

Artículo de investigación

## Adaptive reaction of the sympathoadrenal system of girls on physical activity

Reacción adaptativa del sistema simpático adrenalino de las niñas sobre la actividad física

Reação adaptativa do sistema simpático de adrenalina de meninas em atividade física

Recibido: 10 de mayo de 2018. Aceptado: 11 de junio de 2018

Written by:

Alevtina V. Krulova<sup>1</sup>Tatiana A. Anikina<sup>2</sup>Aleksei A. Zverev<sup>3</sup>Ekaterina N. Zvereva<sup>4</sup>Timur L. Zefirov<sup>5</sup><sup>1,2,3,4,5</sup>Kazan Federal University. Email: Aleksei5@rambler.ru

### Abstract

The study of the functional state of the sympathoadrenal system in girls of 11-16 years old undergoing graduated physical activity was performed on the basis of excretion rates of epinephrine, norepinephrine, dopamine and DOPA. As a functional test, a graduated cycloergometric load of 50% of the individually determined PWC170 was used. The results obtained made it possible to establish the heterochronic nature of the maturation of the hormonal and mediator links of the sympathetic adrenal system. The highest reactivity of the adrenal link of SAS is observed in girls of 12 years old, the lowest – in senior schoolgirls (15-16 years old). In girls of 12-13 years old, the reaction of urgent adaptation to the graduated physical activity is carried out against a background of high excretion of epinephrine (E), norepinephrine (NE), but without sufficient replenishment of the reserve capabilities of SAS, which is confirmed by minimal shifts in the excretion of dopamine (DA) and DOPA in these age groups. At 14-16 years, moderate shifts of E and NE as a reaction to activity are noted against the background of a significant increase in the excretion of precursors, which characterizes the SAS response to the functional test as more saving, with increasing reserve capacities.

**Keywords:** cardiovascular system, sympathetic-adrenal system, physical exercise.

### Resumen

El estudio del estado funcional del sistema simpato-adrenal en niñas de 11-16 años sometidas a actividad física graduada se realizó sobre la base de las tasas de excreción de epinefrina, norepinefrina, dopamina y DOPA. Como prueba funcional, se utilizó una carga cicloergométrica graduada del 50% de la PWC170 determinada individualmente. Los resultados obtenidos permitieron establecer la naturaleza heterócrona de la maduración de los enlaces hormonales y mediadores del sistema adrenal simpático. La mayor reactividad del enlace suprarrenal de SAS se observa en niñas de 12 años, la más baja - en niñas de escuela secundaria (15-16 años). En niñas de 12-13 años de edad, la reacción de adaptación urgente a la actividad física gradual se lleva a cabo en un contexto de alta excreción de epinefrina (E), norepinefrina (NE), pero sin un reabastecimiento suficiente de las capacidades de reserva de SAS. que se confirma por cambios mínimos en la excreción de dopamina (DA) y DOPA en estos grupos de edad. A los 14-16 años, se observan cambios moderados de E y NE como reacción a la actividad en el contexto de un aumento significativo en la excreción de precursores, que caracteriza la respuesta SAS a la prueba funcional como más ahorro, con el aumento de la capacidad de reserva.

**Palabras claves:** sistema cardiovascular, sistema simpático-adrenal, ejercicio físico.

## Resumo

O estudo do estado funcional das raparigas do sistema simpático-envelhecido 11-16 anos, submetidos a actividade física realizada classificados com base em taxas de excreção de epinefrina, norepinefrina, dopamina e DOPA. Como teste funcional, utilizou-se uma carga cicloergométrica graduada de 50% do PWCI70 individualmente determinado. Os resultados obtidos permitiram estabelecer a natureza heterocrônica da maturação dos laços hormonais e mediadores do sistema adrenal simpático. A reatividade mais alta do elo adrenal de SAS observa-se em meninas de 12 anos, o mais baixo - em meninas de escola secundária (15-16 anos). Em raparigas com idades entre 12-13, reacção urgente de adaptação gradual da actividade física ocorre em um contexto de elevada excreção de adrenalina (E), norepinefrina (NE), mas sem capacidades de reabastecimento suficientes Reserva SAS. o que é confirmado por alterações mínimas na excreção de dopamina (DA) e DOPA nestes grupos etários. Aos 14-16 anos, E e NE variações moderadas em resposta à actividade no contexto de um aumento significativo da excreção de precursores, o que caracteriza a resposta SAS para um teste funcional, mais economia, com o aumento observado a capacidade de reserva.

**Palavras-chave:** Sistema cardiovascular, sistema simpático-adrenal, exercício físico.

## Introduction

Neuroendocrine regulation of the functions of the child's organism, its adaptation to physical activity is characterized by relative immaturity and functional instability (Krylova and Anikina, 2014; Krylova et al, 2015; Krylova et al, 2016; Drzhevetskaya, 1987; Krylova, 2014;). The sympathetic adrenal system (SAS) plays a key role in the neurohumoral regulation of adaptive reactions of the body to muscle activity. The use of physical exercises as a functional test allows us to identify the reactivity and functional reserves of the SAS, therefore, the adaptive mechanisms of regulation of the organism in general. The greatest activity of SAS was detected during intensive pubertal processes and is associated with neuroendocrine restructuring of adolescents. In some stages of puberty, the uneconomical and strenuous functioning of SAS is noted (Zverev et al, 2017; Krylova et al, 2015). A number of papers indicate the dependence of excretion of catecholamines on age and puberty, the maximum activity of SAS in the pubertal period is established (Bezrukikh, 2014; Shaikhelislamova et al, 2008, Zverev et al, 2017). The literature data characterizing the SAS response to the dosed physical load of adolescents during puberty, which is not homogeneous and very specific, have not been adequately reflected. All of the above has determined the relevance and objective of our research.

## Objective of the Research

To study the features of adaptive reactions of the SAS of 11-16-year-old girls to graduated moderate exercise.

## Subject and Methods

We examined 156 healthy girls of 11-16 years old, students of a comprehensive school in the city of Kazan. The functional state of SAS was assessed by the level of catecholamine (CA) excretion: epinephrine (E), norepinephrine (NE), dopamine (DA) and their precursor - dihydroxyphenylalanine (DOPA). Catecholamines and DOPA were determined by the fluorimetric method in the portioned urine (Sitdikov and Shaikhelislamova, 2008). The graduated cycle ergometer test of 50% of the individually determined PWCI70 was used as a functional test. Catecholamines and DOPA were determined before and after the exercise. The increase in the excretion of epinephrine on the physical activity assessed the activity of the SAS hormone link, by the excretion of norepinephrine-mediator. On the basis of the shifts in the excretion of dopamine and DOPA, reserve capacities of SAS were evaluated. Statistical processing of the research results has been carried out. Methods of parametric and correlation analysis of inter- and intra-system interrelations between the investigated indicators were applied. The reliability of the differences between the analyzed indicators was determined using Student t-test.

## Results and Discussion

The use of physical activity as a functional test allows identifying reactivity and functional reserves of SAS, and therefore, adaptive regulation mechanisms of the organism in general. Adequate responses of SAS to moderate 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 fact proves that activation of SAS is accompanied by mobilization of its reserves and creates good prerequisites for stable and continuous operation. It was found that schoolgirls of 11-16 years old, in response to the graduated physical activity, showed an increase in activity of SAS: positive shifts in the excretion of CA and DOPA

relative to the initial state were detected. The reactivity of the SAS links, reserve capacities of the system were different for the groups of subjects (Table 1). The study showed that the reactivity of the hormonal link of the SAS changes with age wavyly in the girls under study. It significantly increases from 11 to 12 years and decreases in subsequent age groups. The girls of 11 years old under the influence of a functional test show an increase in the excretion of E from  $6.62 \pm 0.22$  ng/min to  $10.33 \pm 0.47$  ng/min. The shift of this indicator in response to the load is 55.65%. The girls of 12 years old had E excretion after the exercise equal to  $15.26 \pm 0.72$  ng/min against  $8.81 \pm 0.30$  ng/min prior to the clinical study (at rest). The gain in E is maximal within the studied age range and is 72.58%.

Table 1. Levels of epinephrine and norepinephrine excretion in girls of 11-16 years old at rest and after exercise ( $M \pm m$ : ng/min)

Age, years	Epinephrine		Norepinephrine	
	before exercise	after exercise	before exercise	after exercise
11	$6.62 \pm 0.22$	* $10.33 \pm 0.47$	$17.39 \pm 0.91$	* $23.48 \pm 1.26$
12	$8.81 \pm 0.30$	* $15.26 \pm 0.72$	$23.90 \pm 1.01$	* $40.15 \pm 2.13$
13	$6.80 \pm 0.36$	* $10.81 \pm 0.85$	$28.26 \pm 1.11$	* $62.89 \pm 3.34$
14	$5.35 \pm 0.31$	* $7.47 \pm 0.41$	$21.86 \pm 1.12$	* $37.16 \pm 2.81$
15	$5.42 \pm 0.33$	* $7.76 \pm 0.57$	$19.86 \pm 1.34$	$33.18 \pm 2.11$
16	$5.55 \pm 0.32$	* $7.77 \pm 0.39$	$19.42 \pm 1.24$	

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

The girls of 13 years old show a slight decrease in reactivity of a hormonal link. The gain is only 59.73%. In schoolgirls aged 14-16 years, the shift in the E excretion as the reaction to the test differs insignificantly and varies between 40-42%. It should be noted that the observed increase in the value of the analyzed parameter is less than in other age groups.

Thus, the highest reactivity of the adrenal link of SAS is observed in girls of 12 years old, and the lowest – in senior schoolgirls (15-16 years old). The level of excretion of NE in the girls after the functional test is also significantly increased. The increase in NE after the test is observed from 11 to 13 years. In 11-year-old girls, excretion of NE after exercise is only 35.01% higher than the baseline level. In girls of 12 years, the level of NE is much higher, while in schoolgirls of 13 years old the reactivity of the mediator unit of SAS is

the highest within the studied age range. The increase in excretion after the exercise is 123.11% in this age group.

In senior schoolgirls, the reactivity of the mediator link is slightly reduced. The increase in this parameter after the exercise in girls of 14 years old is 70.14%; in schoolgirls of 15-16 years old it varies within the limits of 65-68%, which is much lower than the level characteristic for girls of 12-13 years old, but higher than for 11-year-old schoolgirls.

Thus, the functional test revealed the highest reactivity of the mediator link of SAS in girls of 12-13 years old with a maximum value of 13 years. The senior schoolgirls - girls of 15-16 years old showed relative stability of the reaction of the mediator link of SAS to the standard physical activity.

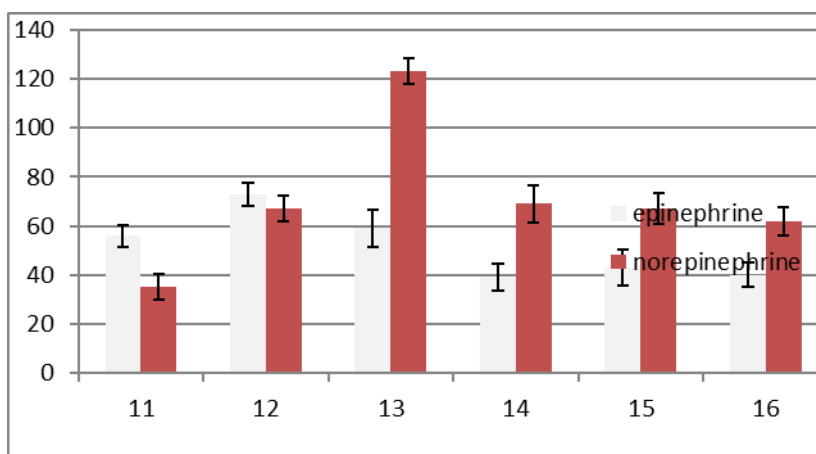


Fig. 1. Levels of epinephrine and norepinephrine excretion in girls of 11-16 years old at rest and after exercise ( $M \pm m$ : ng/min)

When comparing the degree of changes in excretion of E and NE in response to a functional test, attention is drawn to the fact that the highest reactivity of both SAS links was detected in adolescents in those age periods where the highest absolute values of excretion of these CAs were recorded at relative rest (references: SK-2, SK-3). It is also remarkable that the maximum activity of the hormonal link is observed in girls at the age of 12 years, the mediator link – at 13 years old, which is a reflection of the

heterochronous maturation of these SAS links in adolescents. A similar phenomenon was noted earlier in boys, where the hormonal link of this system was outstripping in comparison with the medial link (SK4). A comparative analysis of the activity of SAS links in the reactions of urgent adaptation to the graduated physical activity is of particular interest in the study of the balance of excretion of NE and E in age groups, estimated by the value of the NE/E coefficient before and after the applied effect (Table 2).

Table 2. The excretion indicators of dopamine and DOPA in girls of 11-16 years old at rest and after exercise ( $M \pm m$ : ng/min)

Age, years	Dopamine before exercise	Dopamine after exercise	DOPA before exercise	DOPA after exercise
11	118.75±4.85	*163.88±6.51	34.50±1.01	*50.37±2.61
12	148.69±9.01	*188.84±9.18	41.95±2.13	*53.70±3.13
13	160.39±12.81	*205.30±12.90	45.49±2.27	60.50±3.54
14	175.35±14.89	*277.05±18.31	56.30±1.38	*101.34±2.96
15	181.97±10.10	*283.89±14.81	57.89±1.71	*107.68±1.35
16	187.56±10.03	*286.97±12.10	58.94±1.54	*108.45±2.15

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

The results of the study showed that in 11-year-old girls the functional test causes a greater increase in excretion of E, the NE/E ratio in these schoolgirls drops to 2.41 from 2.66 in the initial state. Thus, the hormonal response of SAS to the exercise is observed. In subsequent age groups, a mediator reaction of this system is noted, an increase in the NE/E ratio relative to the background level is observed. The most significant shift in the CA balance towards the NE is expressed in girls of 13 years old, where the maximum reactivity of the mediator link of the SAS is noted. The NE/E ratio varies in this group

from 4.16 to 0.82. Less pronounced shift in the value of the analyzed ratio is observed in the girls of 12 years old showing the maximum reactivity of the hormonal link of SAS relative to other age groups. Characterizing the change in the excretion of CA precursors in the girls of 11-16 years old, it should be noted that there are significant age differences too in the urgent adaptation reactions by the severity of shifts in DA and DOPA.

Thus, the increase in excretion of DA for a functional test in girls of 11 years old is only

38.29%. It is much lower in the groups of 12 and 13 years old - 27.38% and 28.39%, respectively. The girls aged 14-16 years have the most pronounced shift in excretion of DA within the studied age range, which varies between 58-53%. A similar situation is observed in the dynamics of excretion of DOPA as a reaction to physical activity. The most intensive increase in this indicator was observed in older schoolgirls of 14-16 years old, where the increase is 79-84%, and significantly lower in the girls of 12-13 years old (27-33%). To assess the reserve capabilities of the SAS in the urgent adaptation reaction, our studies analyzed the changes in the magnitude of the CA and DOPA ratios, indirectly reflecting the dynamics of the formation of the CA, as compared to the severity of the excretion of DA and DOPA as a reaction to the graduated physical activity (Table 3). The study showed that the girls examined had significant age differences in the dynamics of the studied indicators.

For example, in 11-year-old girls, the graduated physical activity leads to a decrease in the E+NE+DA/DOPA ratio and an increase in the E+NE+/DA ratio. This allows us to evaluate the response to the exercise as favorable. The girls aged 12-13 years showed along with a pronounced increase in the E+NE/DA and NE/DA ratios, reflecting the intensive formation of E and NE an increase in the ratio of E+NE+DA/DOPA from 4.32 to 4.60 in schoolgirls of 12 years old and from 4.30 to 4.62 in schoolgirls of 13 years old, indicating a decrease in the formation of DOPA relative to the baseline condition.

Therefore, an urgent adaptation reaction in these teens occurs without adequate replenishment of SAS reserves, which is confirmed by minimal shifts in the excretion of DA and DOPA in these age groups. Thus, the observed situation is a reflection of the intense functioning of SAS in these girls, characterized by an uneconomical response of this system to the exercise where significant shifts in the excretion of E and NE are accompanied by a decrease in its reserve capacity relative to the state at rest. It is also noteworthy that girls of 12-13 years old and in the initial state have a lower accumulation of DOPA than in other age groups, higher values of the E+NE+DA/DOPA are noted here and before exercise. A similar pattern was observed in boys aged 13-14 years (SK-2).

The girls of 14-16 years old have a more favorable (mediator) reaction of SAS to physical

activity. There is a significant increase in the excretion of NE, a pronounced increase in the ratio of NE/E. A less pronounced shift in excretion of E and NE, a moderate increase in the ratios of E+NE/DA and NE/DA against a background of a significant increase in precursor excretion and along with a decrease in the E+NE+DA/DOPA ratio indicating enhanced DOPA formation in response to the exercise.

All this characterizes the reaction of the SAS to a functional test in senior schoolgirls as more saving, occurring with increasing reserve capacities. The reactivity of SAS, the nature of the reactions of urgent adaptation in girls of 15-16 years old are close to the definitive level. To identify intra-system relationships between the SAS indices of girls aged 11-16 years, we performed a correlation analysis of the interrelations between the E, NE, DA and DOPA excretion. The correlation coefficient "r" was calculated. It is known that the stronger the relationship between the signs is, the greater the value of the coefficient "r" is, which ranges from -1 to +1. Our analysis of the intrasystemic relationships of the SAS indices before and after exercise showed that the girls aged 11 years have an increase in the strength of the bonds between the SAS indices, reflecting the interdependence of its elements. The strength of the E-NE bond increases from  $r=+0.81$  to  $r=+0.90$ , E-DA from  $r=+0.78$  to  $r=+0.86$ . The correlation between DA-DOPA is maintained before and after the exercise ( $r=+0.70$ ). The girls of 12-13 years old 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  $r=+0.73$  to  $r=+0.61$ , NE-DOPA from  $r=+0.68$  to  $r=+0.30$ , DA-DOPA from  $r=+0.70$  to  $r=+0.33$ , reflecting the relative decline of SAS reserves in girls of 12-13 years old.

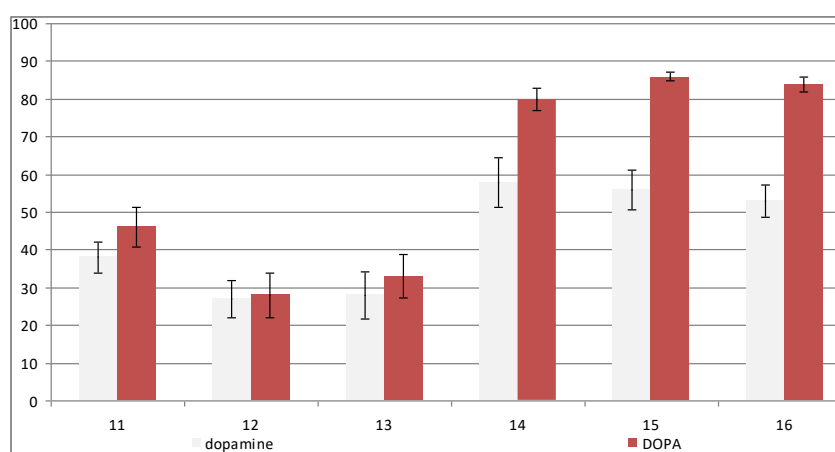
The number and strength of bonds both between catecholamines and between CA and DOPA increases in girls of 14-16 years old. A significant DA-DOPA bond occurs again both before and after exercise ( $r=+0.70$  and  $r=+0.67$ , respectively). Our analysis of the shifts in the excretion of CA and DOPA as the reaction to the graduated physical activity in girls aged 11-16 years showed that there is a pronounced specificity of the urgent adaptation reactions. There is a pronounced difference in the reactivity of the SAS links to the load and in the magnitude of the shifts in excretion of DA and DOPA. The

revealed regularity once again confirms the earlier formation of the hormonal link of SAS in

adolescents with respect to the mediator link of the system (Sk-3, Sk-2)

Table 3. The ratio of catecholamines and DOPA in girls of 11-16 years old at rest and after exercise ( $M \pm m$ : ng/min)

Age, years	E+NE+DA DOPA		E+NE DA		NE/DA		NE/E	
	Before	After	Before	After	Before	After	Before	After
11	3.98.	3.93.	0.20.	0.21	0.15.	0.15.	2.63.	2.27.
12	4.32.	4.60.	0.22.	0.29	0.16	0.21	2.69.	2.63.
13	4.30.	4.62.	0.22.	0.36	0.18	0.31	4.16.	5.82.
14	3.60	3.17.	0.16	0.17.	0.12	0.13	3.66.	4.97.
15	3.58.	3.01.	0.14.	0.15.	0.12	0.12	3.60	4.28.
16	3.60	3.01.	0.13	0.14.	0.10	0.11	3.50.	4.07.



## Conclusion

According to the results of our studies, during the reactions of urgent adaptation to the graduated physical activity in girls of 11 years old, the hormonal link of the sympathetic adrenal system is predominant. In the subsequent age groups, the role of the mediator link of the sympathetic adrenal system increases. The age of 12-13 years is critical and characterized by the intense functioning of the sympathetic adrenal system, the reduction of the SAS reserve capabilities in reactions to physical stress. The adolescent girls of 14-16 years old 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. In our opinion, the results of our studies may be of interest to specialists in the field of age and sports physiology. Trainers of children's sports schools, school teachers and physical education teachers

should take into account the intense functioning of the sympatho-adrenal system of adolescent girls aged 12-13 years, corresponding to the third and fourth stages of puberty, when planning the sport ad work load, and educational process of adolescents.

## Acknowledgements

The work is performed according to the Russian Governments Program of Competitive Growth of Kazan Federal University

## Reference

Bezrukikh M.M. (2014), Actual problems of the child development physiology / M.M. Bezrukikh, D.A. Farber, New Researches, No.39, pp. 4-19  
 Drzhevetskaya, I.A. (1987), Endokrinnaya sistema rastushchego organizma (The Endocrine System in the Growing Organism), Moscow: Vysshaya Shkola.

- Kruloval, A.V., Anikina, T.A., Zverev, A.A., Zaineev, M.M., Zefirov, T.L. (2016), Sympathoadrenal System Activity of Various Puberty Stages Boys, *Research Journal of Medical Sciences* 10 (3), pp. 60-63.
- Krylova A.V., Anikina, T.A. (2014), Changes in hemodynamics in students of different pubertal stages during the school year, *Basic Research*. No.3, pp. 76-80.
- Krylova, A.V., Anikina, T.A., Zaineeyev, M.M., Zefirov, T.L. (2015), Adaptive reaction of cardiovascular system of boys with different level of sexual maturity to physical exercise. *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, T. 6, No. 6, pp. 1463-1468.
- Krylova. A.V., Anikina, T.A., Zaineev, M.M., Zefirov, T.L. (2015), Adaptive reactions of cardiovascular system of boys with different level of sexual maturity to physical exercise, *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, No. 6, pp. 1463-1468.
- Krylova, A.V., Biktemirova, R.G. (2014), Change of SAS Activity for Teenagers on Different Puberty Stages, In: IV Congress of Physiologists of the CIS, Publishing House Quality, Sochi, Moscow, p. 186.
- Menshikov, V.V. (1987), *Laboratory methods of research in clinic*, Moscow, p. 368
- Shaikhelislamova M.V., Sitdikov, F.G., Sitdikova, A.A., Kuzmina, L.I., Valeeva, F.V. (2008), The sympathetic-adrenal system and the adrenal cortex in the pre- and pubertal periods of human development, *ONTOGENESIS*. Vol. 39, No. 2, pp. 116-124.
- Sitdikov, F.G., Shaishelislamova, M.V. (2008), Hormonal status and vegetative tone in 7-15-year-old children, Kazan: TSHPU, p. 147.
- Zverev, A.A., Kruloval, A.V., Anikina, T.A., Zaineev, M.M., Zefirov, T.L. (2016), Adaptive reaction of boys' sympathetic-adrenal system to physical activity in puberty, *International Journal of Advanced Biotechnology and Research (IJBR)*, Vol. 7, Issue. 2, pp. 791-797.
- Zverev, A.A., Kruloval, A.V., Anikina, T.A., Zaineev, M.M., Zefirov, T.L. (2017), Adaptive reactions of the cardiovascular system of girls of different stages of puberty on physical activity during the academic years, *Indo American journal of pharmaceutical science*, Issue. 9, pp. 3050-3054.