Universal Journal of Public Health 12(4): 717-729, 2024 http://www.hrpub.org
DOI: 10.13189/ujph.2024.120411

Dynamics of Indicators of the Cardiovascular System and Its Autonomic Regulation during Overwintering in the Arctic

Nataliya B. Pankova[1], Roman P. Buynov[1], Kirill V. Filchuk[2], Irina B. Alchinova[1], Anton B. Cherepov[1], Mikhail Yu. Karganov[1,*]

[1]Laboratory of Physical, Chemical and Ecological Pathophysiology, Institute of General Pathology and Pathophysiology, Russia
[2]Department of Oceanology, Arctic and Antarctic Research Institute, Russia

Received April 11, 2024; Revised June 29, 2024; Accepted July 21, 2024

Cite This Paper in the Following Citation Styles

(a): *[1] Nataliya B. Pankova, Roman P. Buynov, Kirill V. Filchuk, Irina B. Alchinova, Anton B. Cherepov, Mikhail Yu. Karganov , "Dynamics of Indicators of the Cardiovascular System and Its Autonomic Regulation during Overwintering in the Arctic," Universal Journal of Public Health, Vol. 12, No. 4, pp. 717 - 729, 2024. DOI: 10.13189/ujph.2024.120411.*

(b): *Nataliya B. Pankova, Roman P. Buynov, Kirill V. Filchuk, Irina B. Alchinova, Anton B. Cherepov, Mikhail Yu. Karganov (2024). Dynamics of Indicators of the Cardiovascular System and Its Autonomic Regulation during Overwintering in the Arctic. Universal Journal of Public Health, 12(4), 717 - 729. DOI: 10.13189/ujph.2024.120411.*

Abstract Most studies on the adaptation of humans to extreme conditions of the polar regions were performed in Antarctic expeditions. Our research aims to study the same parameters in the Arctic. The study was conducted at the North Pole 41 drifting polar station (NP-41) and involved 14 men. The participants were divided into two groups: "ice" – working mainly outdoors (n=8), and "laboratory" – working mainly indoors (n=6). A semi-annual monitoring included assessment of the parameters of cardiac performance, heart rate variability (HRV), and blood pressure variability (BP). During the study, no significant changes were revealed in parameters of cardiac performance and HRV. In group “ice”, according to the indicators of BP variability, a decrease in the pulse BP both at rest and under conditions of controlled respiration was noted during the first 3 weeks of overwintering. At later terms, no dynamics of this indicator was found. In group “laboratory”, an increase in pulse BP was detected from the third week to 6 months of overwintering also at rest and under conditions of controlled respiration. The test with controlled respiration allowed us to demonstrate the contribution of the LF range power to BP change. Conclusions: the pattern of adaptive changes during overwintering in the North depends on the type of occupational activity.

Keywords Adaptation, Extreme Climate, Cardiovascular System, Heart Rate Variability, Blood Pressure Variability

1. Introduction

Technological advances of modern society make exploration of the vast uninhabited areas of the polar regions very tempting and promising for humankind. However, along with technical support, this process also requires adaptation of the human body to extreme environmental factors, primarily to climatic and geographic conditions, including geomagnetic instability, low temperatures combined with winds, unusual photoperiodism with general shortage of ultraviolet light in circumpolar regions [1], and also seasonality inversion during expeditions to the opposite hemisphere. The extreme conditions of polar expeditions suggest that people spend most time in confined spaces, specially equipped rooms, and in small geographically and socially isolated groups, which create additional risks for their mental health.

The capabilities of adaptation of the human body to extreme polar conditions are studied during Arctic and Antarctic expeditions of varying duration. In these studies, the functional state of the body is usually assessed by non-invasive methods: assessment of parameters of the cardiovascular system, psychological and psychophysiological indicators. Before and after the expedition (or in the laboratories of stationary bases), biochemical analysis of various body media (blood, urine, saliva) is carried out if possible.

In recent years, heart rate (HRV) and blood pressure (BP) variability parameters that correlate with functional activity of the regulatory systems of the body are recorded. For HRV, it has long been accepted that such indicators as statistical RMSSD (Root mean square of successive variances of NN intervals or the absolute value of the average change in interval between any two normal beats), and the power of the high frequency (0.15–0.40 Hz, HF) range of the variability spectrum are the markers of the functional state of the parasympathetic regulation [2–4]. Statistical indicator SDNN (Standard deviation of NN intervals) and the power of the low frequency (0.04–0.15 Hz, LF) range are considered as the markers reflecting the level of sympathetic activity. To assess the effect of autonomic regulation of BP, spectral indicators of BP variability (systolic, diastolic, mean) are used; their functional significance is interpreted similarly [5, 6]. It should be noted that this approach to interpretation of the results is convenient for applied research, but is very simplified. According to modern concepts, nervous regulation of the cardiovascular system is implemented by a complex and hierarchically organized structure, the so-called “autonomic brain” [7] that includes the brainstem, hypothalamic, and extrahypothalamic structures directly (through neural pathways) affecting the bulbar centers of sympathetic and parasympathetic autonomic regulation. Morpho functional characteristics of the autonomic brain are now actively studied by the neuroimaging methods [8].

Nevertheless, changes in such indicators as the power of the LF range in the HRV and BP variability spectra revealed in monitoring studies allow assuming their relationship with changes in the activity of the sympathetic regulation of the cardiovascular system of the subjects.

Thus, in long-term (more than a year) Antarctic expeditions, changes in the autonomic regulation of the cardiovascular system with a shift of the initial balance towards sympathectomy were described; the most pronounced shifts were observed in the last trimester of observations. These changes were traced by HRV indicators in studies at the Antarctic stations Neumeier III (Germany) [9] and Akademik Vernadsky (Ukraine) [10]. In members of the Indian Antarctic Expedition, increased sympathetic activity, in addition to HRV indicators, was also evidenced by increased heart rate and BP at rest and increased norepinephrine excretion with the urine [11].

During overwintering in Antarctica (from February to October), the metabolomic analysis of the blood serum from the expedition members revealed shifts clearly attesting to an adaptation period characterized by an increase in the levels of circulating glutamine and lipids mobilized to supply the body energy requirements, with subsequent changes in metabolic processes that can potentially be interpreted as physiological adaptation [12].

In shorter Antarctic expeditions lasting up to 2 months, increased levels of catecholamines (epinephrine, norepinephrine, and dopamine) were detected in the urine and increased content of cortisol, leptin, and pro-inflammatory IL-8 and decreased level of angiogenic factor VEGF were found in the saliva; no changes in HRV and in the content of melatonin and testosterone were found [13, 14]. In the urine, a decrease in citrate and creatinine levels was also reported, probably due to the absence of fresh fruits and vegetables in the diet [15]. In repeated measure studies, a non-linear pattern of change in the parameters was observed: the excretion of epinephrine and norepinephrine in the urine and cortisol in the saliva increased on day 7, and the increase in HRV indicators correlating with sympathetic activity occurred on days 7 and 30 [11].

The adaptive changes in the members of polar expeditions are induced by a complex of environmental factors, however, at a subjective level, cold is the leading and the most important factor for the participants from countries with warm climate (China [16], India [11, 15]).

Three primary patterns of cold acclimatization are distinguished: habituation, metabolic adjustment, and insulative adjustment. Habituation is characterized by physiological changes in which the response is attenuated compared to an unacclimatized state. Metabolic acclimatization is characterized by enhanced thermogenesis, whereas insulative adjustment is characterized by enhanced heat conservation mechanisms. The pattern of acclimatization depends on changes in skin and core temperature, as well as on the duration of exposure [17]. An important physiological mechanism of adaptation to cold is blood redistribution from the periphery to the center of the body. Under these conditions, the risks of impaired blood supply to the extremities are compensated by elevation of systemic BP with a simultaneous increase in vascular stiffness (increase in peripheral resistance). These changes are mediated by increased activity of the sympathetic nervous system and enhanced production of circulating catecholamines, however, the response to cold greatly varies in different individuals [18].

High information content of BP parameters during implementation of the mechanisms of urgent adaptation to cold was shown in experimental studies involving humans and animals. Thus, in humans, facial cooling (a variant of the cold test) increases peripheral and central systolic and diastolic BP [19]. In a traditional cold test with hand immersion in cold (10°C) water, a significant increase in systolic and diastolic BP recorded on vessels of the fingers was noted [20]. However, in a study conducted in our laboratory with a similar design and methodology, the presence and severity of shifts in the cardiovascular system indicators were variable [21]. When the duration of cold exposure is increased to 2 minutes and the water is cooled to 0–4°C, a decrease in statistical (pNN50, RMSSD) and spectral indicators of HRV (power of the LF and HF ranges) is described, with an increase in diastolic blood pressure [22].

In divers diving in very cold water (<5°C), the autonomic nervous system is activated, especially its parasympathetic part due to the trigeminocardiac reflex, as well as stimulation of baroreceptors and cardiac stretch receptors [23]. Studies involving divers working near the Arctic Circle have demonstrated a significant increase in parasympathetic activity at the beginning of the dives. In 5–10 min, the vagal activity decreased and then again significantly increased (15–20 min and onward) [24]. Similar shifts, in particular, an increase in parasympathetic activity in the HRV spectrum accompanied by an increase in systolic and diastolic BP, were observed in people exposed to cold (–20°C for 10 min) in a cold chamber [25].

In experiments on rats exposed to cold daily for a week (immersion of bare palms and soles of each rat in water at a temperature of 4°C for 10 min), an increase in the total power of the HRV and BP variability spectra was accompanied by a decrease in their LF component (a correlate of sympathetic activity): by 5 times in the BP spectrum and by 2 times in the HRV spectrum [26]. High coherence in the power of the LF ranges in the HRV and BP variability spectra and an increase in NO production were also noted [27]. The authors conclude that cold stress changes the pattern of sympathetic regulation of the cardiovascular system: its tone increases, but the amplitude of fluctuations decreases. An important role in this process is played by endogenous angiotensin II; its level increases during stress [28]. This conclusion is confirmed by the results of experiments using a non-selective angiotensin receptor blocker AT1 losartan [26].

Long-term adaptation of the cardiovascular system to cold seems to be implemented via epigenetic mechanisms [29], affecting, in addition to local mechanisms of BP regulation, also modulation of the autonomic sympathetic activity, the renin-angiotensin-aldosterone system, and endothelial functions [30]. For instance, the lower values of HRV indicators in Greenlandic Inuit compared with representatives of other ethnic groups can be a result of such adaptation [31]. Comparative studies were also conducted with the participation of indigenous people and migrants in the Magadan region (Russia) characterized by extreme continental (subarctic) climate with winter temperatures up to –60°C and summer temperatures up to +35°C. Analysis of HRV indicators at rest in a series of "migrants (zero generation)" — "descendants of the first and second generations" — "permanent residents” showed an increase in the contribution of parasympathetic influences [32], with a decrease in the total prevalence of arterial hypertension and prehypertension [33], in the etiopathogenesis of which sympathetic hyperfunction plays a leading role [34].

Unfortunately, the above data on the adaptation in humans to extreme conditions of the polar regions were primarily obtained in Antarctic expeditions, while the results of similar studies in the opposite part of the planet, in the North, are significantly less presented in available databases of scientific publications. Our study of the dynamics of the cardiovascular system parameters in over winterers in the North is designed to fill this gap.

We used the spiroarteriocardiorhythmograph (SACR) instrument complex [35] that allows noninvasive assessment of changes in the sympathetic component of the autonomic regulation simultaneously in relation to cardiac activity and BP. Its effectiveness was shown in the analysis of the functional state of the cardiovascular system in participants of short-term Arctic marine expeditions [36]. Objective was to study the dynamics of the cardiovascular system parameters and their autonomic regulation in members of the Arctic overwintering during a long-term polar expedition.

2. Materials and Methods

2.1. Sample

The study was conducted at the drifting polar station North Pole 41 (NP-41) during the period from October 5, 2022 to April 3, 2023. The expedition started from a point with coordinates N 82°37’ E 155°31’.

Information about the expedition North Pole 41 is available on the website of the Arctic and Antarctic Research Institute, St. Petersburg 199397, Russia: https://www.aari.ru/ekspeditsii/ekspeditsiya-severnyy-polyus-41-(na-lsp-severnyy-polyus)

Fourteen men included in the study were divided into two groups: "ice" – working mainly outdoors 5-6 hours a day without breaks (n=8), and "laboratory" – working mainly indoors (n=6). All study participants were practically healthy and did not need constant medication, including those affecting vascular tone. Alcohol intake was prohibited during the expedition.

The groups did not differ by the age and anthropometric parameters, and at the first testing point they also did not differ by the basic indicators of the cardiovascular system and physical performance (Table 1).

Table 1. Initial characteristics of the studied groups

Parameter	Groups		p
	«Ice»	«Laboratory»	
Age [years]	49.5±4.5	41.7±5.9	0.316
Height [cm]	178.1±1.7	175.8±1.3	0.323
Weight [Kg]	91.0±6.7	82.0±3.7	0.305
Body mass index [Kg/m^2]	28.7±2.1	26.6±1.4	0.457
Heart rate [counts per minute] *	76.0 (68.5; 88.5)	74.0 (67.0; 96.0)	0.949
Systolic blood pressure [mmHg]	136.7±6.6	134.8±8.5	0.859
Diastolic blood pressure [mmHg]	81.3±2.8	81.8±3.8	0.900
Pulse blood pressure [mmHg]	55.5±5.0	53.0±6.0	0.879
Stange test [s] *	43.0 (34.5; 57.0)	37.5 (32.0; 48.0)	0.606
Genchi test [s] *	19.5 (17.0; 32.5)	22.0 (21.0; 31.0)	0.606
Ruffier index (c.u.)	6.8±1.2	7.9±1.9	0.603

* Note: indicator samples marked with "*" have a distribution different from normal one, their values are presented as median and interquartile range (Me (Q1; Q3)), intergroup differences are assessed using the Mann-Whitney U-test; the other indicators have a normal distribution, their values are presented as the mean and standard error (M±SE), intergroup differences are assessed using the Student's T-test.

The study was performed in compliance with international and Russian legislative acts on the legal and ethical principles of conducting studies involving human subjects and was approved by the Ethics Committee of the Research Institute of General Pathology and Pathophysiology (Protocol No. 3, July 6, 2022).

2.2. Equipment

The parameters of the cardiovascular system were assessed using an automatic blood pressure monitor (Microlife BP 3AG1, Switzerland) and a SACR instrument complex (INTOX LLC, Russia). SACR performs continuous recording of an electrocardiogram in standard lead I, BP on the middle phalanx of the finger by photoplethysmography, and respiratory parameters using ultrasound sensors, followed by signal processing: analysis of HRV, variability of systolic and diastolic finger BP (fBP), assessment of cardiac performance and spontaneous arterial baroreflex [35].

2.3. Study Design

The total duration of the observation period was 6 months and included 5 series of tests: October 5-7, 2022 – point 1 (3–5 days after the start of the expedition), October 25 – point 2, December 2 – point 3, February 2 – point 4, April 3 – point 5.

At each term, common indicators of the functional state of the body were recorded:

- body length and weight with calculation of body mass index;
- heart rate, systolic and diastolic BP with calculation of pulse BP (measured by pressure monitor);
- Stange and Genchi hypoxic tests (holding breath) were performed and the Ruffier index was calculated (HR response to exercise).

Registration on the SACR device was conducted in a warm room after the end of the work shift. Two 2-min records were done at each point: at rest (without spirometric mask, background) and under conditions of controlled respiration (breathing with a frequency of 6 cycles per minute), which, according to our data, is a functional load test with a typical pattern of changes in the assessed parameters [37]. Thus, the respiratory volume during the test increases to 2-2.5 liters (vs 0.8–1.0 liters in the background), and special analysis of the composition of exhaled air revealed a decrease in oxygen absorption (from 0.45–0.60 to 0.25–0.35 liters per minute) and carbon dioxide release (from 0.35–0.45 to 0.30–0.35 liters per minute) by the end of the second minute, while the respiratory metabolism coefficient increases [38]. At the same time, the minute ventilation and the ventilatory equivalent for carbon dioxide do not change, whereas the ventilatory equivalent for oxygen tends to increase.

2.4. Statistical Analysis

Biomedical procedures were not included in the main part of the expedition and participation in the study was voluntary; that is why the groups consisted of a small number of subjects. To compensate for this limitation and highlight significant statistical trends, as well as to avoid errors caused by random fluctuations in indicators, the methods of multidimensional statistics were applied.

For statistical processing of the BP monitor readings, repeated measure ANOVA followed by comparison of the means using the Tukey test or its non-parametric analogue

Freidman test followed by Dunn test for paired comparisons of the median values was applied (GraphPad Prizm 8).

The indicators recorded on the SACR device were divided into three blocks.

- Cardiac performance: heart rate; minimum and maximum duration of intersystolic intervals, range of fluctuations of intersystolic intervals; end-diastolic, end-systolic, and stroke volumes, and cardiac output.
- HRV: spectral indicators – total spectral power (TP), absolute and relative powers of standard spectral ranges (high frequencies – HF and HF%, low frequencies – LF and LF%, very low frequencies – VLF and VLF%); calculated indexes (LF/HF, centralization index, stress index); statistical indicators (SDNN, RMSSD, pNN50) [2–4].
- fBP variability: mean, minimum, and maximum values of systolic fBP (fSBP) and diastolic fBP (fDBP), the range of fSBP and fDBP oscillations; pulse fBP; total power of the fSBP and fDBP variability spectra (TPS, TPD), absolute and relative powers of standard spectral ranges (HFS, LFS, VLFS, HFS%, LFS%, VLFS%; HFD, LFD, VLFD, HFD%, LFD%, VLFD%) [5,6]; the sensitivity of spontaneous arterial baroreflex and its analogue, the calculated alpha index [39].

Each block of SACR indicators was analyzed separately, according to the following scheme:

- First, a discriminant analysis (an algorithm for direct step-by-step analysis) of the indicators was performed within the groups of subjects and in the total sample throughout the entire study period – from point 1 to point 5; the statistical significance of the actual discriminant functions was evaluated using canonical analysis (Statistica 7.0).
- In the presence of statistically significant changes, the dynamics of significant indicators (determined at the previous stage of statistical processing) and intergroup differences in the dynamics were checked (Friedman's test, Dunn's test; GraphPad Prizm 8).
- If the dynamics of the indicator was confirmed, selective pairwise comparisons of its values at significant points were carried out (Wilcoxon paired test; GraphPad Prizm 8).

The indicators recorded at rest (background) and under conditions of controlled respiration, as well as their reactivity, i.e. the degree of changes (in %) with a change in the recording conditions, were evaluated separately.

The calculated power of the used statistical tests was >98% (Statistica 7.0).

3. Results

When analyzing the obtained results, we revealed no significant changes between the groups and in the total sample in the general indicators of the functional state of the body, as well as indicators included in the blocks of cardiac performance and HRV of SACR throughout the observation (from point 1 to point 5).

In group “ice”, discriminant analysis revealed no significant changes in the fBP variability indicators under baseline conditions (registration without a mask), while in group “laboratory”, these changes were found: Wilks' Lambda = 0.230; $F_{(16, 61)} = 2.383$; $p<0.008$. Pulse fBP was the only significant ($p=0.005$) indicator with the maximum weight in the canonical function. According to the Friedman's test, this indicator demonstrated a statistically significant dynamics in group “ice”: χ^2 (n=5, df=4) = 10.40; p=0.034. In group "laboratory", on the contrary, no dynamics was found: χ^2 (n=4, df=4) = 5.80; p=0.214. The differences in the dynamics of pulse fBP between the groups were statistically significant: $F_{(4, 28)} = 2.82$; p=0.044. The results of pairwise comparison of the pulse fBP values within the groups according to the Dunn's test revealed a decrease in the indicator in group "ice" during the first month on NP-41 (from point 1 to point 2) and an increase from point 2 to point 5 in group "laboratory" (Figure 1, a).

In the total sample, discriminant analysis also showed significant changes only for pulse fBP (Wilks' Lambda: 0.612; F (16, 168) = 1.837; p<0.029). The presence of dynamics was confirmed by the Friedman's test: $\chi 2$ (n=9, df=4) = 9.96; p=0.041. According to the Dunn's test, this parameter tended to decrease between test points 1 and 2, and, conversely, to increase from point 2 to point 5 (Figure 2, a).

It should be noted that no changes in this parameter were detected when measurements were performed with a pressure monitor (under similar conditions – without a spirometric mask).

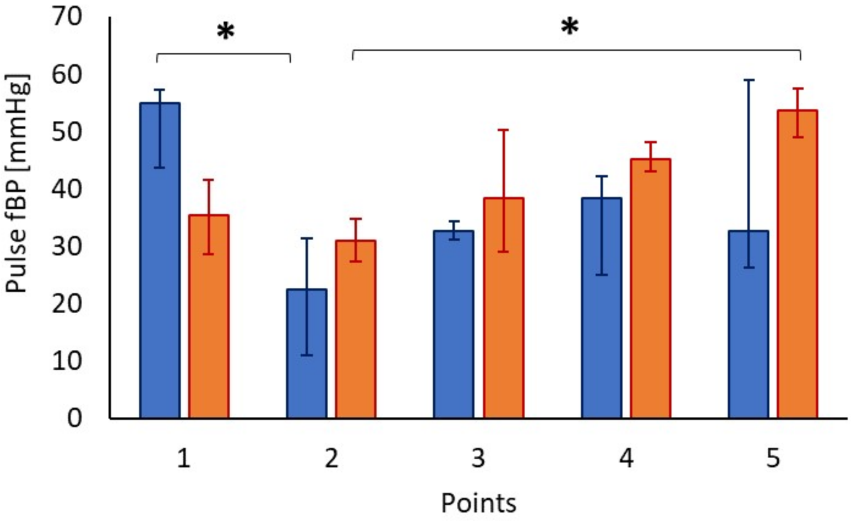
Similar patterns were found in the indicators of fBP variability under conditions of controlled respiration in group "laboratory”: Wilks' Lambda = 0.126; $F_{(24, 64)} = 2.162$; $p<0.007$. Under these conditions, in addition to the pulse fBP (p=0.003), the relative power of the LF range of the fDBP variability spectrum (LFD%, p=0.021) was also a significant indicator.

In group "ice", changes in the complex of fBP variability parameters were at the level of a trend: Wilks' Lambda =0.284; $F_{(24, 84)} = 1.535$; $p<0.078$, while significant indicators were the relative power of the LF range of the fSBP variability spectrum (LFS%, p=0.031), and, at the trend level – the same indicator of the fDBP spectrum (LFD%, p=0.073).

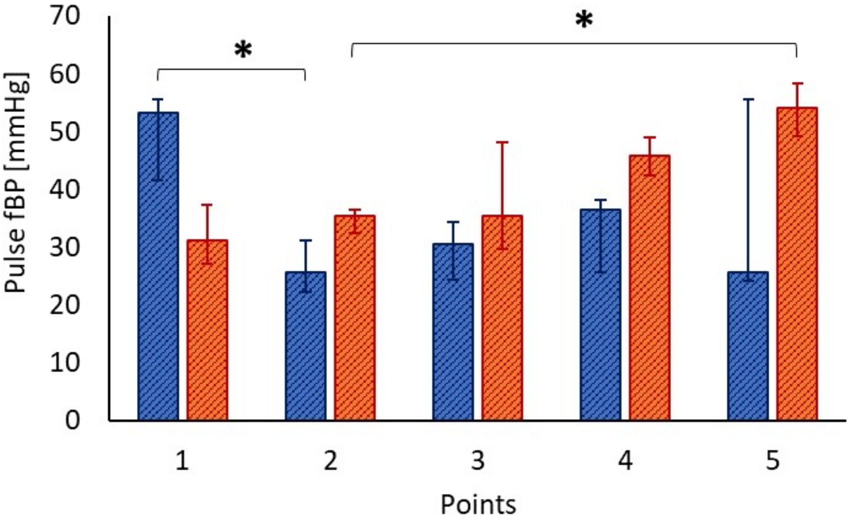
According to the Friedman's test, this indicator demonstrated dynamics in group “ice” (χ^2 (n=5, df=4) = 9.76; p=0.044, and group “laboratory” (χ^2 (n=4, df=4) = 9.00; p=0.061), and the differences in the dynamics between the groups were statistically significant: F (4, 28) = 3.62; p=0.017. The pairwise comparison of the pulse fBP values within the groups according to the Dunn's test revealed a decrease in the indicator in group "ice" during the first month on NP-41 (from point 1 to point 2) and an increase from point 2 to point 5 in group "laboratory" (Figure 1, b).

In the total sample under conditions of controlled respiration, discriminant analysis also showed the presence of significant changes (Wilks' Lambda: 0.562; F $_{(20, 176)}$ = 1.675; p<0.041), but significant indicators were not pulse fBP, but the relative power of the LF ranges in the fSBP and fDBP variability spectra (LFS% and LFD%). According to Friedman's criterion, no dynamics of pulse fBP was detected: χ^2 (n=9, df=4) = 5.68; p=0.223. However, differences in the dynamics of this indicator in different groups were revealed: F $_{(4, 28)}$ = 3.616; p=0.017; according to the Dunn's test, this indicator tended to decrease between test points 1 and 2, and to increase from point 2 to point 5 (Figure 2, b) as it was observed during recording at rest.

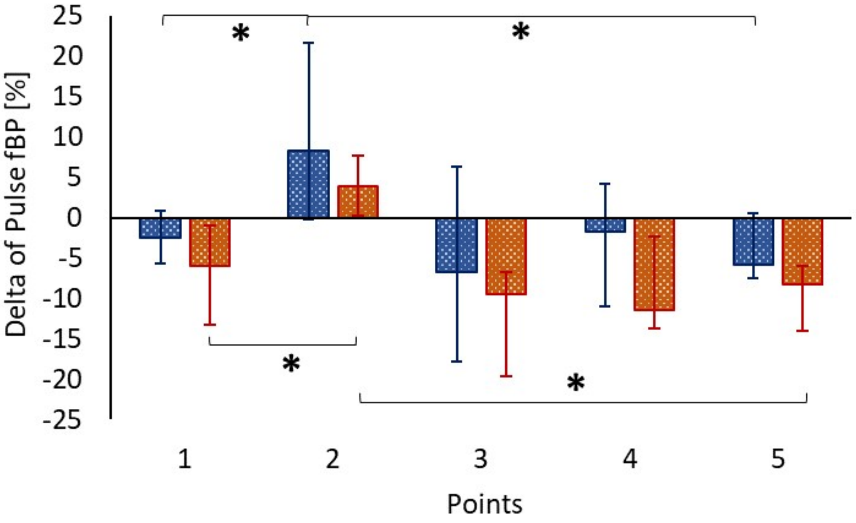
Under these conditions, significant dynamic shifts were detected using the paired Wilcoxon test in the relative power of the LF range of the fSBP and fDBP variability spectra (LFS% and LFD%) from point 1 to point 2: a decrease in both indicators in group "ice" and no dynamics in LFS% and an increase in LFD% in group "laboratory" (Figure 3).



(a)

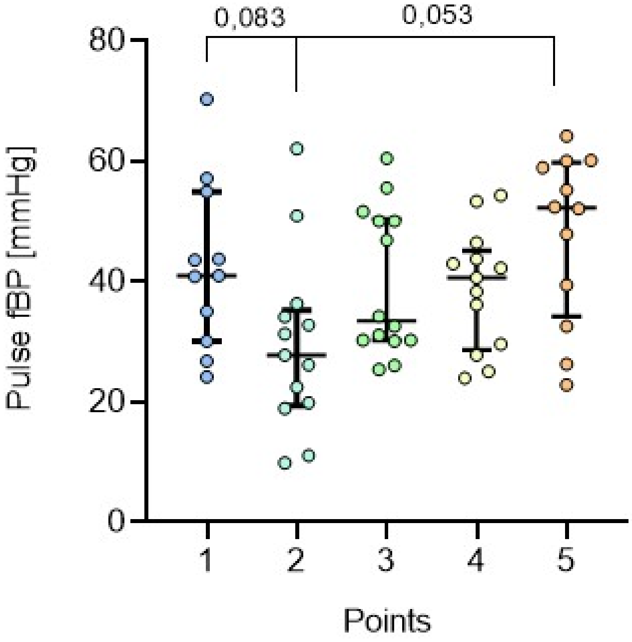


(b)

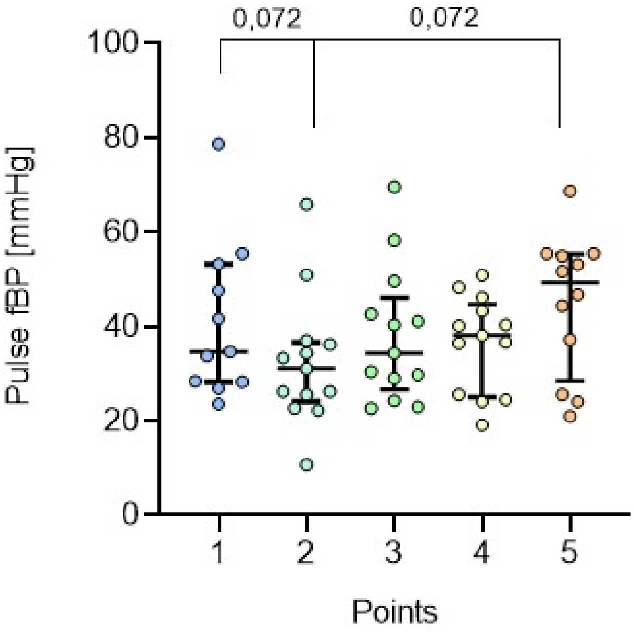


(c)

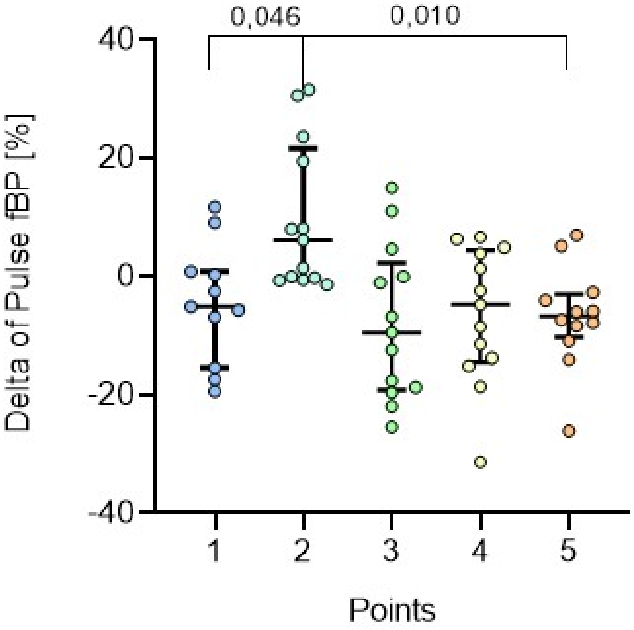
Figure 1. Dynamics of pulse fBP in different groups: the "ice" group is indicated in blue, the "laboratory" group is indicated in brown. (a) when testing under baseline conditions (at rest), (b) when testing under conditions of controlled respiration (breathing with a frequency of 6 cycles per minute), (c) the degree of change (in %) in pulse fBP during the transition from a resting state to controlled breathing. Statistical significance: * – $p<0.05$ according to Dunn's test.



(a)



(b)



(c)

Figure 2. Dynamics of pulse fBP in the total sample. (a) when testing under baseline conditions (at rest), (b) when testing under conditions of controlled respiration (breathing with a frequency of 6 cycles per minute), (c) the degree of change (in %) in pulse fBP during the transition from a resting state to controlled breathing. Statistical significance: * – $p<0.05$ according to Dunn's test.

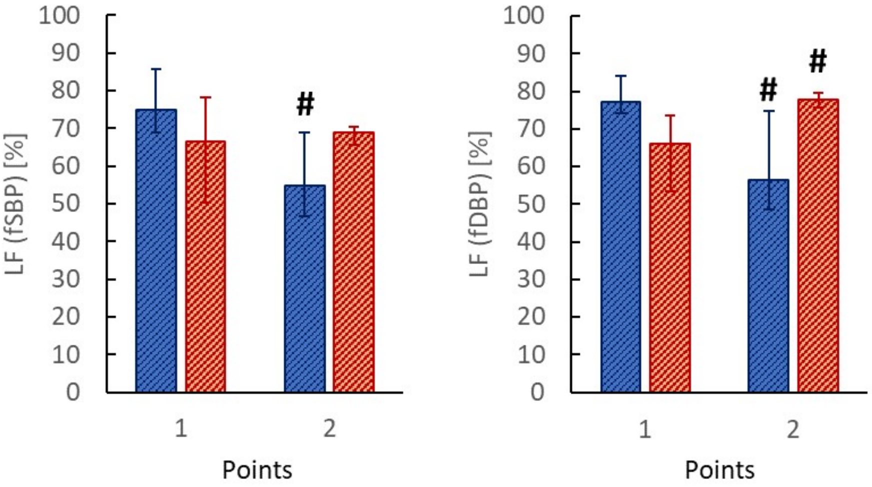


Figure 3. Dynamics of the relative power of the LF range in the spectra of variability of fSBP (left) and fDBP (right) from point 1 to point 2. Statistical significance: * – $p<0.05$ by Wilcoxon test.

Discriminant analysis applied for evaluation of changes in indicators (reactivity) during transition from background testing to controlled respiration test also showed that significant changes occurred only in group "laboratory": Wilks' Lambda =0.093; $F_{(28,\ 62)} = 2.081$; $p<0.008$; significant indicators were pulse fBP ($p=0.004$) and absolute (in mm Hg2) power of the LF range of the fDBP variability spectrum (LFD, $p=0.008$). In group "ice", the changes were at the level of a trend: Wilks' Lambda =0.501; $F_{(12,\ 71)} = 1.787$; $p<0.066$; pulse fBP was the only significant indicator ($p=0.028$).

Friedman's test revealed dynamics of pulse fBP only in the total sample (χ^2 (n=9, df=4) = 12.71; p=0.012), but not in group "laboratory" (χ^2 (n=5, df=4) = 5.76; p=0.217) and group "ice" (χ^2 (n=4, df=4) = 8.00; p=0.091) separately; there were also no differences between the groups ($F_{(4,\ 28)}$ = 1.481; p=0.234). Pairwise comparisons according to the Dunn's test for the total sample showed a statistically significant increase in the reactivity of the pulse fBP from point 1 to point 2 followed by a decrease in this indicator to point 5 (Figure 2, c). This regularity was also found within the groups (Figure 1, c).

Fluctuations in other indicators were statistically insignificant.

4. Discussion

In our work, we studied manifestations of urgent adaptation to the conditions of the North. We found no dynamic shifts in the basic cardiovascular system parameters measured by a pressure monitor and in indicators of cardiac performance, which is consistent with our previous results obtained during short-term (3–4 weeks) high-latitude marine Arctic expeditions [36].

We revealed no changes in HRV indicators, which is consistent with the observations of colleagues during Antarctic expeditions [14]. However, some authors described such shifts [11].

In our previous studies, ambiguous results were obtained for the HRV indicators. For instance, during the marine expedition to the Franz Josef Islands in 2017, an increase in the power of the LF range was noted while testing without a spirometric mask, whereas in 2019 the dynamics of HRV parameters was absent. It is possible that this group of indicators has high individual variability, and dynamic shifts occur not in all examinees [18].

Dynamic shifts in diastolic BP were more reproducible: we have described an increase in this indicator measured with a pressure monitor in 2017 and an increase in the maximum of fDBP value in SACR in 2019. In this study, we observed the dynamics of pulse fBP: a decrease in the 3-week interval from point 1 to point 2 in group “ice”, which is close to the duration of marine expeditions.

A decrease in the pulse BP in healthy individuals is usually a consequence of increased diastolic BP, and its increase is a consequence of increased systolic BP [40]. Continuous fBP registration by the SACR method increased the possibility of detecting these shifts. In general, pulse pressure arises from the interaction of cardiac output (stroke volume) and the properties of the arterial circulation [41]. In our work, no changes in cardiac performance were detected, so we have every reason to believe that the shifts in pulse BP in this case are primarily determined by changes in the functional state of blood vessels. These changes are more likely to be recorded on relatively small vessels, e.g. on fingers, in the form of corresponding manifestations of fBP parameters [42]. This is probably why we detected shifts in diastolic BP only by the SACR method with a finger sensor, but not when measuring BP with a conventional pressure monitor on larger vessels of the shoulder. It should be emphasized that the detected shifts in pulse BP did not exceed the normal range: from 25% ADS to 100 mm Hg [43].

In the obtained data, we can identify two distinct clusters.

First, we have found that the adaptive processes in overwinterers with different types of activity proceed in different ways. The participants working primarily indoors (group "laboratory") demonstrated shifts similar to those observed in members of long-term Antarctic expeditions: an increase in the sympathetic component in the autonomic regulation of the cardiovascular system [9–11]. In our case, this was recorded in the test with controlled respiration, with respect to fDBP, with a simultaneous increase in pulse fBP. This dynamic was observed after the initial adaptation period until the end of observations (point 5). It is possible that with a longer stay (12–14 months), such changes can transform into an increase in fSBP, as it was described for members of Antarctic expeditions.

In members of the NP-41 expedition, who worked mainly outdoors (group “ice”), the initial adaptation period was characterized by a decrease in pulse fBP, both at rest and during controlled respiration. The results of the respiratory test indicated possible causes of this phenomenon: a decrease in the relative power of the LF range (a correlate of sympathetic activity in the autonomic regulation of BP) in the fSBP and fDBP spectra. This reaction is similar to urgent adaptive changes in polar divers [23] and in people exposed to cold in a cold chamber [25]. At later terms, from point 2 to point 5, no dynamics of fBP and its variability indicators was observed.

Second, we identified some shifts that did not depend on the type of occupational activity: in point 2 (3 weeks after the start of work on NP-41), an increase in the reactivity of only one significant indicator, pulse fBP, was noted in both experimental groups during the test with controlled respiration. This fact probably reflects adaptation of the overwinterers to a new place of work. The presence of an adaptation period during the first month of the Antarctic expedition was described previously [11].

Repeated registration of the cardiovascular system parameters during overwintering on NP-41 revealed nonlinear nature of their changes, which was consistent with our earlier results obtained during marine expedition to the North [41] and with the reports of foreign colleagues [13].

As in earlier studies, records made under conditions of the respiratory test had higher informative value than records made at rest. In particular, during the respiratory test we detected not only changes in fDBP, but also dynamic shifts in the spectral parameters of fBP variability, indicating possible physiological mechanisms of this process, in particular, the involvement of the sympathetic component of autonomic regulation in the process. It is known that pathologically enhanced sympathetic activity is often the cause of hypertension [34, 44]. In turn, arterial hypertension itself is the cause of excess mortality [45] and a risk factor of other cardiovascular diseases [46, 47]. Unfortunately, there is a high risk of missing the signs of this disease during routine blood pressure measurement [45], which may explain the existence of a high proportion (up to 20%) of undiagnosed hypertension [48]. In this context, our data show the possibility of using this respiratory test as a stress test and indicate which indicators are the most sensitive and informative for clinicians.

5. Conclusions

The results obtained in our study indicate that during overwintering in the North, pronounced shifts occur in the human body, which can be classified as adaptation to harsh climatic and geographical conditions. The results of tests with controlled respiration attest to the involvement of the sympathetic autonomic regulation in the formation of the observed shifts. The pattern of adaptive changes depends on the type of occupational activity.

According some reports, changes in the indicators of the cardiovascular system in longer Antarctic expeditions (up to 14 months) are most pronounced during the last 3–4 months. Therefore, our observations need to be continued.

List of Abbreviations

NP-41 – polar station North Pole 41; SACR – spiroarteriocardiorhythmograph (instrument complex).

IL-8 – Interleukin 8; VEGF – Vascular Endothelial Growth Factor.

HRV – Heart Rate Variability; BP – Blood Pressure; fBP – finger BP; fSBP – systolic fBP; fDBP – diastolic fBP.

RMSSD – Root Mean Square of Successive Variances of NN intervals; SDNN – Standard Deviation of NN intervals; pNN50 – the percentage of successive normal cardiac NN intervals greater than 50 msec.

HRV spectral indicators: TP – total spectral power (ms^2), HF and HF% – absolute (ms^2) and relative (%) powers of standard high frequencies (0,15–0,40 Hz) spectral range, LF and LF% – absolute (ms^2) and relative (%) powers of standard low frequencies (0,04–0,15 Hz) spectral range, VLFS and VLFS%) – absolute (ms^2) and relative (%) powers of standard very low frequencies (0,015–0,04 Hz) spectral range.

fSBP variability spectral indicators: HFS, HFS% –absolute (mmHg^2) and relative (%) powers of standard HF spectral range, LFS and LFS% – absolute (mmHg^2) and relative (%) powers of standard LF spectral range, VLF and VLF%) – absolute (mmHg^2) and relative (%) powers of standard VLF spectral range.

fDBP variability spectral indicators: HFD, HFD% – absolute (mmHg^2) and relative (%) powers of standard HF spectral range, LFD and LFD% – absolute (mmHg^2) and relative (%) powers of standard LF spectral range, VLFD and VLFD%) – absolute (mmHg^2) and relative (%) powers of standard VLF spectral range.

Funding

The study was realized within the framework of a State Assignment of Institute of General Pathology and Pathophysiology on the topic: "Assessment of adaptive responses of the body to the action of physicochemical and environmental factors" (No. FGFU-2022-0010).

Acknowledgements

The authors thank Marina Demorzhi for her help in preparing equipment and materials for conducting research on the expedition. We are very grateful to Elena Pozdeeva for her translation and constructive suggestions to improve this paper.

REFERENCES

[1] V. I. Hasnulin, [Human health and cosmogeohysical North factors], Ekologiya cheloveka (Human Ecology), No.12, 3–13, 2013. (Article in Russian)

[2] 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, Vol.17, No.3, 354–381, 1996. PMID: 8737210.

[3] F. Shaffer, J. P. Ginsberg, An Overview of Heart Rate Variability Metrics and Norms, Front Public Health, No.5, 258, 2017. DOI: 10.3389/fpubh.2017.00258

[4] R. M. Baevsky, A. G. Chernikova, Heart rate variability analysis: physiological foundations and main methods. Cardiometry, No.10, 66, 2017. https://doi.org/10.12710/cardiometry.2017.10.6676

[5] G. Parati, J. P. Saul, M. Di Rienzo, G. Mancia, Spectral analysis of blood pressure and heart rate variability in evaluating cardiovascular regulation. A critical appraisal. Hypertension, Vol.25, No.6, 1276–1286, 1995. https://doi.org/10.1161/01.hyp.25.6.1276

[6] H. M. Stauss, Identification of Blood Pressure Control Mechanisms by Power Spectral Analysis, *Clin Exp Pharmacol Physiol,* Vol.34, No.4, 362–368, 2007. https://doi.org/10.1111/j.1440-1681.2007.04588.x

[7] J. K. Ruffle, H. Hyare, M. A. Howard, A. D. Farmer, A. V. Apkarian, S. C. R. Williams, Q. Aziz, P. Nachev, The autonomic brain: Multi-dimensional generative hierarchical modelling of the autonomic connectome, Cortex, Vol.143, 164–179, 2021.https://doi.org/10.1016/j.cortex.2021.06.012

[8] P. S. Matusik, C. Zhong, P. T. Matusik, O. Alomar, P. K. Stein, Neuroimaging Studies of the Neural Correlates of Heart Rate Variability: A Systematic Review, J Clin Med, Vol.12, No.3, 1016, 2023. https://doi.org/10.3390/jcm12031016

[9] M. A. Maggioni, G. Merati, P. Castiglioni, S. Mendt, H. C. Gunga, A. C. Stahn, Reduced vagal modulations of heart rate during overwintering in Antarctica, Sci Rep, Vol.10, No.1, 21810, 2020. https://doi.org/10.1038/s41598-020-78722-3

[10] V. V. Kalnish, G. Y. Pyshnov, E. V. Moiseyenko, V. V. Opanasenko, L. M. Alekseyeva, L. G. Vysotska, [Heart rate regulation during adaptation to conditions in Antarctica]. Fiziol Zh (1994), Vol.62, No.3, 20–29, 2016. https://doi.org/10.15407/fz62.03.020 (Article in Ukrainian)

[11] K. Harinath, A. S. Malhotra, K. Pal, R. Prasad, R. Kumar, R. C. Sawhney, Autonomic nervous system and adrenal response to cold in man at Antarctica, Wilderness Environ Med, Vol.16, No.2, 81–91, 2005. https://doi.org/10.1580/pr30-04.1

[12] L. Del Coco, M. Greco, A. Inguscio, A. Munir, A. Danieli, L. Cossa, D. Musarò, M. R. Coscia, F. P. Fanizzi, M. Maffia, Blood Metabolite Profiling of Antarctic Expedition Members: An 1H NMR Spectroscopy-Based Study, Int J Mol Sci, Vol.24, No.9, 8459, 2023. https://doi.org/10.3390/ijms24098459

[13] M. M. Moraes, R. S. Bruzzi, Y. A. T. Martins, T. T. Mendes, C. B. Maluf, R. V. P. Ladeira, C. Núñez-Espinosa, D. D. Soares, S. P. Wanner, R. M. E. Arantes, Hormonal, autonomic cardiac and mood states changes during an Antarctic expedition: From ship travel to camping in Snow Island, Physiol Behav, Vol.224, 113069, 2020. https://doi.org/10.1016/j.physbeh.2020.113069

[14] M. M. Moraes, T. T. Mendes, L. Borges, A. L. Marques, C. Núñez-Espinosa, D. A. P. Gonçalves, C. B. Simões, T. S. Vieira, R. V. P. Ladeira, T. G. B. Lourenço, D. V. Ribeiro, E. Hatanaka, D. Heller, R. M. E. Arantes, A 7-Week Summer Camp in Antarctica Induces Fluctuations on Human Oral Microbiome, Pro-Inflammatory Markers and Metabolic Hormones Profile, Microorganisms, Vol.11, No.2, 339, 2023. https://doi.org/10.3390/microorganisms11020339

[15] B. Bhushan, D. Upadhyay, U. Sharma, N. Jagannathan, S. B. Singh, L. Ganju, Urine metabolite pr ofiling of Indian Antarctic Expedition members: NMR spectroscopy-based metabolomic investigation, Heliyon, Vol.7, No.5, e07114, 2021. https://doi.org/10.1016/j.heliyon.2021.e07114

[16] Y. H. Lu, Y. L. Xiong, L. Fang, N. Chen, C. L. Xu, [Effects of rapid and progressive ascent to Tibet plateau on cardiovascular function and stress factors of pre-selected expeditioners for Chinese Antarctic expedition for Kunlun station], Zhongguo Ying Yong Sheng Li Xue Za Zhi, Vol.36, No.5, 419–42, 2020. https://doi.org/10.12047/j.cjap.5910.2020.089 (Article in Chinese)

[17] J. W. Castellani, A. J. Young, Human physiological responses to cold exposure: Acute responses and acclimatization to prolonged exposure, Auton Neurosci, Vol.196, 63–74, 2016. https://doi.org/10.1016/j.autneu.2016.02.009

[18] F. Haman, S. C. S. Souza, J. W. Castellani, M. P. Dupuis, K. E. Friedl, W. Sullivan-Kwantes, B. R. M. Kingma, Human vulnerability and variability in the cold: Establishing individual risks for cold weather injuries, Temperature (Austin), Vol.9, No.2, 158–195, 2022. https://doi.org/10.1080/23328940.2022.2044740

[19] D. G. Edwards, M. S. Roy, R. Y. Prasad, Wave reflection augments central systolic and pulse pressures during facial cooling, Am J Physiol Heart Circ Physiol, Vol.294, No.6,

H2535–H2539, 2008. https://doi.org/10.1152/ajpheart.01369.2007

[20] K. Prakash, A. Thakur, A. S. Malhotra, Association of heart rate variability, blood pressure variability, and baroreflex sensitivity with gastric motility at rest and during cold pressor test, Gastroenterol Hepatol Bed Bench, Vol.14, No.2, 132–140, 2021. PMID: 33968340.

[21] N. B. Pankova, [Functional tests for the assessment of the healthy people state using heart rate variability], Ross Fiziol Zh Im I M Sechenova, Vol.99, No.6, 682–696, 2013. PMID: 24459877. (Article in Russian)

[22] J. Jarczewski, A. Furgała, A. Winiarska, M. Kaczmarczyk, A. Poniatowski, Cardiovascular response to different types of acute stress stimulations, Folia Med Cracov, Vol.59, No.4, 95–110, 2019. https://doi.org/10.24425/fmc.2019.131383

[23] R. V. Lundell, T. Ojanen, A systematic review of HRV during diving in very cold water, Int J Circumpolar Health, Vol.82, No.1, 2203369, 2023. https://doi.org/10.1080/22423982.2023.2203369

[24] R. V. Lundell, A. K. Räisänen-Sokolowski, T. K. Wuorimaa, T. Ojanen, K. I. Parkkola, Diving in the Arctic: Cold Water Immersion's Effects on Heart Rate Variability in Navy Divers, *Front Physiol*, Vol.10, 1600, 2020. https://doi.org/10.3389/fphys.2019.01600

[25] D. B. Demin, [Cardiovascular response to whole-body cold exposure in humans with different initial autonomic tone], Med Biol Socio Psychol Problem Safety Emerg Sit, No.2, 93–99, 2022. https://doi.org/10.25016/2541-7487-2022-0-2-93-99 (Article in Russian)

[26] Y. P. Liu, Y. C. Lin, C. C. Lin, S. H. Tsai, C. S. Tung, Spectral analysis of cardiovascular oscillations in the 7-day regimen of losartan administration with and without cold stress, Chin J Physiol, Vol.65, No.4, 171–178, 2022. https://doi.org/10.4103/0304-4920.354802

[27] Y. P. Liu, Y. H. Lin, Y. C. Chen, P. L. Lee, C. S.Tung, Spectral analysis of cooling induced hemodynamic perturbations indicates involvement of sympathetic activation and nitric oxide production in rats, Life Sci, Vol.136, 19–27, 2015.https://doi.org/10.1016/j.lfs.2015.06.011

[28] G. Yang, Y. Wan, Y. Zhu, Angiotensin II – An important stress hormone, Biol Signals, Vol.5, No.1, 1–8, 1996. https://doi.org/10.1159/000109168

[29] A. V. Rubinskii, N. S. Linkova, N. I. Chalisova, L. A. Noskin, V. N. Marchenko, V. K. Khavinson, [Epigenetic regulation of adaptogenesis by pathology and aging], Uspekhi Gerontol, Vol.34, No.1, 10–17, 2021. https://doi.org/10.34922/AE.2021.34.1.001 (Article in Russian)

[30] L. Markel, O. E. Redina, Epigenetic Mechanisms of Blood-Pressure Regulation, *Mol Biol*, Vol.52, 151–164, 2018. https://doi.org/10.1134/S0026893317050120

[31] M. M. B. Christensen, C. S. Hansen, J. Fleischer, D. Vistisen, S. Byberg, T. Larsen, J. C. Laursen, M. E. Jørgensen, Normative data on cardiovascular autonomic function in Greenlandic Inuit, BMJ Open Diabetes Res Care, Vol.9, No.1, e002121, 2021. https://doi.org/10.1136/bmjdrc-2021-002121 Erratum in: BMJ Open Diabetes Res Care, Vol.12, No.1, 2024. PMID: 34598933.

[32] V. Averyanova, A. L. Maksimov, [Cardiohemodynamic and heart rate variability changes observed in the North newcomer Caucasians and people born to them in the 1st – 2nd generations at active orthostatic test exposure], Siberian Sci Med J, Vol.41, No.3, 45–52, 2021. https://doi.org/10.18699/SSMJ20210306 (Article in Russian)

[33] V. Averyanova, S. I. Vdovenko, [Indicators of the cardiovascular system in Caucasoid residents of the Magadan Region, depending on the duration of residence in the northeast of Russia], Yakut Med J, No.4, 89–91, 2018. https://doi.org/10.25789/YMJ.2018.64.27 (Article in Russian)

[34] G. Grassi, R. Dell'Oro, F. Quarti-Trevano, J. Vanoli, S. Oparil, Sympathetic Neural Mechanisms in Hypertension: Recent Insights, *Curr Hypertens Rep*, Vol.25, No.10, 263–270, 2023. https://doi.org/10.1007/s11906-023-01254-4

[35] V. V. Pivovarov, A Spiroarteriocardiorhythmograph, *Biomed Eng*, Vol.40, 45–47, 2006. https://doi.org/10.1007/s10527-006-0038-2

[36] N. B. Pankova, I. B. Alchinova, A. B. Cherepov, E. N. Yakovenko, M. Yu. Karganov, Cardiovascular system parameters in participants of Arctic expeditions, *Int J Occup Med Environ Health*, Vol.33, No.6, 819–828, 2020. https://doi.org/10.13075/ijomeh.1896.01628

[37] A. I. Trukhanov, N. B. Pankova, N. N. Khlebnikova, M. Yu. Karganov, The use of spiroarteriocardiorhythmography as a functional test for estimating the state of the cardiorespiratory system in adults and children, Human Physiology, Vol.33, No.5, 585–594, 2007. https://doi.org/10.1134/S036211970705009X

[38] N. B. Pankova, E. N. Arkhipova, I. B. Alchinova, M. Yu. Karganov, A. G. Fesenko, A. D. Fesyun, K. S. Ternovoy, A. A. Abakumov, [Comparative analysis of methods for express assessment of the functional state of the cardiovascular system], Bull Rehab Med, No.6(46), 60–63, 2011 (Article in Russian)

[39] A. Rydlewska, B. Ponikowska, L. Borodulin-Nadzieja, W. Banasiak, E. A. Jankowska, P. Ponikowski, [Assessment of the functioning of autonomic nervous system in the context of cardiorespiratory reflex control], Kardiol Pol, Vol.68, No.8, 951–957. 2010. PMID: 20730734. (Article in Polish)

[40] R. V. Khursa, [Pulse pressure of the blood: role in the hemodynamic and applied possibilities in functional diagnostics], Med Novosti, No.4, 13–18, 2013. (Article in Russian)

[41] A. M. Dart, B. A. Kingwell, Pulse pressure--a review of mechanisms and clinical relevance, J Am Coll Cardiol, Vol.37, No.4, 975–984, 2001. https://doi.org/10.1016/s0735-1097(01)01108-1

[42] C. Flint, C. Conell, X. Ren, N. M. Banki, S. L. Chan, V. A. Rao, R. B. Melles, D. L. Bhatt, Effect of Systolic and Diastolic Blood Pressure on Cardiovascular Outcomes, N Engl J Med, Vol.381, No.3, 243–251, 2019. https://doi.org/10.1056/NEJMoa1803180

[43] T. D. Homan, S. J. Bordes, E. Cichowski, Physiology, Pulse Pressure, Online Available: https://www.ncbi.nlm.nih.gov/

books/NBK482408/ (accessed on 10.02.2024).

[44] F. Quarti-Trevano, G. Seravalle, G. Grassi, Clinical Relevance of the Sympathetic-Vascular Interactions in Health and Disease, Biomedicines, Vol.9(8). 1007, 2021. https://doi.org/10.3390/biomedicines9081007

[45] L. C. Armitage, M. E. Whelan, P. J. Watkinson, A. J. Farmer, Screening for hypertension using emergency department blood pressure measurements can identify patients with undiagnosed hypertension: A systematic review with meta-analysis, J Clin Hypertens (Greenwich), Vol.21, No.9, 1415–1425, 2019. https://doi.org/10.1111/jch.13643

[46] P. MacDonald, E. Alsrayheen, C. Taylor, R. Baillie, C. Ferguso, The Effectiveness of Community-based Cardiovascular Risk Factors Screening Program in Rural Community Shopping Mall: Health Takes Heart Study, Universal Journal of Public Health, Vol.11, No.2, 232–241, 2023. https://doi.org/10.13189/ujph.2023.110205

[47] H. Mahamane, B. G. Damien, I. Alkassoum, Z. Mamoudou, B. Aguemon, Factors Associated with Stroke in Adult Patients in Two Referral Hospitals in Niamey from 2019 to 2021, Universal Journal of Public Health, Vol.11, No.5, 724–730, 2023. https://doi.org/10.13189/ujph.2023.110522

[48] L. K. Solbana, E. E. Chaka, D. E. Tola Undiagnosed hypertension and its associated factors in Ethiopia: A systematic review and meta-analysis, Health Sci Rep, Vol.6, No.11, e1696, 2023. https://doi.org/10.1002/hsr2.1696