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Case Study

Adaptive reaction of boys' sympathetic-adrenal system to physical activity in puberty.

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ABSTRACT

This paper deals with the study of adaptive reactions of the sympathetic-adrenal system of 11-16-year-old boys to graduated exercise at different pubertal stages. To evaluate the functional state of the cardiovascular system, the heart rate, systolic and cardiac output were determined. The state of the sympathetic-adrenal system was analyzed by the excretion level of catecholamines and DOPA. Cardiac output in response to graduated exercise in boys at pubertal stages 1-2 is substantially ensured by the increased heart rate, and at the other stages of puberty - mainly due to increase in stroke volume, which is estimated as a favorable response to exercise. In mechanisms of urgent adaptation to graduated exercise, the boys of third and fourth pubertal stages show an intensive functioning of the cardiovascular system and a reducing reserve capacity of the sympathetic-adrenal system. The adolescents of fifth pubertal stage show economical response to functional tests, a reduced reactivity of the components of the sympathetic-adrenal system on the background of a significant increase in the excretion of precursors.

Keywords: cardiovascular system, sympathetic-adrenal system, primary-school pupils, physical exercise.

1.INTRODUCTION

The period of intensive pubertal processes is associated with the neuroendocrine restructuring of a teenager's body. The development of all systems of the body at this time places high demands on the cardiovascular system (CVS) as the body's life-support system, and the sympathetic-adrenal system (SAS), which regulates its activity [1,2,3,4,5]. Puberty is an inhomogeneous, very specific period, therefore the age-mate teens have the expressed individual variations in the timing of puberty and different levels of biological maturity [6,7]. At certain pubertal stages there is a wasteful and stressed functioning of a number of body systems: SAS, the contractile myocardium [8], the regional blood flow [3,9], and energy metabolism [10]. This causes a need for a comprehensive study of the functionality of CVS and SAS of teens of different pubertal stages (PS). Use of physical activity as a functional test allows identifying CVS reactivity, SAS activity and functional reserves, and therefore, adaptive regulation mechanisms of the organism in general.

1.1.OBJECTIVE OF RESEARCH

To study the features of adaptive reactions of the CVS and SAS of 11-16-year-old boys to graduated exercise at different PS.

2.METHODS

Virtually healthy 11-16-year-old boys, students of Kazan general education school were examined. The total number of the examined teenagers was 140.

To evaluate the functional state of the cardiovascular system, the heart rate (HR), systolic (SO) and cardiac output (CO) were determined. Heart rate was determined with the use of a cardio-pulmonary automated complex (AD-03M), cardiac output - by rheographic method with RPG-2-02 impedance plethysmograph. To assess the state of SAS, the level of catecholamine (CA) excretion was determined: adrenaline (A), noradrenaline (NA), dopamine (DA) and their precursor - dihydroxyphenylalanine (DOPA). Catecholamines and DOPA in first void urine were determined by fluorometric method. As a functional test, a graduated cycloergometric load of 50% of the individually determined PWC_{170} was used. Pubertal period of the teens was evaluated by J. Tanner scale. Results of the study were statistically processed by the parametric and correlation analysis of intra- and inter-system relations of the studied parameters. To assess the significance of differences, standard Student t-test values were used.

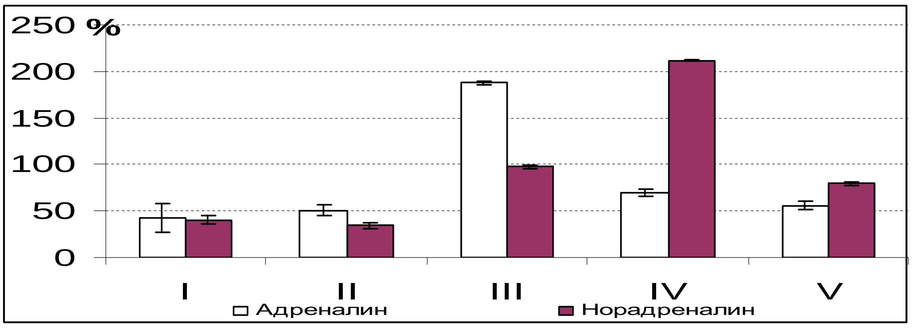
3.RESULTS

Favorable responses of SAS to physical exercise are considered those, which show an increase in the excretion of E and NE accompanied by simultaneous increase in urinary excretion of their precursors. This proves that activation of SAS is accompanied by mobilization of its reserves and creates good prerequisites for stable and continuous operation [3].

Our analysis of the shifts in CA and DOPA excretion in boys of PS 1-5 has shown that in most of groups examined the proposed functional test has caused an increase in excretion of the studied parameters (Table 1,2,3; Fig. 1,2).

The level of reactivity of the adrenal component of SAS changes wavily during puberty. Excretion of E increases from PS 1 to 3 and slightly decreases in subsequent age groups. Increase in this value in response to exercise in boys of PS 1-2 averages to 43.42% ($p < 0.05$). Boys of PS 3 show a significantly higher value - 174.73% ($p < 0.01$). Teenagers of PS 5 show significantly less changes in excretion of E in response to the proposed functional test than in the previous groups. Shift in excretion is only 56.96% ($p < 0.05$).

Thus, the highest reactivity of the adrenal component of SAS occurs in boys of PS 2-3 with its maximum during 3 PS.



Epinephrine *Norepinephrine*

Fig. 1. Levels of epinephrine and norepinephrine excretion in boys of pubertal stages 1 to 5.

It is noteworthy that the most pronounced shifts in excretion of E in the boys of the studied age range are observed during the age periods, when its highest absolute values were recorded in a state at relative rest.

Increase in excretion of NE after the functional test can be seen from pubertal stage 1 to 4. NE in the boys of PS 1 was 35.04% ($p < 0.05$), PS 3 - 93.01% ($p < 0.01$), and PS 4 - 213.99% ($p < 0.01$). Teenagers of PG 5 showed less increase in excretion of NE in response to exercise, which was 80.00% ($p < 0.05$).

Thus, the highest reactivity of the mediator component of SAS occurs in boys of PS 3-4 with its maximum during PS 4.

Changes in the activity of certain SAS components in teenagers vary by groups of subjects. The priority of a hormonal or mediator component of SAS was estimated by the NE-E ratio (Table 3).

Studies have shown that boys of PS 1-3 have urgent adaptation reaction accompanied by a predominant shift in E excretion, and NE/E coefficient decreases in this case. A different situation is observed in adolescents of PS 4, where urgent adaptation of SAS is carried out with the predominant activity of the sympathetic component. The NE/E ratio increases after the test from 4.04 in the initial state up to 7.38 after exercise. Teenagers of PS 5 have mediator type of reaction continuing.

Thus, boys of PS 1-3 show hormonal response of SAS to the graduated cycloergometric load, and the teenagers of PS 4-5 - mediator response.

According to our data, there are also significant age differences in the expression of shifts in DA and DOPA excretion during urgent adaptation (Table 2, Fig. 2). Thus, the increase rate in DA excretion at functional tests in boys of PS 1 is 29.90% ($p<0.05$), PS 2 - 46.20 ($p<0.05$). Groups of teenagers of PS 3-4 show increase rate of 33.9% and 36.20%, respectively ($p<0.05$). Otherwise, teenagers of PS 5 have the most pronounced shift in DA excretion, which averages 70.74% ($p<0.05$), respectively.

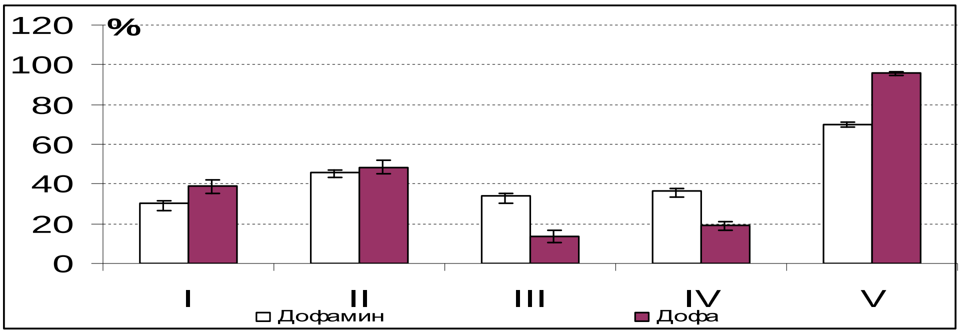


Fig. 2 Levels of dopamine and DOPA excretion in boys of 1-5 pubertal stages (M±m: ng/min)

The most intensive increase in DOPA excretion at functional test is observed in teenagers of PS 5 (96.11%, $p<0.05$). The lowest increase was observed in teenagers of PS 3-4 (12.00-20.04%, $p<0.05$), where the rate of DOPA excretion increased slightly against the background of a significant increase in the E and NE excretion. Boys of PS 1-2 show increase rate of 38.1% and 47.40%, respectively.

Analysis of changes in CA and DOPA ratios in response to the graduated exercise is of special interest for the evaluation of SAS reserves.

Boys of PS 1-2 show the downward trend of the E+NE+DA/DOPA ratio, indicating an increase in the synthesis of DOPA. Along with this, the examination of pupils revealed an increase in the coefficients E+NE/DA and NE/DA, indicating the intensive formation of CA. Therefore, the boys of PS 1 have response to cycloergometric load with a sufficient replenishment of SAS reserves.

An intensive formation of end products of CA synthesis in boys of PS 3-4 in response to the functional test leads to a significant increase in the coefficient E+NE/DA and NE/DA, reflecting the intensive formation of A and AT. At the same time, the ratio of E+NE+DA/DOPA increases (from 4.16 to 5.57 and from 4.11 to 5.56 in boys of PS 3 and 4, respectively), indicating a decreased formation of DOPA with respect to the background level. Therefore, an urgent adaptation reaction in these teens occurs without adequate replenishment of SAS reserves. This fact is also confirmed by the revealed minimum shifts in DA and DOPA excretion in boys of PS 3-4, reflecting their intensive consumption as CA precursors. It is noteworthy that teenagers of PS 3-4 also showed accumulation of DOPA lower than in the other groups, and the high values of the coefficient E+NE+DA/DOPA are marked also before exercise.

Boys of PS 5 showed a more favorable mediator response of SAS to physical activity, expressed in a significant increase in NE excretion and NE/E ratio. There is a decrease in reactivity of SAS components: less pronounced shift in E and NE excretion on the background of significant increase in the excretion of the precursors. We observe a decrease in the ratio of E+NE+DA/DOPA, indicating an intensive formation of DOPA at a given physical activity. All this characterizes the SAS reaction to the functional test in teenagers of PS 5 as more economical, occurring against the background of large reserves of the system.

Analysis of intra-system bonds between SAS indicators both before and after exercise showed that boys of PS 1-2 have an increased strength of bonds between SAS indicators, reflecting the interdependency of its elements. Bond strength of E-NE increases from r=+0.85 to r= +0.93, E-DA from r=+0.81 to r=+0.89.

DA-DOPA correlation bond remains both before and after exercise (r=+0.72). Boys of PS 3-4 show a significant weakening of all available bonds. DOPA bonds with other CAs disappear or go below a statistically significant level, which indicates an intensive operation of SAS. The strength of NE-DA bond decreases from r=+0.76 to r=+0.63, NE-DOPA from r=+0.71 to r=+0.28, DA-DOPA from r=+0.72 to r=+0.23, reflecting the relative decline of SAS reserves in boys of PS 3-4. The number and strength of bonds both between catecholamines and between CA and DOPA increases at PS 5. A significant DA-DOPA bond occurs again both before and after exercise (r=+0.78 and r=+0.75, respectively).

Since the sympathetic-adrenal system plays a key role in the neurohumoral regulation of adaptive reactions of the body to the muscular activity, it is interesting to consider the reactions of urgent adaptation of the cardiovascular system as a system that limits the body's reaction to the load.

According to our data, boys of PS 1 and 2 in response to the functional tests show an increase in heart rate by 24.81-25.02% ($p<0.05$). During puberty, a shift in heart rate at exercise is reduced and is only 9.93% ($p<0.05$) in teenagers of PS 5.

Inotropic responses of CVS to exercise in teen intensify with age. The lowest increase in SO is detected in boys of PS 1-2 (13.12% and 13.83%, respectively; $p<0.05$), the highest one - in teenagers of PS 3-4 (32.6% and 31.8%, respectively; $p<0.05$). Reaction of CO to functional teat increases in PS 4 up to 52.91% ($p<0.05$). Teenagers of PG 5 showed increase in CO equal to 26.04% ($p< 0.05$). The most pronounced chronotropic effect on the moderate graduated physical activity was detected in boys of PS 1-2, and the inotropic effect - in boys of PS 3-4. Teenagers of PS 5 show more economical response of CVS to standard exercise, and moderate changes in HR, SO, and CO. It should be noted that the increase in cardiac output in response to graduated exercise in boys at pubertal stages 1-2 is substantially ensured by the increased heart rate, and at the other stages of puberty - mainly due to increase in stroke volume, which is estimated as a favorable response to exercise. The correlation analysis of intersystem bonds of the CVS indicators of teenagers showed that the adaptation of CVS to physical activity is accompanied by a significant change in the strength of relations between heart rate and cardiac output at rest. It is known that the stronger the relation between the characteristics, the greater the value of the correlation coefficient "r", which ranges from -1 to +1. Boys of PS 1-2 show increased HR-CO relation (from r=+0.68 to r=+0.82) on the background of a relatively stable

SO-CO relation (r=58), which confirms the leading role of HR in the provision of CO during the first stage of puberty.

In response to exercise, teenagers of PS 3-4 show increased SO-CO relation (from r=+0.78 to r=+0.93) due to the weakening of HR-CO relation (r=+35), reflecting the SO priority in the provision of CO. At the same time, the emergence of the negative HR-SO relation (r=-63) reflects an imbalance of CVS components, confirming the fact of the intensive functioning of CVS in boys during intensive puberty [7].

At the final stage of puberty (PS 5), the strength of the SO-CO relation increases (from +0.91 to +0.95), indicating the leading role of SO in the provision of CO.

The dynamics of relations between indicators of CVS and SAS in boys of different PS at the graduated physical activity is of specific nature, quite natural and allows finding out the value and inter-correlation of the individual parameters of CVS and SAS at the various stages of formation of these systems. Relations between indicators of CVS and SAS are dynamic and change according to PS. In early puberty period (PS 1-2) the relations of epinephrine with the CVS indicators are more numerous: E-HR (r=+0.80), E-SO (r=+ 0.74), and E-CO (r=+ 0.84). Starting from PS 3, the effect of norepinephrine on the cardiac output value increases. There occur significant relations of NE-SO (r=+0.79.) and NE-CO (r=+0.77). Boys of PS 4 show increase in the relations between NE and indicators of cardiac output (r=+0.93 and r=+0.94, respectively), and decrease in E-CO relation (r=+0.57). The number and strength of intersystem bonds increases at PS 5. A significant relation between A and SO and CO disappears, while the relations of NE with the indicators of cardiac output remain. There occur the significant relations of DA-CO (r=+0.74.) and DOPA-CO (r=+0.69). Thus, the analysis of the dynamics of the CVS and SAS relations showed there is an increase in all available correlations in boys of PS 1-2 and 5 under the influence of the graduated physical activity. While the boys of PS 3-4, on the contrary, show their decrease, indicating a reduction in the cooperative of CVS and SAS elements and the tension of regulator mechanisms.

4.CONCLUSION

In mechanisms of urgent adaptation to graduated exercise, the boys of first and second pubertal stages show the predominance of cardiac chronotropic response and hormonal component of the sympathetic-adrenal system. At later pubertal stages, the role of inotropic component of cardiac activity and mediator component of the sympathetic-adrenal system increases. The third and fourth pubertal stages are critical and characterized by intensive functioning of the cardiovascular and sympathetic-adrenal systems, and decrease in SAS reserves in the reactions to physical stress. The adolescents of fifth pubertal stage show economical response to functional tests, a reduced reactivity of the components of the sympathetic-adrenal system on the background of a significant increase in the excretion of the catecholamine precursors.

5. SUMMARY

1. The highest level of reaction of the adrenal component of the sympathetic-adrenal system to physical activity is observed in boys of PS 2 and 3, with its maximum at pubertal stage 3.
2. Urgent adaptation to graduated exercise in boys of PS 3 and 4 is performed with a predominant activity of the sympathetic component of the sympathetic-adrenal system.
3. Urgent adaptation reaction to physical activity in boys of PS 3-4 occurs without adequate replenishment of the reserves of the sympathetic-adrenal system.
4. The dynamics of correlations of the indicators of the cardiovascular and sympathetic-adrenal systems in boys of different pubertal stages at graduated physical activity confirms the fact of the intensive functioning of the cardiovascular system of the boys during intensive puberty.

Table 1. Levels of epinephrine and norepinephrine excretion in boys of 1-5 pubertal stages (M±m: ng/min) at rest and after exercise

Pubertal stage	Epinephrine		Norepinephrine	
	before exercise	after exercise	before exercise	after exercise
1	4.31±0.19	6.15±0.94*	12.02±0.28	16.88±0.76*
2	5.91±0.22	8.92±0.48*	15.20±1.00	20.45±0.65*
3	11.05±0.33	31.81±0.52*	18.20±1.16	35.92±0.84*
4	7.20±0.47	12.25±0.46*	28.99±1.37	90.43±0.96*
5	5.57±0.32	8.68±0.39*	19.05±1.32	34.22±0.74*

Note: *- difference with the state at rest is significant at ($p \leq 0.05$)

Table 2. Levels of dopamine and DOPA excretion in boys of 1-5 pubertal stages (M±m: ng/min) at rest and after exercise

Pubertal stage	Dopamine before exercise	Dopamine after exercise	DOPA before exercise	DOPA after exercise
1	106.07±7.65	138.19±4.91*	30.56±1.24	42.42±1.51*
2	128.67±6.39	187.76±5.32*	36.60±1.23	54.35±1.74*
3	140.84±8.11	188.36±6.14*	40.47±2.12	45.91±1.36*
4	170.89±8.63	233.19±7.41*	50.78±2.01	60.42±1.42*
5	230.73±10.32	392.43±5.28*	67.97±2.14	132.93±1.35*

Note: *- difference with the state at rest is significant at ($p \leq 0.05$)

Table 3. Catecholamine to DOPA ratio in boys of 1-5 pubertal stages

Pubertal stage	$\frac{E+NE+DA}{DOPA}$		$\frac{E+NE}{DA}$		NE/DA		NE/E	
	Before	After	Before	After	Before	After	Before	After
1	4.01	3.80	0.16	0.17	0.11	0.12	2.91	2.62
2	4.04	3.99	0.16	0.17	0.11	0.11	2.54	2.29
3	4.16	5.57	0.21	0.36	0.13	0.19	1.67	1.13
4	4.11	5.56	0.21	0.44	0.17	0.39	4.04	7.38
5	3.75	3.27	0.10	0.11	0.08	0.09	3.44	3.94

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