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Original Research Article

Evaluation of adaptive capabilities of students of different nationalities: cross sectional study

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ABSTRACT

Background: The autonomic nervous system actively regulates the body's reactions to various external and internal factors, ensuring physiological balance in a person. Advances in information technology now allow for a dependable and non-intrusive examination of this system through an in-depth analysis of heart rate variability. This approach is not only a recognized instrument in cardiac studies but is also growing in its utilization for numerous clinical purposes. This overview details the foundational theories and practical uses of this evolving method. The purpose of the study is to study the adaptive reserves and indicators of autonomic regulation in students of different nationalities.
Methods: We conducted a cross sectional study of 110 students studying in Grodno State Medical University using photoplethysmography method via an app "Pulse HRV"during the period of December 2022- February 2023. The students were grouped into three groups: Group 1 being Southeast Asian students, Group 2 being Nigerian students and Group 3 being Belarussian students.
Results: As a result of the analysis, it was found that AP in group 2 was significantly different from groups 1 and 3. At the same time endurance coefficient was above norm in all groups, which indicated a weakening of the cardiovascular system, while in students from group 2 it was significantly less than in groups 1 and 3.
Conclusions: Students from Nigeria have significantly higher adaptive reserves than students from Belarus and Southeast Asia, which may be due to the prevalence of increased tone of the parasympathetic nervous system.

Keywords: Autonomic nervous system, Heart rate variability, Internal factors

INTRODUCTION

The modern education system places an increased demand on the functional state of students. So, the body of students is exposed to a complex of factors that cause activation of adaptive mechanisms for a long time. Adaptive capacity or capability is the capacity to respond of changes in the external and internal environment in order to continue to thrive in that environment.[1] Meanwhile, the cardiovascular system is the most sensitive indicator of the adaptive activity of the whole organism. The autonomic nervous system is well known for its close relation to cardiovascular system and regulatory functions throughout the whole body, helping it to adapt for many conditions and regulating the body's reactions to various factors, ensuring physiological balance in a person.

One of the captivating and progressively adopted non-invasive diagnostic techniques within the field of medicine involves the meticulous examination of heart rate variability (HRV). This refined and intricate analysis of heart rate fluctuations serves as an indirect means to evaluate the autonomic regulation of cardiac function. Notably, alterations in the heart rate variability pattern have emerged as an advanced and perceptive precursor indicative of potential health challenges at an early stage.[2] Heart rate variability indicates the time difference between successive heartbeats.[3] In other words, it's the variance from beat to beat in either heart rate or R-R interval length.[4] And the physiological variation in the duration of these intervals is what is measured by HRV.

HRV is a measure of the balance between sympathetic and parasympathetic tone in the autonomic nervous system, and it has significant implications for cardiovascular health and predicting outcomes; commercially available HR monitoring systems have made ambulatory monitoring on a large scale possible.[5] A higher HRV indicates a more flexible and adaptable autonomic nervous system, which is associated with better cardiovascular health and resilience to stress. On the other hand, lower HRV is linked to higher risk of cardiovascular disease, as well as other health problems such as depression and anxiety.[5] Heart rate could also change due to mental and physical stress, pharmacological or invasive treatment.[6] Heart rate variations demonstrate a clear synchronization showing an increase during inspiration and a reduction during expiration (i.e. respiratory sinus arrhythmia) and it is believed these changes occur as a result of cardiac autonomic regulation.[7] Autonomic nervous system imbalance causing increased sympathetic tone is shown to increase the risk of mortality.[6]

When a person is exposed to any type of a stressor, the parasympathetic nervous system is suppressed while the sympathetic nervous system is expressed.[8] During this, there is a release of epinephrine and norepinephrine into the bloodstream which acts throughout the body causing blood vessels to constrict, increase blood pressure, increase muscle tone, increase heart rate and HRV. This reaction is commonly referred to as “fight or flight “reaction.[9] Once the stressor is absent, a negative feedback system takes part in the body which stops body from producing cortisol and ideally reach to a sympathovagal balance resulting in homeostasis between the parasympathetic (vagal) and sympathetic nervous system. The HRV depends on genetic composition, age, gender and environment. According to one theory, females have a trend of “tend and befriend “reaction to stress as opposed to a “fight or flight “response in males due to the maternal investment and the relatively low levels of androgen.[10] Cycles in HRV occur in healthy people in conjunction with respiration.[11] This respiratory variability has a high frequency (about 0.2 Hz or 15 times per minute at rest) and can be eliminated by vagal blockade. These two elements imply that the parasympathetic nature of this particular type of high frequency cyclical HRV. The cyclical variation happens in conjunction with changes in baroreceptor activity as well, but it happens at a lower frequency (typically 0.10 Hz or six times per minute) that may be influenced by sympathetic nerve activity.[12] These factors indicate that while parasympathetic activity is a key player in high frequency cyclical changes, sympathetic activity is a key mediator of low frequency cyclical changes. These cyclical changes are accompanied by frequent, abrupt, large beat-to-beat changes in R-R intervals, which are superimposed on the cyclical changes that take place throughout the day and night in relation to the body's needs.[2]

The study of HRV has a long history. In 1733, Reverend Stephen discovered that the respiratory cycles have an impact on the level of arterial pressure and the interval between heartbeats.[7] Carl Ludwig, a renowned scientist from 1816 to 1955, utilized his own creation, the smoked drum kymograph, to measure and document the cyclic variations in the strength and timing of arterial pressure waves. This innovative device enabled him to observe the alterations in synchronization with respiration as early as 1847. He noted that the dog's pulse consistently increased during inhalation and decreased during exhalation, thus becoming the pioneer in documenting what would subsequently be referred to as the RSA. Willem Einthoven (1860-1927) pioneered the initial perpetuation of consistent recordings concerning the electrical activity of the heart in the latter part of the 19th century and the early segment of the 20th century, by means of galvanometers to accurately gauge modifications in electrical currents. The progression and standardization of the electrocardiogram facilitated the evaluation of moment-to-moment variations in the cardiac rhythm.[7] Several research groups utilized power spectral analysis to examine the physiological component of each frequency component that formulate the recurrent fluctuations in heart rate, commencing in the initial years of the 1970s. HRV has been quantified using time domain techniques as well as frequency domain techniques. The HRV's non-linear dynamic attributes have been recently assessed through techniques derived from the emerging field of deterministic "chaos". The famous scholar Franciscus C. Donders (1818-1889) hypothesized that the variability in heart rate caused by respiration is a consequence of the activation of the cardiac vagus nerve. Vasomotor waves and increments in sympathetic nerve activity occur concomitantly, as indicated by the scientific investigation conducted by Arthur C. Guyton (1919-2003) and his associates. According to Katona and Jih's (1975) theory, cardiac parasympathetic regulation could be made noninvasively by using periodic changes in heart rate that matched respiration. Since these ground-breaking studies, numerous other investigations have been conducted. In conclusion, the outflow of sympathetic nerves, changes in arterial pressure, and respiration have all been found to be strongly correlated.[7]

HRV can be measured using various technologies, including electrocardiography (ECG), photoplethys-mography (PPG), and wearable devices such as smartwatches and fitness trackers. Then these data could be analysed in various ways; time domain analysis, frequency domain analysis and non-linear techniques.[6]

Time domain analysis measures the amount of variability present in a continuous electrocardiogram over a pre-specified time period using mathematically straightforward techniques.[2,13] This is the most common method of HRV analysis used in clinical practice and the simplest to calculate.[6,14] The normal-to-normal R-R intervals are measured and subjected to basic statistical analysis after editing out non-sinus beats and artifacts. The most popular method and the simplest is to calculate the frequency distribution's standard deviation by plotting a histogram of R-R interval duration against the number of R-R intervals in a 24-hour period (SDNN index). As the monitoring period gets smaller, SDNN predicts cycle lengths that get shorter and shorter. Due to its dependence on the length of the recording period, SDNN is not a statistical quantity that can be defined with precision on randomly chosen ECGs.[15] Use of a method based on geometrical analysis of the 24h R-R interval histogram (St George's index or HRV index) is an alternative method.[16] These techniques are very similar to the SDNN index, but they have the advantage of requiring less precise beat classification, which eliminates the need for extensive editing of ambulatory electrocardiograms. Each of these indices measures the total variability recorded over the course of a 24-hour period and is affected by variations in sympathetic nervous system and parasympathetic nervous system activity. Although they can't be used to quantify precise changes in sympathetic or parasympathetic activity, they are useful clinical tools for identifying abnormalities of autonomic activity. There isn't a single time-domain HRV parameter that could be regarded as to primarily capture the sympathetic modulation of the heart alone.[6,17,18]

Measuring successive beat-to-beat R-R interval differences and computing an index that expresses the distribution of these differences, such as the rMSSD index, based on the standard deviation of successive differences are two methods for determining R-R interval variability that provide interchangeable measurements of parasympathetic activity .This is the proportion obtained by dividing pNN50 by the total number of NN intervals, and NN50 is the square root of the mean squared differences of subsequent NN intervals greater than 50ms.[15] Another approach is to tally the quantity of significant rhythms. When there are longer than 50 ms intervals between significant beat-to-beat changes (referred to as sNN50), a measure that differentiates between individuals with normal parasympathetic function and those with dysfunction is determined. These measures provide accurate, interchangeable measurements of parasympathetic activity in the time domain, which can be easily assessed in clinical-grade ambulatory electrocardiograms.[2]

Beat-to-beat power spectral analysis in both clinical settings and scientific research, HRV has been extensively used as a quantitative probe to assess autonomic function.

Heart rate data must be artifact-free and adhere to rigid mathematical requirements in order for frequency domain techniques to accurately assess autonomic activity. These requirements can only be met when subjects are studied in a controlled environment.[2] Analysis of the beat-to-beat power spectrum in both clinical settings and academic research, HRV is frequently used as a quantitative probe to assess the autonomic nervous system. Using spectral analysis, we can determine the distribution of HRV power in terms of frequency.[6] It is known that the high-frequency power is a quantitative measure of parasympathetic heart function; both sympathetic and parasympathetic activity can affect the low-frequency power; and the ratio of these two spectral power components is regarded by some as the balance of sympathetic and parasympathetic activity.[9] In order to calculate PSD there are two primary main categories: parametric and nonparametric. Using non-parametric methods such as the Fast Fourier Transform (FFT) gives the advantage of being a simple algorithm along with a high processing speed while using parametric methods will provide more easily distinguishable spectral components with a smoother range that could be used independently of previously chosen frequency bands.[15] Long-term recordings (24-hour ambulatory) are less accurate for frequency domain analysis because there is a high likelihood of artefact, ectopy, and non-stationary heart rate behaviours, which makes analysis difficult and yields subpar results. The short-term recordings (2-5min), made under controlled circumstances, have little artifact or noise, which makes analysis easier.[14] While satisfying technical and clinical prerequisites for meaningful power spectral analysis of heart rate variability, this type of rapid analysis makes frequency domain techniques more easily applied in clinical settings.[2]

According to the length of the analysis, spectral components could be divided into short term and long term categories. The three short-term spectral components-very low frequency (VLF), low frequency (LF), and high frequency-are calculated over a time period of 2 to 5 minutes (HF).[15] VLF, LF, and HF power components are typically measured in terms of absolute power (ms2), but LF and HF can also be measured in terms of normalized units (n.u.), which represent each component's relative value in relation to the total power minus the VLF component.[11,19] The representation of LF and HF in n.u. highlights the controlled and balanced behaviour of the two autonomic nervous system branches. In order to fully describe the distribution of power in spectral components, n.u. should always be quoted with absolute values of LF and HF power. The sequence of NN intervals over the course of a 24-hour period can be examined using long-term recordings and spectral analysis. In addition to the previously mentioned elements, this also includes Ultra Low Frequency (ULF). There are some technical guidelines that must be followed when using frequency domain techniques. To obtain accurate spectral estimation, one must always clearly distinguish between short- and long-term spectral analyses, and the analysed ECG must also meet a number of requirements.[15] It is significant to note that HRV measurements from long-term recordings, when circadian rhythms are present and patient activity is uncontrolled, offer different physiological information from HRV measurements from short-term recordings, when conditions are typically stable or under control.[18]

Non-linear methods are influenced by intricate interactions between, electrophysiological, humoral variables and hemodynamic as well as by autonomic nervous system and central nervous system controls. It is speculated that by examining HRV using non-linear dynamics, informative information can be obtained for the physiological understanding of HRV and the assessment of the risk for sudden death. Three variables-1/f scaling of Fourier spectra, H scaling exponent, and Coarse graining spectral analysis have been employed in order to quantify the nonlinear characteristics of HRV.[15,20-22] Various techniques such as Poincare plots, low-dimension attractor plots, attractor trajectories, and singular value decomposition, and have all been utilized to depict the data.[23,24]

Although the time-domain methods, in particular the RMSSD and SDNN methods, could be used to study recordings of short periods, the frequency methodologies are generally able to produce more readily interpretable data in terms of physiological regulations. Time-domain techniques are often the most effective for assessing long-term recordings; the decreased stability of heart rate modulations during long-term recordings makes the results of frequency techniques more difficult to understand.[15]

HRV monitoring has become increasingly popular in recent years, as it provides a non-invasive and convenient way to assess cardiovascular health and track changes over time.[5]

Thus, using the possibilities of HRV measurement in combination with other simple methods of assessing the adaptive abilities of the body will allow us to evaluate the adaptive reactions of students of different nationalities studying at our university. This will make it possible in the future to develop different approaches in the educational process, taking into account the individual characteristics of various nationalities.

METHODS

We conducted a cross sectional study during December 2022- February 2023among healthy 110 students of the Grodno State Medical University (Belarus), united in 3 main groups. Frist group: students from southeast Asia (n=87, 8 of them from the Maldives, 14 from India, 65 from Sri Lanka, average age 22 (22; 24) years, 51 women, 36 men) since there were no differences in all studied indicators in the different nationalities of group 1 students it was decided to consider them as one group in whole, Group 2-students from Nigeria (n=13, mean age 20 (19; 21) years, 10 women, 3 men), Group 3-Belarusian students (n=10, mean age 18.5 (18; 19) years, 5 men, 5 women).

Inclusion criteria

Student of Grodno State medical University, and study year 1, 2 or study year 5, 6.

For data collection we used the HRV via an app “Pulse HRV” which uses the photoplethysmography (PPG) technique and consists of detecting fluctuations in blood volume during a cardiac cycle by illuminating the skin and measuring in light absorption.

After extracting the PPG we were able to get the required markers of autonomic nervous system activity, in particular parasympathetic nervous system activity. We were able to record the HR, RR avg, rMMSD, SDSD, SDNN, PNN50, HRV1, T1NN, S1, SD1, SD2, SD1/SD2, LF, HF, LF/HF, LF nu and HFnu using the PPG technique.

An important indicator of the functional state of the cardiovascular system are the blood pressure level and heart rate, which are in a certain dependence on age, gender, national and constitutional characteristics of the body, climatic and geographical factors. So adaptive potential (AP) and endurance coefficient were calculated among all students based on these parameters. Simple AP1 (according to the equation of L.A. Konevsky) and complex AP2 (according to R. Bayevsky), were calculated in all groups using formulas given below.[25]

AP1=1.238+0.09*HR

AP2=0.011*HR+0.014*SBP+0.008*DBP+0.014*age+0.009*weight-0.009*height-0.273

Where; HR-Heart rate (bpm), SBP-systolic blood pressure (mmHg), DBP-diastolic blood pressure (mmHg).

If adaptive potential is less than 7.2 is satisfactory value if adaptive potential is between 7.0-8.24 is consider as tension of adaptation mechanism. If adaptive potential is between 8.25-9.85 is unsatisfactory adaptation.

The endurance coefficient was assessed as a criterion of the level of stress resistance of students and was calculated by the Kvass formula:

$$CE = \frac{\text{HR} * 10}{\text{Pulse Pressure}}$$

Where HR-heart rate (bpm), PP- pulse pressure (mmHg). PP is calculated as the difference between the SBP and DBP.[26]

If the coefficient of endurance (Kvass formula) is normally 12-16 conventional units; it is considered to have satisfactory endurance.[26] An elevation in the indicator indicates a weakening of the function of the cardiovascular system; a decrease indicates an increase in function.

The Kerdo vegetative index (KI), which is frequently used in physiology, rehabilitation, and neurological investigations, was utilized to evaluate the prevalence of the autonomic nervous system in the regulation of adaptive processes in addition to HRV.

$$KI = (1-DBP/HR)*100$$

Where DBP is Diastolic Blood Pressure and HR is Heart rate.[27] The autonomic balance is characterized by the KI equal to 0. Positive values of the KI indicate sympathetic dominance, negative values indicate increased parasympathetic tone. This indicates that the pulse is less than the DBP.

The study uses statistical analysis methods: descriptive, comparison of average values, correlation coefficient (non-parametric Mann-Whitney U test, Spearman coefficient). The differences were considered significant at $p<0.05$.

RESULTS

After collecting the data of anthropometric measurements (height, weight) and clinical investigations (BP measurements on both hands, calculation of heart rate) from all students, main indexes of adaptation were calculated. We obtained the results as shown in the table 1 below.

Table 1: Calculated adaptation indexes according to the anthropometric measures and clinical investigations.

	Southeast Asia	Nigerians	Belarusian
AP_1	8.17 (7.09; 8.7)	9.07 (8.17;10.3)*	10.01 (8.5;10.06)
Endurance coefficient (EndCoe)	20.5 (18.06;21.5)	22.9 (19.5;25.6)*	23.9 (20.25;24.9)
KI	11.39(0.0;29.57)	-3.95 (-13.85;2.5)*	18.07 (7.69;21.43)

Table 2: Results of HRV assessment by mobile application.

	Southeast Asia	Nigerians	Belarusian
HF	459 (246;849)	781 (495;955)*	248 (106;573)
SD1	31 (24;46)	53 (28;67)*	29 (16;41)

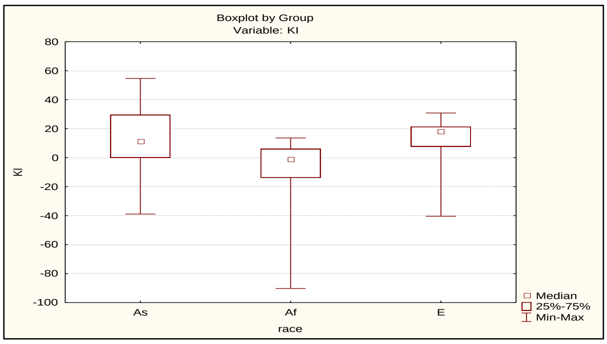

Figure 1: KI findings.

As a result of the analysis, it was revealed that AP in group 2 was significantly different from groups 1 and 3 (8,17 (7,09; 8,7), 9,07 (8,17; 10,3), 10,01 (8,5; 10,06)), while students from Nigeria had significant higher adaptation mechanisms, students from Asia had a poor adaptation, and students from Belarus had a disruption in adaptation. The endurance coefficient was above the norm in all groups, which indicated a weakening of the activity of the cardiovascular system [20,5 (18,06; 21,5), 22,9 (19,5; 25,6), 23,9 (20,25; 24,9)], while in students from group 2 it was significantly less than in groups 1 and 3.

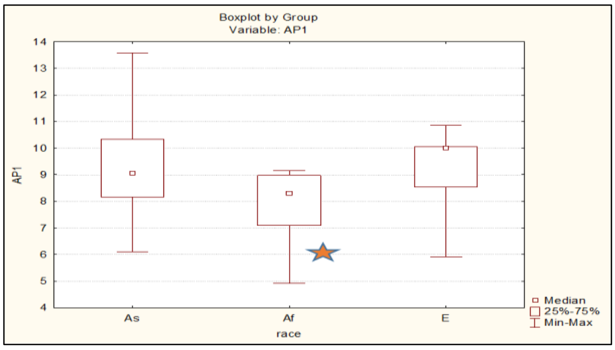

Figure 2: API findings.

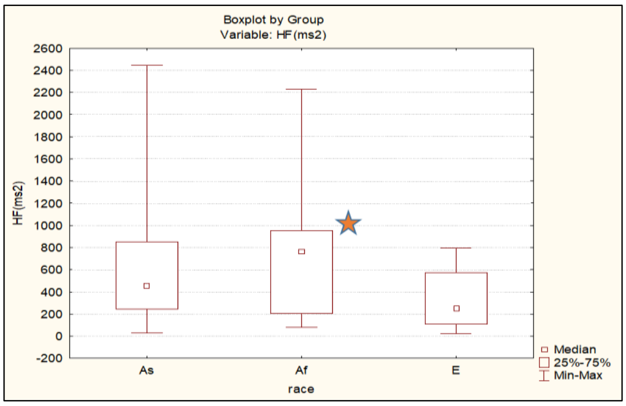

Figure 3: EndCoe findings.

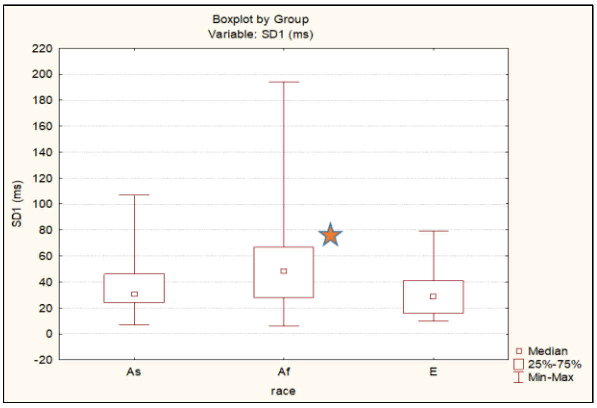

Figure 4: SDI findings.

Table 3: Distribution of demographic data of the population.

Characteristic	Frequency
Volunteers (n)	110
Mean age (years)	
Southeast Asia	22
Nigerians	20
Belarussians	19
Sex	
Female	65
Male	45
Year of study	
1	17
2	45
3	4
4	14
5	18
6	12
Average weight (kg)	
Southeast Asia	62
Nigerians	67
Belarusian	65
Average height (cm)	
Southeast Asia	165
Nigerians	167
Belarusian	171
Average blood pressure (mmHg)	
Southeast Asia	113/75
Nigerians	116/79
Belarusian	117/77
Average heart rate (BPM)	
Southeast Asia	90
Nigerians	74
Belarusian	90

This can be explained by a significant prevalence in the regulation of the cardiovascular system in students from Nigeria of the parasympathetic nervous system (KI -3.95 (-13.85; 2.5)), and in students from Asia (KI 11.39 (0.0; 29.57)) and Belarus (KI 18.07 (7.69; 21.43)) sympathetic tone. A significant prevalence of the parasympathetic nervous system in Nigerians maintains better adaptation to study and new conditions appeared due to changes in climate and region.

These changes are confirmed by the results of HRV assessment by mobile application. It was established that students from Nigeria have significantly higher HF (High frequency, which is considered that it's modulated by the parasympathetic activity of ANS) than students from Belarus (781 (495; 955) and 248 (106; 573)) and SD1 than students from Asia (53 (28; 67) and 31 (24; 46)). There were no significant differences between groups 1 and 3. Also, there were no differences in groups depending on the period of study.

DISCUSSION

The ANS has an impact on various aspects of human physiology, including metabolism, thermoregulation, and cardiac activity. The two subdivisions of the ANS, the sympathetic and parasympathetic nervous systems, function differently in various contexts to control homeostasis. The parasympathetic and sympathetic nervous systems work antagonistically with one another. The vagus nerve inhibits heart rate when the parasympathetic system is activated. Additionally, the sympathetic nervous system targets the atrioventricular node for the forceful contraction of the heart chambers while the vagus nerve initially acts upon the sinoatrial node, the heart's pacemaker, to initiate a conduction system.[28]

HVR is one of the easiest methods for determining the ANS's condition. When the parasympathetic mode is active, the variation in heartbeat is greater than when the sympathetic mode is active. High HRV indicates greater cardiac fitness, whereas low HRV implies CVDs such as hypertension. Understanding HRV is one of the best ways to judge how different elements, such as thoughts, environment, emotion, and feelings, affect the nervous system and how the nervous system reacts as a result.[29,30]

There are mainly two techniques to taking recordings of the HRV readings; electrocardiography (ECG) and photoplathysmograpy (PPG).[31] For the purpose of heart rate monitoring, PPG is a simple and economical optical measurement technique. PPG is a form of non-invasive testing that uses a source of light to shine on the skin's surface to assess the volumetric fluctuations in blood circulation using a photodetector.[31] PPG sensor-based HR monitoring methods have a number of advantages over conventional ECG-based methods. PPG sensors, for example, require only one sensor to be placed on the body for operation and have simpler hardware implementation and lower costs in contrast to conventional ECG recordings. For our research we used the PPG methods due to these advantages mentioned.[32]

In our study, we looked at the differences in autonomic function between international and native students taking the same course in the same climate. Since when students are attending university, which comes with high levels of mental and emotional stress, frequent forced violations of the work-and-rest schedule, and nutrition. All of this may strain the body's compensatory and adaptive systems and harm one's health.[26] We also measured the potential for adaptation among different nationalities to see how they changed from the start of the course to the end. It is known that disruption of the adaptation of the body, in turn, leads to a decrease in working capacity, educational activities of students and severe influxes on final result of study.

According to our results we were able to conclude that students from Nigeria have significantly higher adaptive reserves than students from Belarus and Southeast Asia, which may be due to the prevalence of increased tone of the parasympathetic nervous system. The parasympathetic nervous system promotes relaxation and restoration in the body. That means Nigerian students may have a greater ability to relax, recover, and restore their physiological and psychological balance in comparison to other persons.

The main limitation is the duration of HRV registration (1 min), which prevents the analysis of circadian rhythm disruptions. Furthermore, it would be beneficial to compare the adaptation characteristics at the onset and conclusion of the study year in order to provide a more comprehensive description of the adaptive abilities of various races and nations. Unfortunately, we encountered a single instance of investigation. Therefore, further investigations will be necessary.

CONCLUSION

Based on simple methods of adaptation assessment (adaptive potentials, endurance coefficient, Kerdo vegetative index) it was established that medical students of all nationalities have generally weak cardiovascular system activity. Meanwhile students from Nigeria had significant higher adaptation mechanisms, students from Asia had a poor adaptation, and students from Belarus had a disruption in adaptation. It can be explained by higher prevalence at Nigerians of the parasympathetic nervous system in regulating the cardiovascular system, while students from Asia and Belarus had a higher sympathetic tone. This suggests that Nigerian students may have a greater ability to relax, recover, and restore their physiological and psychological balance. It can help in planning of level of studies activity for different groups of students based on their nationality and vegetative status.

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