of these parameters has an opposite direction. This may be evidence of the stress effect of physical activities resulting in the adaptive reactions of the CVS, rather than pubertal changes in its functional activity.

Keywords: 11- to 15-year-old hockey players, hemodynamics, puberty stages, graded physical activities
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It is undoubted that the cardiovascular system (CVS), which is formed with age and under the training impact of muscular activity, is one of the leading systems that ensure the adaptation of a growing organism to physical activity [1–3]. Despite a significant number of studies that reflect the hemodynamic status of young athletes, changes in its parameters are usually assessed only from the standpoint of children's training status [4, 5]. At the same time, no account is taken of the influence exerted by a number of endogenous factors and, in particular, age-specific morphofunctional transformation of the CVS, neuroendocrinal reconstructions in puberty, which cause the growth of sympatic impulses into the neuromuscular apparatus of the heart and blood vessels [6]. The role of sympatic regulation in the periods of the pubertal surge is undoubtedly high, and its growth is biologically expedient and necessary for the morphological and functional properties of the CVS to be completely formed. However, the increased lability of nervous processes, which is immanent to puberty [6], decrease in the excitability threshold of the autonomic nervous system, and insufficient participation of the parasympactic division in compensatory and adaptive reactions of the body [1, 7] cause functional disorders of the CVS, which arise in puberty as hypertonic phenomena, sinus arrhythmia, and premature ventricular contraction [8]. An excessive and irrational physical activity can not only change the dynamics of the age-specific evolutive processes in the heart and vessels, but also cause cardiovascular disorders in young athletes [9–12]. All this is important due to the wide development of child and youth sports originally aimed at health maintenance in the young generation. The study of hemodynamics in young hockey players, because playing ice hockey requires high speed–power and coordination body capabilities as a sports with an acyclic type of the training process; the success in this game is determined by the complex functioning of hemodynamics, vestibular, visual, and motor analyzers and the degree of emotional stability of the players [3, 12]. However, there are no published longitudinal studies on the CVS in young hockey players and no information on the properties of their hemodynamics at different puberty stages (PSs), although it is recognized to be indisputable that the puberty level affects the physical capability and adaptive potential of the blood circulation system in young athletes [13].

All this has determined the importance of this study aimed at investigating the functional state of the CVS in 11- to 15-year-old hockey players with consideration of age and puberty stages.

METHODS

The study enrolled male adolescent athletes (58 subjects) who were taught at specialized sport classes at school no. 1 of the city of Kazan and went in for ice hockey with a weekly duration of physical activity of 12–14 h. The examinations were all performed in the competition period combined with everyday training, when 11-year-old children were at the initial stage of intense muscular training. In order to reliably judge on the specific impact of physical activity on the state of the CVS in adolescents, boys from control classes who did physical exercises at the level of a general nonspecialized school were examined in parallel (48 subjects). Observation was made over the same children continuously during five years from 11 to 15 years of age inclusive. For eliminating the influence exerted by circadian rhythms of the functional activity of physiological systems [14], as well as the impact of teaching load on a child's body, the examinations were carried out in the same time of day (before noon, in the middle of a week, at the beginning of the academic year).

To study the functional state of the CVS, tetrapolar chest rheoplethysmography was performed with the use of a Rheo-Specter-2 software–hardware rheographic complex (Neurosoft, Ivanovo, Russia). The stroke volume (SV) was calculated by Kubichek's equation in Pushkar's modification [15]; cardiac output (CO) was estimated as a product of SV and heart rate (HR). Total peripheral vascular resistance (TPVR) was calculated by Poiseuille's equation [16], and blood pressure (BP) was measured by Korotkov's method with an MF-30 half-automatic device (Japan). Systolic (BP_s) and diastolic (BP_d) blood pressures and average hemodynamic pressure (AHP) were determined [17]. A graded physical activity of 1.5 W/kg body weight, which was performed for 3 min using a Rhythm VE bicycle ergometer (Kiev, Ukraine), was used as a functional test.

Puberty stages were determined by Tanner's method (1968) depending on the expression of secondary sex characters [18].

The obtained data were statistically processed by common variation statistical methods using the Microsoft Excel 2007 software package. To estimate the significance of differences, the *T* test based on Student's *t* test was used.

RESULTS AND DISCUSSION

The study has shown that the age-specific dynamics of HR and SV are quite regular in young hockey players and agree with the results of earlier studies (Table 1). Specifically, HR is observed to significantly decrease with age by 18.74 bpm, which is the most pronounced from 14 to 15 years of age ($p < 0.05$); this does not contradict the ideas of the formation of the chronotropic function in children and the direct dependence between the degree of HR fall and level of their motor activity [1, 6]. However, in boys from the control class, HR significantly grew at the age of 14 years by 7.56 bpm ($p < 0.05$) against the background of its decrease in the periods from 11 to 13 and from 14 to 15 years of age ($p < 0.05$). The stabilization or growth of this CVS parameter in 13- to 15-year-old adolescents with the medium level of physical development is also pointed out in other works [19], which is regarded as a pubertal HR surge due to the strengthened sympatic regulation of the cardiac function [6]. SV was found to be at a relatively high level at all stages of the examination (within 53.91 ± 1.40 and 67.81 ± 1.52 mL); from 13 to 15 years of age, it was observed to significantly grow by 5.41 and 7.42 mL ($p < 0.05$); the boys who did not go in for sport had lower indices of this parameter at all stages than in the sport class, and the differences are within 11.84–15.96 mL ($p < 0.05$). The same pattern was found for CO: it was relatively higher in hockey players aged 11, 12, and 13 years than in the control subjects ($p < 0.05$).

Of special interest is analysis of the age-specific changes in TPVR, since cardiac output and peripheral vascular resistance are leading factors in the self-regulating blood circulation system [20]. Specifically, the dynamics of TPRV in young hockey players are characterized by its growth with age and, consequently, in proportion to the growth of the level of training in adolescents, which is the most strongly pronounced from 12 to 13 and from 13 to 14 years of age, when the growth is 202.90 and 327.18 dyn s^{-1} cm^{-5} ($p < 0.05$); at the age of 15 years, the outlined trend persists. The boys from the control class exhibited a significant decrease in TPRV by 14 years of age, despite its relatively larger level at 11 and 12 years of age ($p < 0.05$). Vascular excitation in hockey players can be due to the anatomic properties of the formation of the vascular tree in prepuberty and in puberty [6, 8]; at the same time, the revealed differences from the boys of the control class indicate that the progressive growth of TPVR with age is provoked in athletes just by intense physical activity. The arising problem of vascular excitation gives trouble, since arteriolar spasm and growth of peripheral vascular resistance are leading factors in the pathogenesis of hypertonic states in children [17, 21, 22], which is particularly important in the context of intense muscular exercises and should attract close attention of specialists. Then, it was shown that the differences in the indices of TPRV between the boys from the sport and control classes at 11 and 12 years of age were comparable with the values of CO. The increased values of CO in the athletes, which are 1.5 and 1.3 times higher than in the control group, are accompanied by a relative decrease in TPRV at this age; i.e., they are compensated for by the growth of capillary capacity, which indicates the manifestation of the hemodynamics regulation mechanism [20]. At the same time, it is probable that the level of this regulation in young hockey players proves to be insufficient, which is indicated by the results from studying BP, namely, unexpectedly high values of BP_s in 11, 12, 13, and 14 years of age (from 129.66 ± 1.85 to 131.24 ± 2.00 mmHg). This is also accompanied by growth of BP_d at 11 and 12 years of age, which is higher by 8.00 and 7.18 mmHg than in the boys from the control class

Table 1. Parameters of the functional state of the cardiovascular system in 11- to 15-year-old boys from the sports and control classes ($M \pm m$)

Age, years	Parameters													
	HR, bpm		SV, mL		CO, L		BP_s, mmHg		BP_d, mmHg		AHP, mmHg		TPVR, dyn s^{-1} cm^{-5}	
	SC	CC	SC	CC	SC	CC	SC	CC	SC	CC	SC	CC	SC	CC
11			•		•		•		•		•		•	
	84.40 ± 1.90	82.00 ± 1.99	54.90 ± 1.33	38.94 ± 1.36	4.93 ± 0.10	3.10 ± 0.10	131.00 ± 2.50	108.20 ± 1.26	73.00 ± 1.38	65.00 ± 1.08	94.96 ± 2.57	83.06 ± 1.38	1362.60 ± 50.44	1767.38 ± 99.42
12			•		•		•		•		•		•	
	80.70 ± 1.80	78.30 ± 1.66	53.91 ± 1.40	42.07 ± 2.24	4.66 ± 0.20	3.23 ± 0.12	129.66 ± 1.85	110.00 ± 1.19	74.50 ± 1.60	67.32 ± 1.80	95.62 ± 1.76	85.60 ± 1.40	1335.70 ± 58.20	1806.88 ± 116.25
13			•		•		•				•			
	75.62 ± 1.80	75.80 ± 1.34	59.32 ± 1.74*	45.07 ± 1.38	4.52 ± 0.58	3.78 ± 0.09	131.24 ± 2.00	113.10 ± 1.22	63.50 ± 1.21*	68.26 ± 1.56	98.64 ± 2.25	88.06 ± 1.80	1538.60 ± 79.36*	1784.43 ± 100.63
14	•		•				•		•				•	
	72.50 ± 1.30	83.36 ± 1.57*	60.39 ± 1.33	49.90 ± 1.81	4.40 ± 0.13	4.68 ± 0.13*	130.00 ± 2.00	119.62 ± 1.64	64.00 ± 1.02	71.50 ± 1.90	94.73 ± 1.93*	86.66 ± 1.64	1865.78 ± 102.00*	1502.98 ± 75.64*
15	•		•								•		•	
	65.66 ± 1.02*	72.70 ± 1.70*	67.81 ± 1.52*	54.28 ± 2.05	4.14 ± 0.09	4.24 ± 0.19	126.80 ± 1.40	122.19 ± 1.25	69.55 ± 2.01	70.80 ± 1.70	95.87 ± 2.00	86.00 ± 1.70	1829.10 ± 135.20	1428.21 ± 60.52

SC is the sports class ($n = 58$), CC is the control class ($n = 48$). See the deciphering of other abbreviations in the section "Methods." * Significant difference from the previous age group, $p < 0.05$; • significant difference between the SC and CC, $p < 0.05$.

Table 2. Puberty stage distributions of 11- to 15-year-old boys from the sport and control classes (%)

Age, years	Puberty stage									
	SC					CC				
	I	II	III	IV	V	I	II	III	IV	V
11	100					70	30			
12	20	80					70	30		
13		30	70					80	20	
14		10	50	40				10	90	
15			10	70	20				30	70

SC is the sport class, and CC is the control class.

(p < 0.05), in whom BP_s is no higher than 122.19 ± 1.25 mmHg. AHP deserves special interest as the hemodynamic constant that permits one to judge on the correspondence between cardiac output and state of the vascular tone. This parameter is stabilized in the young athletes at relatively high levels (from 94.73 ± 1.93 to 98.64 ± 2.25 mmHg), whereas the non-athletes have an AHP no higher than 88.06 ± 1.80 mmHg. The growth of AHP in the athletes combined with the increase in CO (the age of 11–13 years) may indicate a decreased capillary capacity [6, 20].

The discordance between the cardiac output and state of peripheral blood circulation in the young hockey players becomes most evident after a graded physical activity; it is necessary to note that the reaction of the CVS also depends on age (Fig. 1). At the ages of 11, 12, and 13 years, the chronotropic effect is most evident; the activity of the inotropic cardiac function is decreased, specifically, the change in HR is 20.33, 25.03, and 24.45% (p < 0.05) at each age, respectively, and there is almost no growth of SV; i.e., the growth of CO, which is 20.08, 21.57, and 24.38% (p < 0.05), is ensured by changes in HR. The absence of changes in SV in the hockey players may be due to a significant pre-activity strain of the inotropic cardiac function, when their cardiac output significantly exceeds the data in children from the control class. This may indicate the manifestation of the homeostatic hemodynamics regulation mechanism, namely, Widler's Law of Initial Values, according to which, the high initial activity of a functional state leads to its smaller changes under external impacts [21]. At the same time, the growth of CO in response to a graded activity is accompanied by simultaneous growth of TPRV within the limits from 15.18 to 27.80% (p < 0.05), which is the most evident at the age of 12 years. In addition, BP_d significantly grows, which may on the whole indicate the incompliance between the increasing blood circulation volume and capillary capacity, which is proved by the mathematically significant growth of AHP (the age of 11 and 12 years) (p < 0.05). The hockey players aged 14 and 15 years have, on the one hand, a more balanced ratio of the chronotropic and inotropic cardiac reaction and the increased role of the latter in ensuring CO; they exhibit an increase in HR by 20.78% (p < 0.05) and 11.24% (p < 0.05%) and growth of SV by 20.80% (p < 0.05) and 15.10% (p < 0.05) at 14 and 15 years of age, respectively; At the same time, BP_s is observed to grow by 24.30% (p < 0.05) and by 19.63% (p < 0.05), and BP_d is relatively stabilized. On the other hand, the observed decrease in TPRV by 133.15 and 188.98 dyn s^{-1} cm^{-5} is insufficient in the case of the abrupt growth of CO by 38.25 and 40.05% (p < 0.05), which leads to a significant increase in AHP (p < 0.05). That is, the growth of CO takes place without the necessary decrease in peripheral vascular resistance, owing to which muscular work is done with a significant load on the arterial bed [23]. It is not improbable that the cardiac output growing in this case is a compensatory adaptive heart reaction that is aimed at overcoming vascular resistance [6]. The disorder in the interaction between cardiac output and vascular bed capacity may indicate the earliest changes in the blood circulation regulation in the young hockey players, which cause the manifestation of hypertonic reactions [17, 22].

Considering that the development of the CVS in adolescence strongly depends on the puberty level, the study of its functional state was carried out at each puberty stage of adolescents. In this regard, the puberty stage distribution of boys in the sport and control classes was found to have specific characteristics (Table 2). Among 11-year-old children who do not go in for sports, 30% are already at PS 2, at the same time, all children in the group of hockey players are only at PS 1. At the age of 13 years, the number of boys at PS 3 in the control class grows by 50% compared to 12-year-old boys, and 20% already belong to PS 4; at the same time, in the group of athletes, 30% of adolescents still pass PS 2, and the rest of them are at PS 3. At the age of 15 years, 70% of boys from the control class enter PS 5, and PS 4 is still prevalent in the athletes; moreover, 10% of boys remain at PS 3. That is, the young hockey players aged 11–15 years have a rel-

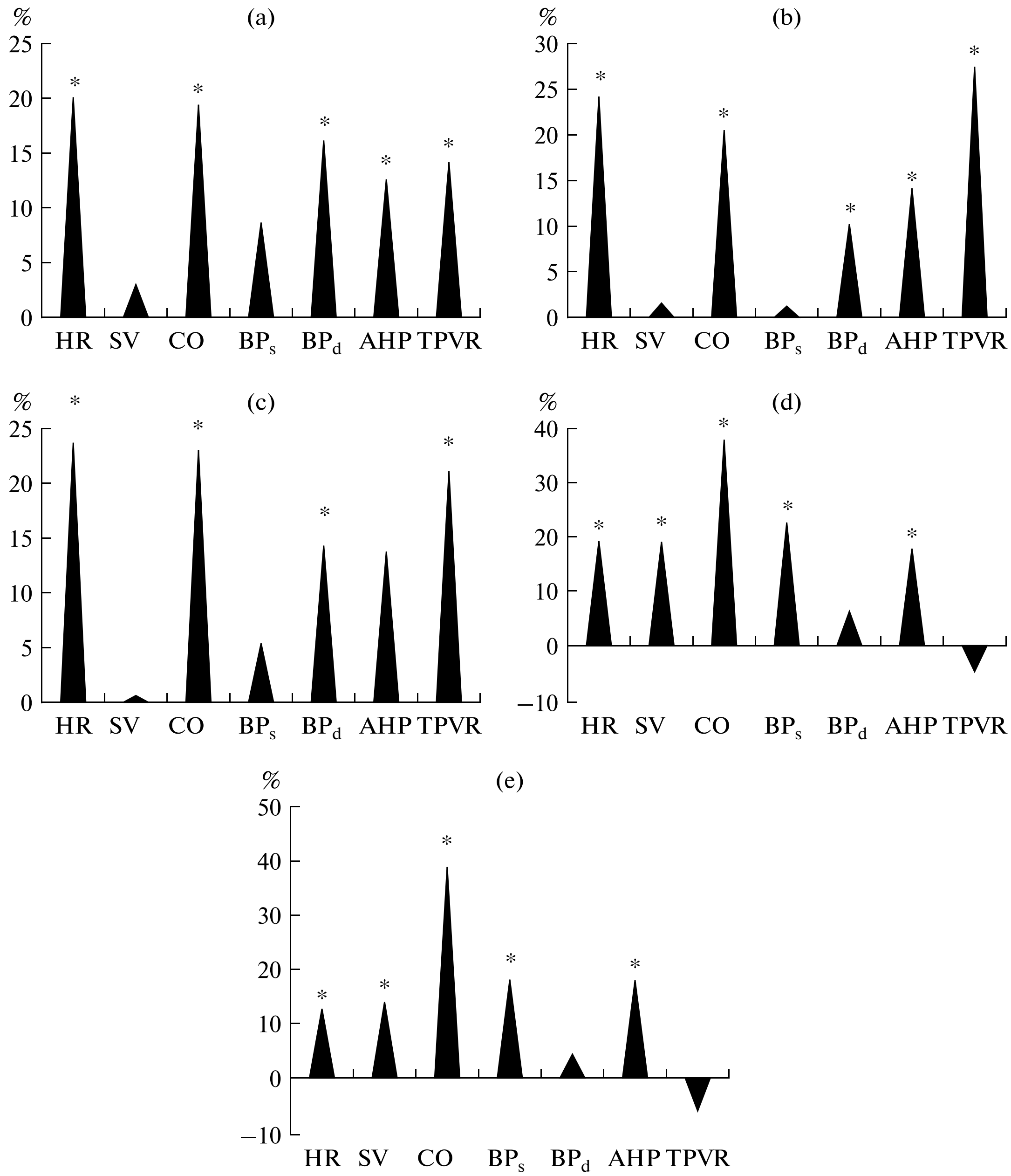

Fig. 1. Reaction of hemodynamics to graded physical activity in young athletes. Age groups: (a) 11 years, (b) 12 years, (c) 13 years, (d) 14 years, (e) 15 years. The abscissa axis: hemodynamic parameters (see the abbreviations here and in Fig. 2 in the section "Methods"). * Significant difference from the resting state, $p < 0.05$.

ative deceleration of sexual development (development of secondary sexual characters), which is probably due to the influence of intense physical activity accompanied, in particular, with the secretion of a large amount of glucocorticoids [24, 25], which can hamper the normal functioning of gonads, thus affecting the processes of sexual differentiation [26].

The study of hemodynamics as dependent on a puberty level in boys has shown that the trends in the development of the CVS found earlier in the young athletes and their differences from the children of the control class, in general, persist; however, their clear correlation with a specific puberty stage and the strongly pronounced dominance of adaptive processes over pubertal ones become evident. Specifically, in the boys from the sport class, the maximal values of a number of hemodynamic parameters are observed at PSs 1 and 2 (Fig. 2), when HR is 82.55 ± 1.82 and 80.20 ± 1.65 bpm, and its significant decrease, which is 7.20 and 6.10 bpm respectively, takes place at PS 3

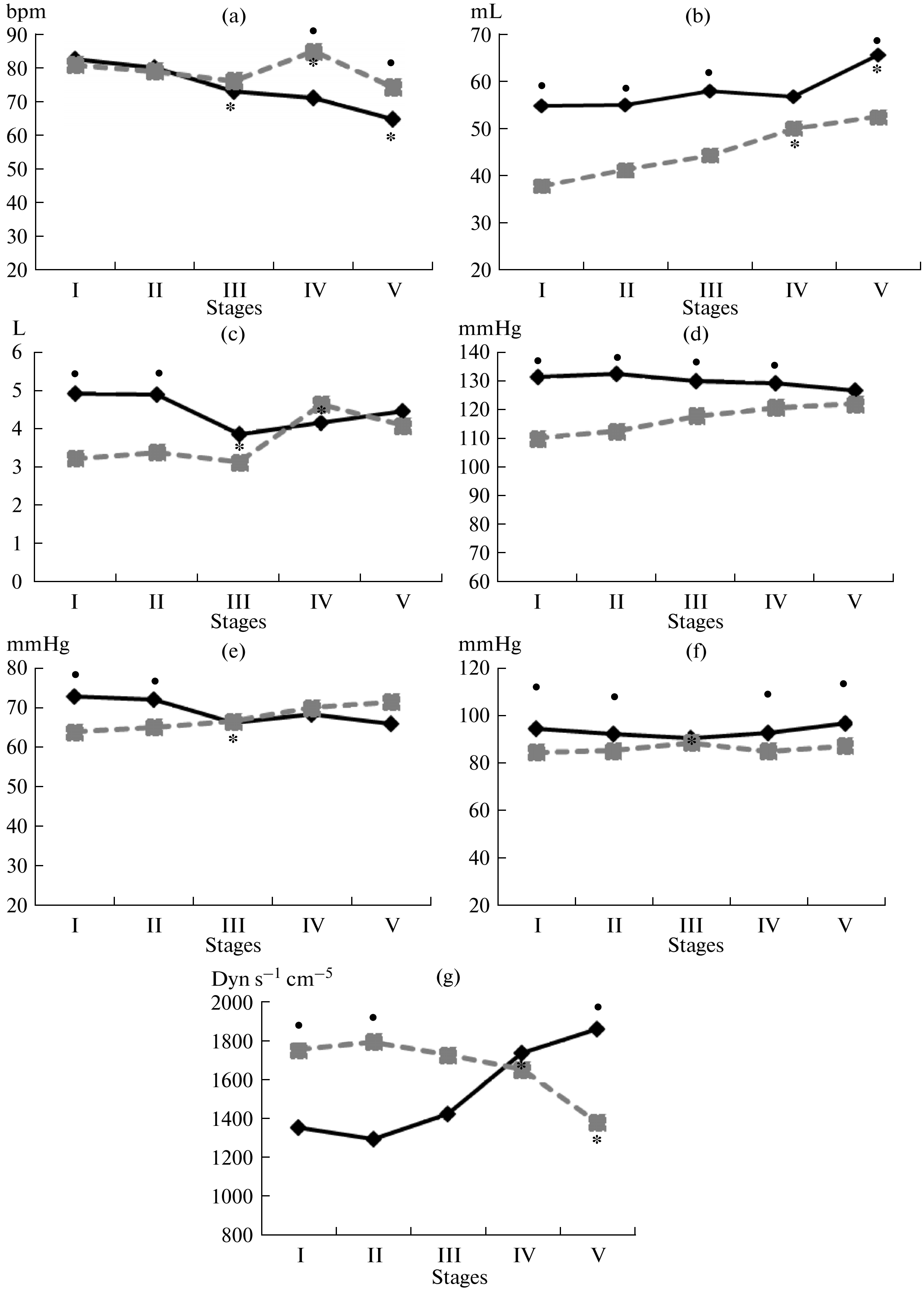

Fig. 2. Changes in the parameters of the functional state of the cardiovascular system in the boys from the sports class (SC, the black solid line) and control class (CC, the gray dashed line) at different puberty stages: (a) HR, bpm; (b) SV, mL; (c) CO, L; (d) BP_s, mmHg; (e) BP_d, mmHg; (f) AHP, mmHg; (g) TPVR, dyn s^{-1} cm^{-5}. * Significant differences from the previous puberty stage, $p < 0.05$; • significant differences between the SC and CC, $p < 0.05$.

and 5 ($p < 0.05$). The greatest indices of CO in the athletes are also found at PSs 1 and 2 (4.93 ± 0.10 and 4.90 ± 0.12 L); it is noteworthy that they decrease by PS 3 by 1.03 L ($p < 0.05$) and then are stabilized within the limits of from 4.17 ± 0.10 to 4.47 ± 0.19 L. At the same time, SV has constant and relatively high values at all PS (from 54.90 ± 1.33 to 65.50 ± 1.66 mL); by PS 5, it is observed to grow even more by 8.70 mL ($p < 0.05$). PS 1 and 2 in the hockey players are also characterized by relatively heightened values of BP_s and BP_d, which are 131.00 ± 2.00, 132.00 ± 2.20 mmHg and 73.00 ± 1.60, 72.20 ± 1.36 mmHg, respectively; BP_d falls by PS 3 ($p < 0.05$), and BP_s decreases insignificantly only by PS 5, when its values do not exceed 126.60 ± 1.50 mmHg. The dynamics of TPVR in the young hockey players are characterized by constant values at PSs 1–3, which do not exceed 1431.40 ± 79.36 dyn s^{-1} cm^{-5}, and growth by PS 4 by 311.42 dyn s^{-1} cm^{-5} ($p < 0.05$); at PS 5, the increased level of this parameter persists.

It is noteworthy that the changes in most hemodynamic parameters in the boys from the control class have a directly opposite character; in contrast to the athletes, their greatest values are found at PSs 3 and 4. Specifically, against the background of decrease in HR in the process of sexual development (from 80.99 ± 1.72 to 74.35 ± 1.38 bpm), its values grow by PS 4 by 8.66 bpm compared to PS 3 ($p < 0.05$). The same dynamics were revealed for SV and CO, which grow by PS 4 by 5.57 mL and 1.52 L, respectively, and SV also continues to grow by PS 5 ($p < 0.05$). Changes in BP in the boys from the control class are less significant; however, there is a trend towards growth of BP_s from the second to the third PS (by 5.26 mmHg) and in BP_d from the third to the fourth PS (by 3.40 mmHg). At the same time, at almost all puberty stages, the indices of BP_s, AHP, and BP_d (at the first and second PSs) are significantly lower in the boys from the control class than in the hockey players. TPVR also has different dynamics: in contrast to the athletes, this parameter in children from the control class decreases during sexual development; moreover, this decrease is the most pronounced from the fourth to the fifth PS and is 267.42 dyn s^{-1} cm^{-5}. According to the data of many studies [6, 7, 19], precisely the third and fourth puberty stages (the stage of activation of gonads and stage of maximal steroid genesis [27]) are critical in the development of the CVS in adolescents (the pubertal HR surge, growth of SV and CO, and vascular excitation), which is explainable from the standpoint of the physiological hyperfunctioning of the pituitary glad, adrenal cortex and medulla [27] due to the abrupt growth of the output of adrenaline, noradrenaline, and cortisol that strengthen the sympatic regulation of the myocardial functions and hemodynamics [6]. The contradiction observed in the group of young hockey players, in whom the pubertal transformations of the CVS go contrary to the well-known patterns (the maximal values of HR, CO, and BP_d at PS 1 and 2 and their reduction by PS 3, stabilization at high values of BP_s, BP_d, and AHP since PS 1, etc.), shows that intensified physical activity in the regime of forced training has a strongly pronounced stress character, and the adaptive reactions of the CVS prevail over its puberty-related evolutive processes. This can be confirmed by the data that we obtained earlier on a long and significant strain of the pituitary–adrenal system of young hockey players, which is accompanied by a large growth of the level of free cortisol excretion from the first up to the fourth PS [28]. It is not improbable that the hymodynamic effects in young hockey players in the state of strained adaptation (growth of SV and BP, growth of tone of peripheral vessels) are caused precisely by glucocorticoids, which can potentiate the cardiostimulative and vasoconstrictive action of catecholamines [29, 30].

CONCLUSIONS

Our longitudinal study has shown that intensified physical activity in the form of regular sports training is the dominant factor in the development of the CVS in adolescents in the puberty period. The comparison of different hemodynamic parameters in the young hockey players, their comparative characteristics with the data of children from the control class have made it possible to determine that the values of individual CVS parameters in the athletes are not beyond the age-specific norms; however, unfavorable changes arise in the system of hemodynamics self-regulation as an inconsistency between cardiac output and vascular capacity, which is accompanied by growth of peripheral vascular resistance, rise in systolic, diastolic, and average hemodynamic blood pressures in the resting state, as well as a strengthened spastic response of the vascular bed to graded physical activity.

The specific impact of intensified physical activity on an adolescent body results in a relative deceleration of sexual development in the young hockey players (the development of secondary sexual characters), as well as opposite, compared to the control, changes in the hemodynamic parameters at different puberty stages. This indicates the strongly pronounced stress-producing character of intense muscular activity, under the effect of which the adaptive reactions of the CVS are prevalent over the pubertal changes in its functional activity. Thus, the age of 11–15 years is a critical and vulnerable period in the development of the CVS in young athletes, which requires close medical supervision and correction of the intensity and regime of sports training.

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