The state of vegetative regulatory systems of pupils with different academic performance

Sotnikova-Meleshkina Zh.V.¹ ², Redka I.V.¹, Mikhalkhuk O.Ya.¹
¹ V.N. Karazin Kharkiv National University
² SI “Institute of Child and Adolescent Health of the National Academy of Medical Sciences of Ukraine”

ARTICLE INFO
Received: 7 July, 2020
Accepted: 12 August, 2020

UDC: 616.839:612.176-057.874

CORRESPONDING AUTHOR
e-mail: zhanna.v.sotnikova@karazin.ua
Sotnikova-Meleshkina Zh.V.

The transition to primary school requires pupils to adapt to new conditions of the educational environment, accompanied by the use of physiological reserves of the body. School stress can hinder the academic success of children and adolescents, creative solutions to complex and new problems, which, in turn, can lead to underestimation of abilities and underestimation of pupils self-esteem. Chronic exposure to academic stress can lead to school burnout and the formation of psychosomatic disorders. The aim of the study was to compare the functional state of autonomic regulatory systems among pupils with different levels of academic achievement. 60 children (10-13 years old) took part in the longitudinal study. The functional state of the autonomic regulatory systems was determined by analyzing 5-minute recordings of the electrocardiogram in a state of quiet wakefulness with eyes closed in a sitting position. Pupils were divided into 3 groups depending on the level of their academic performance, which was determined by the average score of 8 basic subjects. Statistical data processing was performed using the Mann-Whitney, Kraskell-Wallis, Dunnett, Fisher's φ-test. Significant differences in heart rate variability (HRV) parameters depending on the level of academic achievement were found only in the 5th and 6th years of study, which reflected the different physiological cost of adaptation to primary school. The vegetative profile of pupils with academic performance lower than the average in the 5th year of study indicated overstrain of regulatory systems and fatigue. Among pupils with academic performance higher than the average in the 6th year of study 2.4 times more often than pupils with average academic performance, the optimal state of autonomic regulatory systems was observed (respectively, 46.2% and 19.1%, p<0.05), and in the 7th year of study - 2.5 times compared to pupils with academic performance below average (respectively, 46.2% and 18.2%, p<0.05), which may indicate a higher physiological price for adaptation to primary school pupils with academic performance below average. Fatigue and overexertion of the mechanisms of autonomic regulation are characteristic of pupils with academic performance below average, while pupils with academic performance above average had a high level of stress adaptive-compensatory mechanisms in the 6th year of study. The category of pupils with a level of academic performance below average should be assigned to the risk group in terms of the development of autonomic dysfunction and psychosomatic diseases.

Keywords: heart rate variability, vegetative profile, academic performance, pupils.

Introduction
School as a place of socialization and development is of great importance in the lives of adolescents [7]. Increased demands to be successful and productive in modern society can deplete human resources and can lead to stress in adolescents [4, 21]. International studies have shown that adolescents have a significant increase in stress related to school and stress-related health problems [6, 11, 17]. It is shown that school stress can hinder pupils’ academic success [10], including due to the negative impact on memory processes [15, 19]. In addition, stress, by altering the balance between memory systems, can hinder creative solutions to complex and/or new problems, which in turn can lead to underestimation of pupils’ abilities and underestimation of their self-esteem [20].
Chronic exposure to academic stress can lead to school burnout, defined as an emotional state of exhaustion, cynicism, and depersonalization, [21] and the formation of psychosomatic disorders.

Therefore, the aim of our study was to compare the functional state of autonomic regulatory systems among pupils with different levels of academic achievement.

**Materials and methods**

The study involved 60 middle school pupils (10-13 years). The functional state of vegetative regulatory systems was determined by analyzing statistical (Mean, Mo, SDNN, ΔX, AMo, CVr, pNN50), spectral (TP, VLF, LF, HF, VLF%, LF%, HF%, LF/HF, IC) and autocorrelation groups of indicators (CC1, CC0), as well as an integrated indicator of regulatory system activity (IRSA) [3, 13].

HRV measurement was performed at 5, 6 and 7 years of study based on the analysis of 5-minute electrocardiogram recordings in the II standard lead in a state of quiet wakefulness with eyes closed in a sitting position using the hardware-software complex "BrainTest" ("DX-system", Kharkiv, Ukraine). Mathematical analysis of cardio signals was performed using the "Cardio Tension Test" module of the application package "NeuroResearcher® Innovation Suite, V. 17.5" ("Institute of Medical Informatics and Telemedicine", Kharkiv, Ukraine).

Determining the level of academic performance of pupils involved copying the data of annual academic performance from eight basic subjects (Ukrainian language, Ukrainian literature, algebra, world history, biology, physics, chemistry, foreign language), based on which we calculated the average score with further division of pupils into 3 groups: with a level of academic success below average (up to 7.85 points), with an average level (from 7.85 to 9.19 points inclusive) and above average level (over 9.19 points).

To test the hypothesis of equality of measures of the central tendency in pairwise comparisons, the Mann-Whitney test was used, and for multiple comparisons, the nonparametric ANOVA by the Crackell-Wallis test was used, followed by a posteriori comparison by the Dunnett test. Nominal features were described as a percentage, and their pairwise comparison was carried out by the φ-criterion of Fisher's angular transformation. Differences at p < 0.05 were considered significant.

The study was conducted in accordance with the bioethical norms of the Declaration of Helsinki (as amended in 2013) with the informed consent of parents and approved by the Commission on Bioethics of the SI "Institute of Child and Adolescent Health of the National Academy of Medical Sciences of Ukraine".

**Results**

It was found that in the fifth year of study, pupils with higher than average academic performance, compared with pupils with average academic performance, were characterized by probably (p < 0.05) higher values of SDNN, TP, CVr, HF, pNN50 (Fig. 1a).

The same changes in HRV parameters were observed among pupils with below-average academic performance. However, they were also added probably (p < 0.05) lower values of AMo, SI, IARP, VIR, IVB, CC1, LF%, LF/HF and probably (p < 0.05) higher values of Mean, RMSSD, VLF,
HF%, HFn, compared with pupils with average academic performance.

At the same time, in the fifth year of study, we did not find significant differences in the values of HRV between pupils with academic performance above and below average.

At year 6, pupils with below-average academic performance were characterized by significantly (p<0.05) lower IARP, CC1, and probably (p<0.05) higher RMSSD values compared to pupils with average academic performance, whereas among pupils with above-average academic performance higher than the average, only a similar trend was observed (0.07<p<0.10). At the same time, pupils with above-average academic performance were characterized by a significantly (p<0.05) lower heart rate and longer cardio cycle, compared with pupils with average academic performance. A similar trend (p=0.06) was observed among pupils with below-average academic performance. Only pupils with below-average academic performance were characterized by probably (p<0.05) lower CC0 values compared to pupils with average academic performance. Pupils with above-average academic performance were characterized by probably (p<0.05) higher values of RMSSD, pNN50, CC1, CC0.

At the 7th year of study, the vegetative profiles of pupils with different academic performance were similar (Fig. 1c).

A comprehensive assessment of the state of autonomic regulatory systems of pupils with different academic performance according to IRSA (Fig. 2) found that among pupils with academic performance higher than the average in the sixth year of study 2.4 times more often than pupils with average academic performance, observed optimal condition of autonomic regulatory systems (respectively, 46.2% and 19.1%, p<0.05), and at the 7th year of study - 2.5 times compared to pupils with academic performance below average (respectively, 46.2% and 18.2%, p<0.05).

**Discussion**

The transition to primary school requires pupils to adapt to new conditions of the educational environment, accompanied by the use of physiological reserves of the body. The ratio between the achieved level of performance and spent physiological reserves to achieve them speak of the physiological "price" of adaptation [22]. As a performance we used the indicator of academic performance, and physiological resources were evaluated by the parameters of heart rate variability. Lower heart rate variability (HRV) was seen as a sign of limited ability to regulate emotional state, performance, and social functioning [5, 12, 14, 18].

According to the results of one-factor dispersion analysis of Kruskal-Wallis, significant differences in HRV parameters depending on the level of academic performance were found only in 5 and 6 years of study (Fig. 1), which may reflect different physiological costs of adaptation to primary school depending on academic performance.

From the above we can conclude that in the 5th year of study, pupils with above-average academic performance were characterized by an increase in overall heart rate variability due to increased absolute activity of the parasympathetic nervous system, compared with pupils with average academic performance. This state of autonomic regulatory systems in pupils with above-average academic performance can be characterized as a moderate predominance in the state of quiet wakefulness of the activity of the autonomous control circuit over the central while maintaining sympathetic-vagal balance at the level of vegetative regulatory systems of pupils with different academic performance.
of the autonomous control circuit.

In contrast to pupils with above-average academic performance, among pupils with below-average academic performance in the 5th year of study, we observed not only an increase in absolute but also specific activity of the parasympathetic nervous system against a decrease in specific activity of the sympathetic nervous system. In addition, there was an increase in the absolute activity of the suprasegmental structures of the autonomic nervous system against the background of a decrease in the relationship between the central and autonomous circuits of regulation and the lower stress index of regulatory systems. This caused a significant shift in the sympathetic-vagal balance towards vagotonia, which was probably confirmed (p < 0.05) by a lower heart rate and a longer cardiocycle. Such features of the vegetative profile indicate a pronounced predominance of the autonomous control loop and reflect the overstrain of regulatory systems and, probably, fatigue of pupils.

It is noteworthy that at the 6th year of study the vegetative profile of pupils with academic performance above and below average becomes similar and indicates a pronounced vagotonia against the background of a significant reduction in the effects of the central loop of regulation. Although in both cases of deviation of academic performance from the average level, we can talk about the overstrain of the mechanisms of regulation and fatigue of pupils, but these processes are more pronounced among pupils with academic performance below average. At the same time, compensation mechanisms are still included in pupils with above-average academic performance by strengthening the relationship between the central and autonomous control circuits, but there are insufficient central mobilizing influences. This is probably due to the fact that the 6th year of study has a sensitive period of formation of autonomic regulatory systems, which reduces the adaptive reserves of pupils.

Since in the seventh year of study the vegetative profiles of pupils with different academic performance in the conditions of quiet wakefulness are as similar as possible, we can assume that this is a period of stable adaptation to the educational environment of primary school. Note that among pupils with academic performance above the average 2.5 times more often observed the optimal state of autonomic regulatory systems compared with pupils with academic performance below average (respectively, 46.2% and 18.2%, p < 0.05) in which stress/overstrain of autonomic regulation was observed 2.5 times more often (respectively, 53.8% and 81.8%, p < 0.05). This gives grounds to claim that pupils with academic performance below the average pay a higher physiological price for adaptation to primary school.

We do not currently know any studies of the relationship between academic performance and heart rate variability among elementary school pupils. E.V. Fedorova and co-authors [8] found that academically unsuccessful pupils of 5 years of school had lower heart rates. We also observed this trend, however, pupils with above-average academic performance also had lower heart rates than pupils with average academic performance [8]. In a study by O.B. Gileva (2012) found differences in TP and LF/HF between pupils aged 7-16 with different levels of academic achievement, with more stress on adaptation mechanisms found among excellent pupils [9]. Studies by T.V. Agafonkina et al. (2008, 2015) found that “excellent” pupils have better autonomic nervous system and adaptive abilities than pupils who study satisfactorily and well [1] in terms of heart rate, blood pressure and autonomic index of Kerdo at rest, cold and orthostatic tests. At the same time, in a study by L.A. Alexandrova and co-authors (2014) noted that high school pupils with high academic performance have a higher level of stress of physiological mechanisms, and according to the authors this is due to the fact that current tasks are in the zone of immediate development, ie exceed current abilities but trigger mechanisms of personal self-regulation [2].

These data partially coincide with our results on the stress of adaptive-compensatory mechanisms in pupils with academic performance higher than the average at 6 years of study. However, in our study, depletion of the mechanisms of autonomic regulation was observed among pupils with low academic performance.

Prospects for further development are the formation of an algorithm for pre-nosological diagnosis of school maladaptation and its prevention in middle school students.

Conclusions

1. Adaptation to the educational environment of primary school was observed in the third year of study (7th year of school).

2. Deviations of academic success from the average level were accompanied by the predominance of the activity of the autonomous circuit of regulation in conditions of quiet wakefulness. Fatigue and overstrain of the mechanisms of autonomic regulation are characteristic of pupils with academic performance below average, while pupils with academic performance above average had a high level of stress of adaptive-compensatory mechanisms in the sixth year of study.

3. The category of pupils with a level of academic achievement below average should be assigned to the risk group in terms of the development of autonomic dysfunction and psychosomatic diseases.

References

[1] Agafonkina, T. V., & Kostrova, O. Yu. (2008). Indicators of the autonomic nervous system and academic performance of students. Chuvash University Bulletini, 2, 42-45.
[2] Alexandrova, L. A., Belonogova, E. V., Kazin, E. M., & Krivosheina, N. P. (2014). Peculiarities of personality potential in high school students with different types of vegetative regulation at school adaptation conditions. Valeology, 3, 47-57.
СТАН ВЕГЕТАТИВНИХ РЕГУЛЯТОРНИХ СИСТЕМ УЧНІВ З РІЗНОЮ АКАДЕМІЧНОЮ УСПІШНІСТЮ

Сотнікова-Мелешкіна Ж.В., Редька І.В., Михальчук О.Я.

Перехід до основної школи вимагає адаптації учнів до нових умов освітнього середовища, що супроводжується зниженням самооцінки школярів. Хронічний вплив академічного стресу може призвести до шкільного вигорання та формування психосоматичних розладів. Мета дослідження - порівняти функціональний стан вегетативних регуляторних систем учнів з різною академічною успішністю.

Функціональний стан вегетативних регулюючих систем визначали шляхом аналізу 5-хвилинних записів електрокардіограми з використанням критеріїв Манна-Уітні, Краскелла-Уоліса, Даннета.

У лонгітудинальному дослідженні взяли участь 60 дітей (10-13 років).

Статистична обробка даних проведена у стані спокійного неспання з закритими очима в положенні сидячи. Учнів було розподілено на 3 групи у залежності від рівня академічної успішності, що визначався за середнім балом із 8 базових предметів. Статистична обробка даних проведена використовуючи критерії Манна-Уітні, Краскелла-Уоліса, Даннета.

Порівняно з учнями з середньою академічною успішністю спостерігався оптимальний стан вегетативних регуляторних систем (відповідно, 46,2% і 19,1%, р<0,05), а на 7-му році навчання – 2,4 рази частіше з референційною групою з академічною успішністю нижчою за середню.

Список літератури:
[3] Baevsky, R. M., Ivanov G. G., Kukushkin, Yu.A. (2001). Analysis of heart rate variability using different electrocardiographic systems (guidelines). Bulletin arrhythmology, 24, 65-87.
[4] Banks, J., & Smyth, E. (2015). "Your whole life depends on it". Academic stress and high-stakes testing in Ireland. J. Youth Stud., 18, 598-616. doi: 10.1080/13676261.2014.992317
[5] Beauchaine, T. P. (2015). Future directions in emotion dysregulation and youth psychopathology. Journal of Clinical Child & Adolescent Psychology, 1, 1-22. doi.org/10.1080/15374416.2015.1038627
[6] Collishaw, S. (2015). Annual research review: Secular trends in child and adolescent mental health. J. Child. Psychol. Psyс., 56, 370-393. doi: 10.1111/jcpp.12372
[7] Eccles, J. S., & Roeser, R. W. (2011). Schools as developmental contexts during adolescence. J. Res. Adolescence, 21, 225-241. doi: 10.1111/j.1532-7795.2010.00773.x
[8] Fedorova, E. V., Melnikova, I. E., & Babich, M. S. (2005). Psychophysiological features of adaptation of fifth-graders with high and low academic performance to physical and intellectual stress. Natural factors and social conditions for educational success. SPb.: SAGA.
[9] Gileva, O. B. (2012). Psychophysiological bases of success of educational activity. Yekaterinburg: Publishing House URGUPS.
[10] Kaplan, D., Liu, R. X., & Kaplan, H. B. (2005). School related stress in early adolescence and academic performance three years later: the conditional influence of self expectations. Social Psychology of Education, 8, 3-17.
[11] Klinger, D. A., Freeman, J. G., Bilz, L., Liiv, K., Ramelow, D., Sebok, S., ..., Rasmussen, M. (2015). Cross-national trends in perceived school pressure by gender and age from 1994 to 2010. European Journal of Public Health, 25 (Suppl. 2), 51-56. doi: 10.1093/eurpub/ckv027
[12] Laborde, S., Mosley, E., & Mertgen, A. (2018). Vagal tank theory: The three Rs of cardiac vagal control functioning - resting, reactivity, and recovery. Frontiers in neuroscience, 12, 458. https://doi.org/10.3389/fnins.2018.00458
[13] Malik, M. (1996). Heart rate variability. standards of measurement, physiological interpretation, and clinical use. Task force of the european society of cardiology and the north american society of pacing and electrophysiology. Eur. Heart J., 17, 354-381. doi: 10.1093/oxfordjournals.eurheartj.a014868
[14] Saetre, S. S., Sutterlin, S., Lugo, R. G., Prince-Embury, S., & Makransky, G. (2019). A Multilevel Investigation of Resiliency Scales for Children and Adolescents: The Relationships Between Self-Perceived Emotion Regulation, Vagally Mediated Heart Rate Variability, and Personal Factors Associated With Resilience. Frontiers in Psychology, 10, 438. https://doi.org/10.3389/fpsyg.2019.00438
[15] Schwabe, L., & Wolf, O. T. (2010). Learning under stress impairs memory formation. Neurobiology of learning and memory, 93(2), 183-188. https://doi.org/10.1016/j.nlm.2009.09.009
[16] Scrimin, S., Moscardino, U., Finos, L., & Mason, L. (2019). Effects of Psychophysiological Reactivity to a School-Related Stressor and Temperament on Early Adolescents’ Academic Performance. The Journal of Early Adolescence, 39(6), 904-931. https://doi.org/10.1177/0272431618797008
[17] Sebok, S. S., ... Rasmussen, M. (2015). Cross-national trends in perceived school pressure by gender and age from 1994 to 2010. European Journal of Public Health, 25 (Suppl. 2), 51-56. doi: 10.1093/eurpub/ckv027
[18] Thayer, J. F., Ahs, F., & Wagner, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. Neuroscience & Biobehavioral Reviews, 36, 747-756. https://doi.org/10.1016/j.neubiorev.2011.11.009
[19] Tyng, C. M., Amin, H. U., Saad, M., & Malik, A. S. (2017). The Influences of Emotion on Learning and Memory. Frontiers in Psychology, 8, 1454. https://doi.org/10.3389/fpsyg.2017.01454
[20] Vogel, S., Schwabe, L. (2016). Learning and memory under stress: implications for the classroom. NPJ Science Learn, 1, 16011 https://doi.org/10.1038/njpsilearn.2016.11
[21] Walburg, V. (2014). Burnout among high school students: A literature review. Child. Youth Serv. Rev., 42, 28-33. doi: 10.1016/j.childyouth.2014.03.020
[22] Zaikina, A. L. (2016). Psychophysiological "cost" as a criterion of educational process organization effectiveness in terms of excess informational load on schoolchildren. A Young Scientist, 11, 1, 40-43.
Переход в основную школу требует адаптации учащихся к новым условиям образовательной среды, сопровождается использованием физиологических резервов организма. Школьный стресс может препятствовать академической успеваемости детей и подростков, творческому решению сложных и новых проблем, что, соответственно, может привести к недостатку способностей и снижению самооценки школьников. Хроническое воздействие академического стресса может привести к школьному выгоранию и формированию психосоматических расстройств. Цель исследования - сравнить функциональное состояние вегетативных регуляторных систем среди учащихся с разным уровнем академической успеваемости. В лонгитудинальном исследовании приняли участие 60 детей (10-13 лет). Функциональное состояние вегетативных регулирующих систем определялось путем анализа 5-минутных записей ЭКГ в состоянии спокойного бодрствования с закрытыми глазами в положении сидя. Учащиеся были разделены на 3 группы в зависимости от уровня их академической успеваемости, который определялся по среднему баллу по восьми базовым предметам. Статистическая обработка данных проведена с использованием критериев Манна-Уитни, Краскелла-Уоллиса, Даннeta, ф-критерия Фишера. Достоверные различия по параметрам вариабельности сердечного ритма (ВСР) в зависимости от уровня академической успеваемости обнаружены только на 5-м и 6-м годах обучения, что отражало различную физиологическую цену адаптации к основной школе. Вегетативный профиль учащихся с академической успеваемостью ниже средней на 5 году обучения указывал на перенапряжение регуляторных систем и переутомление. Среди учащихся с академической успеваемостью выше средней на 6 году обучения в 2,4 раза чаще по сравнению со школьниками со средней успеваемостью наблюдалось оптимальное состояние вегетативных регуляторных систем (соответственно, 46,2% и 19,1%, р<0,05), а на 7 году обучения - в 2,5 раза по сравнению с учащимися с успеваемостью ниже средней (соответственно, 46,2% и 18,2%, р<0,05), что может свидетельствовать о более высокой физиологической цене адаптации к основной школе учащихся с академической успеваемостью ниже среднего. Переутомление и перенапряжение механизмов вегетативной регуляции характерно для школьников с академической успеваемостью ниже средней, тогда как у учащихся с успеваемостью выше средней наблюдался высокий уровень напряжения адаптационно-компенсаторных механизмов на шестом году обучения. Категория учащихся с уровнем академической успеваемости ниже средней должна быть отнесена к группе риска с точки зрения развития вегетативной дисфункции и психосоматических заболеваний.

Ключевые слова: вариабельность сердечного ритма, вегетативный профиль, академическая успеваемость, учащиеся.