This article belongs to the Special Topic Collection "Circadian Lighting Hygiene, Health, and Well-being"

Original article

Seasonal variations in the mental state and heart rate variability in adolescents residing beyond the Arctic Circle

Natalia K. Belisheva [1], Alla A. Martynova [1], Sergei N. Kolomeichuk [2]

[1] Kola Science Centre of the Russian Academy of Science, Apatity, Russia
[2] University Research Institute of Biotechnology, Tyumen State Medical University, Tyumen, Russia

Received 6 November 2024, Revised 18 November 2024, Accepted 29 November 2024

Abstract: *Background* — Residence beyond the Arctic Circle is associated with a distinct condition, Polar Tension Syndrome (PTS), which shares similarities with Seasonal Affective Disorder (SAD). However, the interplay of mental state and heart rate variability within the context of seasonal photoperiodicity in both PTS and SAD remains poorly understood.

Objectives — This study investigated the effects of polar photoperiodicity on the mental and physiological states of male adolescents living in the Kola Peninsula, Russia (67°34′ N, 33°23′ E), a region beyond the Arctic Circle.

Methods — Mental state was assessed using the State-Trait Anxiety Inventory (STAI) and the Self-Esteem of health, Activity, and Mood (SAM) scales. Heart rate variability (HRV) indices provided objective measures of the psychophysiological state.

Results — Significant associations were found between state and trait anxiety (StA and TrA) and seasonal photoperiodicity in adolescents residing beyond the Arctic Circle. Reduced parasympathetic (HF) and increased sympathetic (LF) Autonomic Nervous System (ANS) contributions to heart rate (HR) regulation during the polar night may underlie the physiological manifestations of polar tension syndrome (PTS) and seasonal sffective disorder (SAD), both characterized by elevated anxiety. Analysis revealed monthly fluctuations in the dominance of HF and LF contributions to HR regulation, with LF predominating during the polar night and in March.

Conclusion — This study demonstrates an association between state and trait anxiety (StA and TrA), heart rate regulation, and seasonal photoperiodicity in adolescents residing beyond the Arctic Circle. Adolescents with anxiety and low parasympathetic (HF) HRV activity show an increased risk of developing PTS and SAD symptoms.

Keywords: mental state, heart rate variability, adolescents, Arctic Circle, photoperiodicity.

Cite as Belisheva NK, Martynova AA, Kolomeichuk SN. Seasonal variations in the mental state and heart rate variability in adolescents residing beyond the Arctic Circle. *Russian Open Medical Journal* 2024; 13: e0416.

Correspondence to Natalia K. Belisheva. E-mail: natalybelisheva@mail.ru.

Introduction

Residence beyond the Arctic Circle exposes individuals to an extreme high-latitude environment [1, 2], characterized by specific photoperiodicity – the varying duration of daylight (including polar night and polar day) [3-6]. Above the Arctic Circle (66.33° N), the sun remains above the horizon for at least one 24-hour period annually and, conversely, below the horizon for at least one 24-hour period annually [5].

Decreased daylight hours during the polar night are associated with a distinct mental and physiological condition known as *Polar Tension Syndrome* (PTS) [7-9]. PTS manifests as shortness of breath, mental instability, fatigue, irritability, loss of appetite, sleep disorders, decreased activity, and depression [10], sharing similarities with seasonal affective disorder (SAD) [11-13]. According to Rosenthal [14], 6.1% of the population of the USA suffers from SAD, and 14.3% suffers from sub-SAD. The pathogenesis of SAD remains unclear, although light deficiency in fall and winter may play a significant role [14]. Sleep disturbances, insomnia, mood disturbances, depression, hostility, and irritability have been observed in Arctic and Antarctic crews and termed winter-over syndrome [3, 6, 15-18]. Lingjærde et al. [19] observed the typical midwinter insomnia in northern Norway. In fact, PTS, SAD, winter-over syndrome, and midwinter insomnia share similar mental and psychophysiological features associated with decreased seasonal daylight.

The relationship between mental and physiological disorders and reduced daylight is expected to be strongest beyond the Arctic Circle. However, supporting evidence is limited, primarily derived from studies of polar explorers and observations of SAD, where the relationship between SAD, latitude, and reduced daylight remains poorly understood [20-29].

The lack of an explicit link between SAD and latitude may be due to studies focusing on adult populations, in whom social factors may outweigh the influence of daylight duration. Therefore, examining the association between children's mental state and photoperiodicity might yield more robust results.

Indeed, epidemiological and clinical data demonstrate a strong association between SAD and childhood and adolescence [30–32]. According to Carskadon and Acebo [31], about 3–4% of American schoolchildren suffer from SAD. This syndrome often begins in childhood (23%) and is associated with eating disorders (25.5%) [33]. An association between seasonal photoperiodicity, attention deficit, hyperactivity disorders, nocturnal mobility, and daytime arousal was also found in children in Canada [34]. The studies carried out in Finland have revealed the problem of SAD among seventh and ninth graders [32]. It was found that during February and March, girls residing at the 67th latitude reported a higher prevalence of seasonal distress compared to those residing at the 60th latitude. The authors conclude that pediatric SAD and related problems among adolescents must be recognized. Seasonal alterations in child and adolescent behavior are not well understood and need to be investigated more thoroughly [32].

To address inconsistencies in studies examining the relationship between psychophysiological disorders, latitude, and seasonal photoperiodicity, a novel methodological approach is needed. This approach should incorporate not only subjective assessment of mental state but also objective measurement of psychophysiological indicators, such as heart rate variability (HRV) [35, 36].

Currently, emotional dysfunctions are considered closely linked to cardiac psychophysiology [37]. Anatomical and psychophysiological evidence implicates the autonomic nervous system is an essential underlying mechanism involved in emotion regulation, including behavior, anxiety and affective disorder [38, 39, 40, 41]. Hence, vagal modulation of cardiac activity (HRV) is conceived as a transdiagnostic biomarker of psychopathology [37, 42] and it is an essential modulator of emotion and emotion regulation.

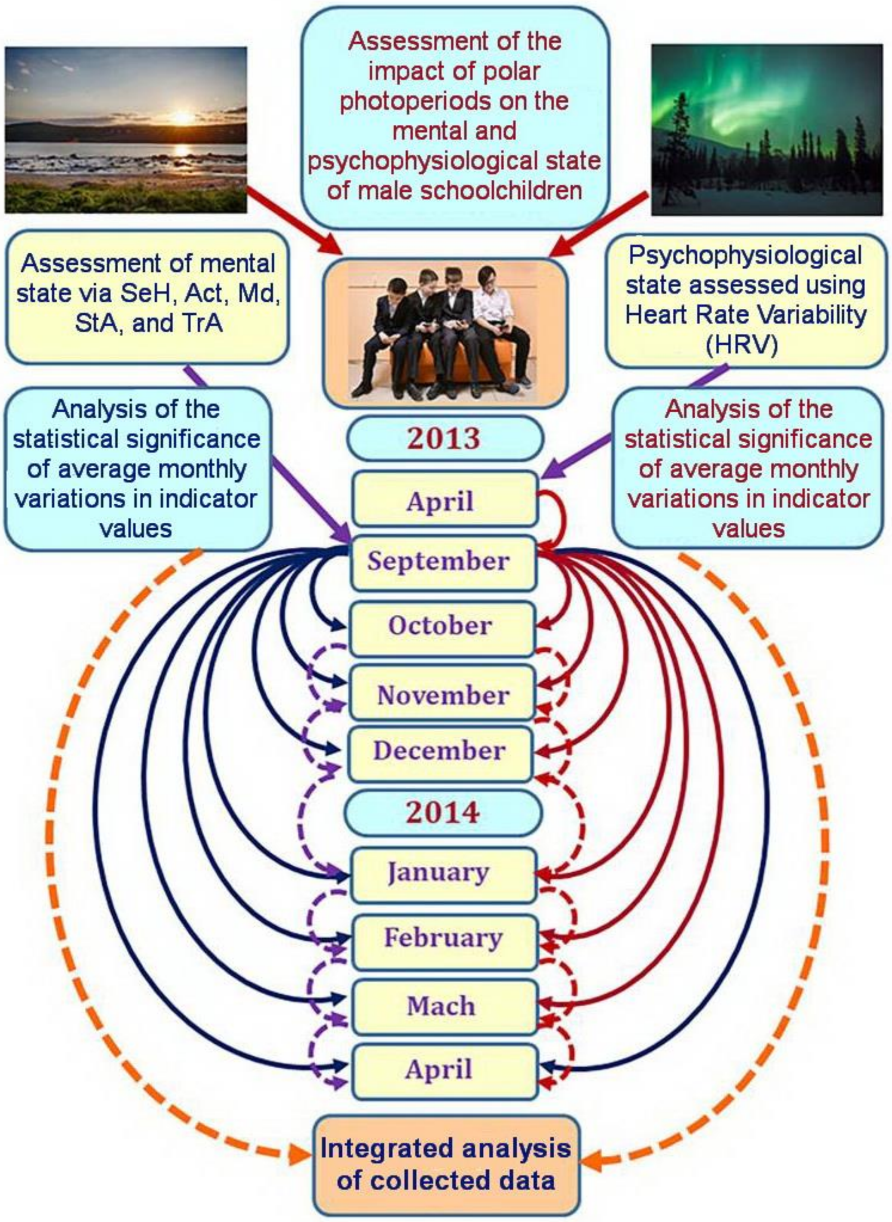

Figure 1. **Study Design. The details are elucidated within the text.**

ISSN 2304-3415, Russian Open Medical Journal
2024. Volume 13. Issue 4 (December). Article CID e0416
DOI: 10.15275/rusomj.2024.0416

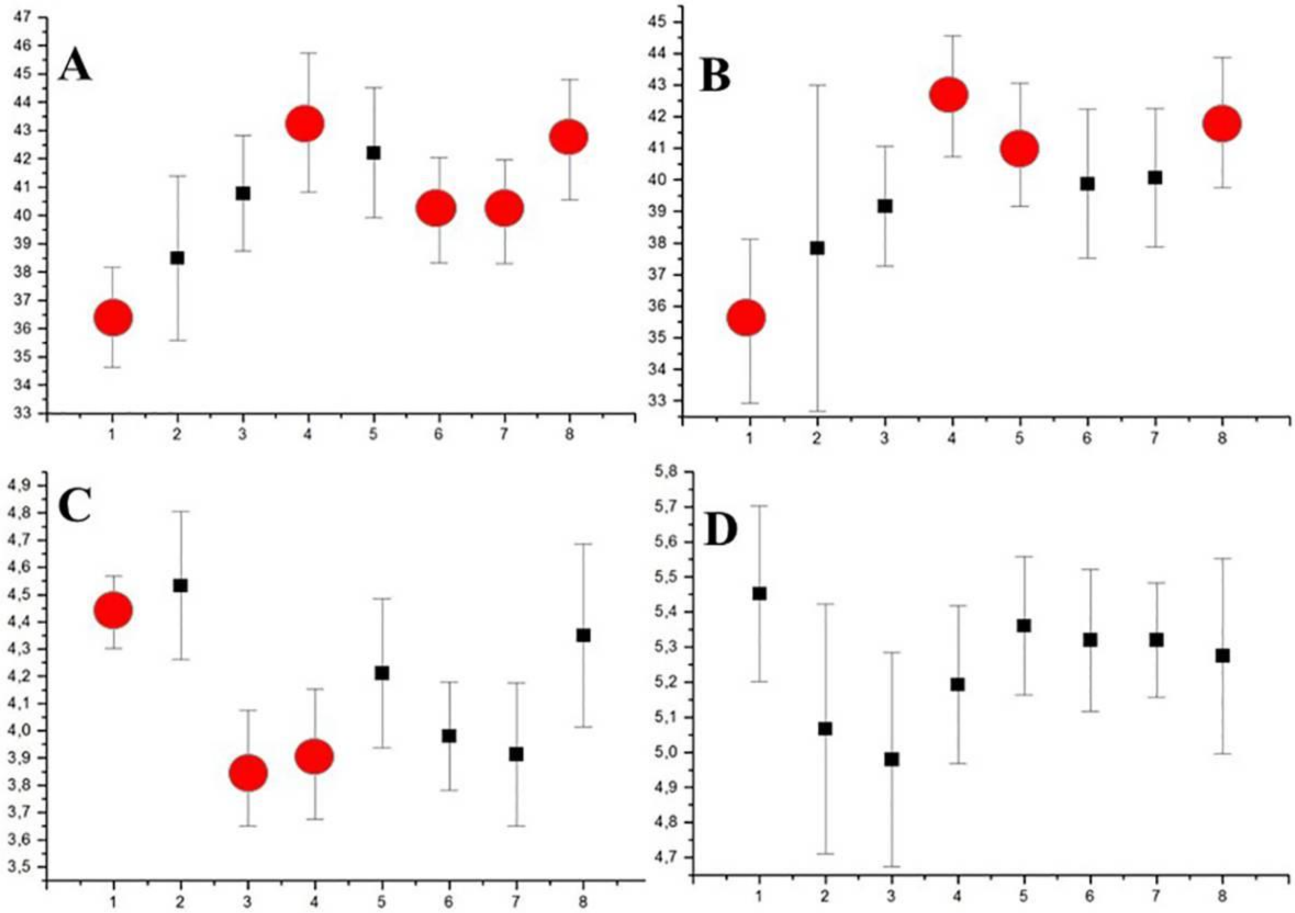

Figure 2. Monthly average values of StA (A), TrA (B), Act (C), Md (D) in adolescents. The x-axis represents the months of the year, where 1=September; 2=October; 3=November; 4=December (2013); 5=January; 6=February; 7=March; 8=April (2014). Y-axis: values of indicators (M±SEM), points. The circles indicate statistically significant differences ($p<0.05$) in relation to the corresponding indicators in September.

StA, state anxiety; TrA, trait anxiety; Act, activity; Md, mood.

Table 1. The correlation coefficients between daily average values (n=129) of state anxiety (StA), trait anxiety (TrA), self-esteem of health (SeH), activity (Act), and mood (Md)

	Mean	*Sd(±)*	*StA*	*TrA*	*ShE*	*Act*	*Md*
StA	40.71	6.05	1.00	0.92*	-0.48*	-0.57*	-0.41*
TrA	39.50	5.58	0.92*	1.00	-0.42*	-0.52*	-0.33
ShE	5.20	0.53	-0.48*	-0.42*	1.00	-0.01	0.67*
Act	4.04	0.54	-0.57*	-0.52*	-0.01	1.00	-0.04
Md	5.17	0.53	-0.41*	-0.33	0.67*	-0.04	1.00

* Correlation coefficients in bold italics are indicated at the $p < 0.05$ level of statistical significance. StA, state anxiety; TrA, trait anxiety; she, self-esteem of health; Act, activity; Md, mood.

This study employed a comprehensive approach to investigate the effects of photoperiodicity on the psychophysiological state of adolescents residing beyond the Arctic Circle. Mental state indicators – including state-trait anxiety, self-esteem of health (SeH), activity (Act), and mood (Md) – along with HRV indices (as transdiagnostic biomarkers of psychophysiology), were measured monthly for nine months to assess the relationship between the human physiological state and high-latitude photoperiodicity. A better understanding of the etiology of seasonal mental disorders will facilitate the development of preventive interventions to address behavioral problems in at-risk adolescents. This is particularly critical for adolescents prone to addictive behaviors, which can be exacerbated during specific seasons of the year.

Material and Methods

Study Design

This study investigated the effects of polar photoperiods on the mental and psychophysiological states of male schoolchildren residing on the Kola Peninsula, Russia (67°34′N, 33°23′E). A longitudinal, observational cohort study design was employed, encompassing two data collection periods: April 2013 and the period spanning September 2013 through April 2014 (*Figure 1*).

Mental state assessments were performed monthly from September 2013 to April 2014, and HRV measurements were collected monthly from April 2013 to April 2014, excluding school vacation periods. Multiple assessments of both mental state and HRV were conducted during the second ten-day period of each month. The study's schedule, necessitated by school vacations and examinations, resulted in some unavoidable overlap in data collection for mental state and HRV assessments.

Average monthly values for each mental state and HRV indicator were computed by averaging the daily values across all participants. These averaged monthly values then served as the basis for longitudinal analysis to identify seasonal variations in both mental state and HRV.

ISSN 2304-3415, Russian Open Medical Journal
2024. Volume 13. Issue 4 (December). Article CID e0416
DOI: 10.15275/rusomj.2024.0416

Table 2. The percentiles for the monthly average values of StA and TrA

Months, (n)	StA					TrA				
	10	25	50	75	90	10	25	50	75	90
Sep (17)	29.0	32.0	35.0	38.0	51.0*	26.0	29.0	33.0	35.0	51.0*
Oct (6)	32.0	33.0	35.5	47.0*	48.0*	25.0	29.0	34.5	44.0	60.0*
Nov (24)	30.0	33.5	39.0	49.0*	50.0*	28.0	32.0	36.5	48.0*	52.0*
Dec (14)	30.0	37.0	46.5*	50.0*	54.0*	33.0	36.0	43.0	49.0*	51.0*
Jan (19)	30.0	33.0	43.0	50.0*	56.0*	30.0	33.0	43.0	47.0*	55.0*
Feb (16)	31.0	32.0	41.0	46.0*	50.0*	29.0	31.0	37.5	48.5*	52.0*
Mar (15)	30.0	32.0	41.0	47.0*	48.0*	31.0	32.0	40.0	47.0*	51.0*
Apr (16)	30.0	38.0	47.0*	48.5*	50.0*	31.0	35.0	42.5	48.0*	53.0*

* The indicators exceed the normal value. StA, state anxiety; TrA, trait anxiety.

Table 3. The percentiles for the monthly average values of SeH, Act, and Md

Months, (n)	SeH					Act					Md				
	10	25	50	75	90	10	25	50	75	90	10	25	50	75	90
Sep (17)	4.3	5.1	5.6	5.8	5.9	3.8*	4.1*	4.4	4.6	5.3	3.8*	4.8	5.5	6.4	6.5
Oct (6)	3.5*	4.1*	5.2	5.3	6.2	3.9*	4.1*	4.3	4.9	5.7	3.8*	4.5	5.1	5.7	6.2
Nov (24)	3.5*	4.2*	5.6	6.2	6.4	2.6*	3.1*	3.8*	4.7	5.2	3.1*	3.8*	5.4	5.8	7.0
Dec (14)	4.1*	4.4*	5.0	5.9	6.4	2.5*	3.5*	3.8*	4.4	5.1	4.2*	4.4	5.5	5.6	6.4
Jan (19)	3.8*	4.6*	5.8	6.1	6.4	2.7*	3.4*	4.4	4.7	5.5	4.0*	4.8	5.4	6.0	6.4
Feb (16)	3.7*	4.2*	5.5	5.8	6.4	3.2*	3.4*	4.2	4.5	4.8	4.2*	4.6	5.5	5.7	6.6
Mar (15)	3.8*	4.6*	5.6	5.9	6.2	2.1*	3.2*	4.2	4.7	5.0	4.4*	4.7	5.6	5.8	6.0
Apr (16)	3.7*	4.2*	5.6	6.4	6.4	2.0*	3.7*	4.4	5.0	6.4	4.0*	4.4	5.2	6.4	6.5

* The indicators are below the normal value. she, self-esteem of health; Act, activity; Md, mood.

Pairwise comparisons of monthly time series data for each subject's index values were performed to identify significant seasonal differences in mental state and HRV indices, using standard statistical criteria for significance. September values served as the baseline for assessing monthly variability of each index.

To identify correlations between indicators of mental state and separately between HRV indicators, we employed a time series analysis, whereby daily values of each indicator were averaged over a sample of subjects. In order to identify correlations between mental indices and HRV, time series of the average daily values of the indices on the same dates as the study were employed.

To examine relationships between mental state and HRV indicators, we performed a multidimensional cluster analysis employing Ward's method, with results presented as a hierarchical classification.

Study Participants

The study included 11 male schoolchildren (age 14.5±0.2 years) residing in Apatity, Murmansk region, Kola Peninsula, Russia, during 2013-2014. Participation required parental consent and classification as Grade 1 health status. The study adhered to ethical principles outlined by the UN General Assembly (1992), the Council of Europe Convention on Bioethics (1997), and the Russian Academy of Sciences Council on Bioethics (January 18, 2017). The parents of all children who participated in the study were informed about the purpose and conditions of the study and provided written consent for their child's involvement.

Research Tools

Mental State. Mental state was assessed using two questionnaires: the SAM (Self-Esteem of health (she), Activity (Act), Mood (Md)) [43, see *Supplementary 1*], which assesses mood and states, and the State-Trait Anxiety Inventory (STAI) [44], which measures anxiety levels. While administered independently, these questionnaires are frequently used in combination to provide a more comprehensive understanding of the etiology of elevated anxiety. The STAI is a 40-item self-report inventory that assesses two types of anxiety: state anxiety (StA), or anxiety related to a specific event; and trait anxiety (TrA), reflecting an individual's inherent anxiety level. StA encompasses feelings of fear, nervousness, and discomfort and is associated with the autonomic nervous system (ANS) arousal in response to perceived threats. TrA reflects a person's baseline level of stress, worry, and discomfort experienced in daily life [44]. Using the SAM questionnaire, SeH, Act, and Md scores above 4 indicate a favorable state, scores below 4 suggest an unfavorable state, and scores between 5.0 and 5.5 represent the normal range. For the State-Trait Anxiety Inventory, scores up to 30 indicate low anxiety, 31-45 moderate anxiety, and above 46 high anxiety.

Heart Rate Variability. Physiological testing was conducted using indices of heart rate variability (HRV). The methods of the Task Force on HRV were observed for short-term HRV recording [45]. Data were acquired using the Omega-Medicine (Omega-M) diagnostic suite (Dynamic Technologies LLC, Russia). HRV is a standard, reliable, and non-invasive method for quantitatively and qualitatively assessing the autonomic nervous system (ANS) function [46-48]. Heart rate (HR) regulation is mediated by the ANS and CNS, involving various humoral and reflex mechanisms. The CNS coordinates the body's overall functional activity in response to environmental influences.

HRV analysis was based on a 5-minute recording obtained during seated rest using the Omega-M system (https://dyn.ru/). Fast Fourier transformation of the recording yielded spectral power (ms^2) in the very low frequency (VLF; 0.003-0.04 Hz), low frequency (LF; 0.04-0.15 Hz), and high frequency (HF; 0.15-0.4 Hz) bands. Calculated parameters included total power spectral density (PSD=VLF+LF+HF), normalized LF (LFnu=LF×100/(PSD-VLF)), normalized HF (HFnu=HF×100/(PSD-VLF)), and the LF/HF ratio

(LFnu/HFnu). The relative contributions of each PSD component (VLF%, LF%, HF%) to the total (100%) were determined. Additionally, the Root Mean Square of Successive Differences (RMSSD) index (ms), defined as the square root of the mean of the squares of the successive differences between adjacent NN intervals, the SI (stress index), and the D-index (psychoemotional state characterization index) were utilized as indicators of psychophysiological state.

Statistical Data Processing. Descriptive statistics (mean, standard deviation, median, minimum, maximum, and 95% confidence intervals) were computed using STATISTICA 10.0 (StatSoft, Inc., USA) to characterize the sample. Normality of distributions was assessed using Kolmogorov–Smirnov, Lilliefors, and Shapiro-Wilk tests. Central tendencies and the variance of the quantitative characters with an approximately normal distribution were described using the mean and standard deviation (M±SD). The significance of differences between monthly average values of all indicators was assessed using nonparametric methods (Mann-Whitney U test, Kolmogorov-Smirnov test) as well as the t-test analysis for independent variable. Correlations among mental state indicators, among HRV indicators, and between mental state and HRV indicators were assessed using pairwise correlations and Spearman rank correlations. The differences between the average monthly values or correlation coefficients of mental state indicators and HRV were assumed to be statistically significant at the p<0.05 level. The relationships between mental state and HRV indicators were examined using multidimensional cluster analysis, with the results presented in the form of a hierarchical classification based on Ward's association rule. This approach entailed the sequential exclusion of variables with distances exceeding 1000.

Results

Mental State

Table 1 presents correlation coefficients among mental state indicators: state anxiety (StA), trait anxiety (TrA), self-esteem of health (SeH), activity (Act), and mood (Md). StA and TrA exhibited a significant positive correlation (p<0.05). Conversely, both StA and TrA showed significant negative correlations with SeH and Act, with StA also exhibiting a negative correlation with Md. These findings demonstrate a consistent pattern in the data. Table 1 demonstrates that higher anxiety levels are associated with lower SeH, Act, and Md scores, reflecting a deterioration in subjective feelings of well-being. Conversely, an increase in Md is associated with an improvement in SeH, while a decrease in Md is associated with a decline in SeH.

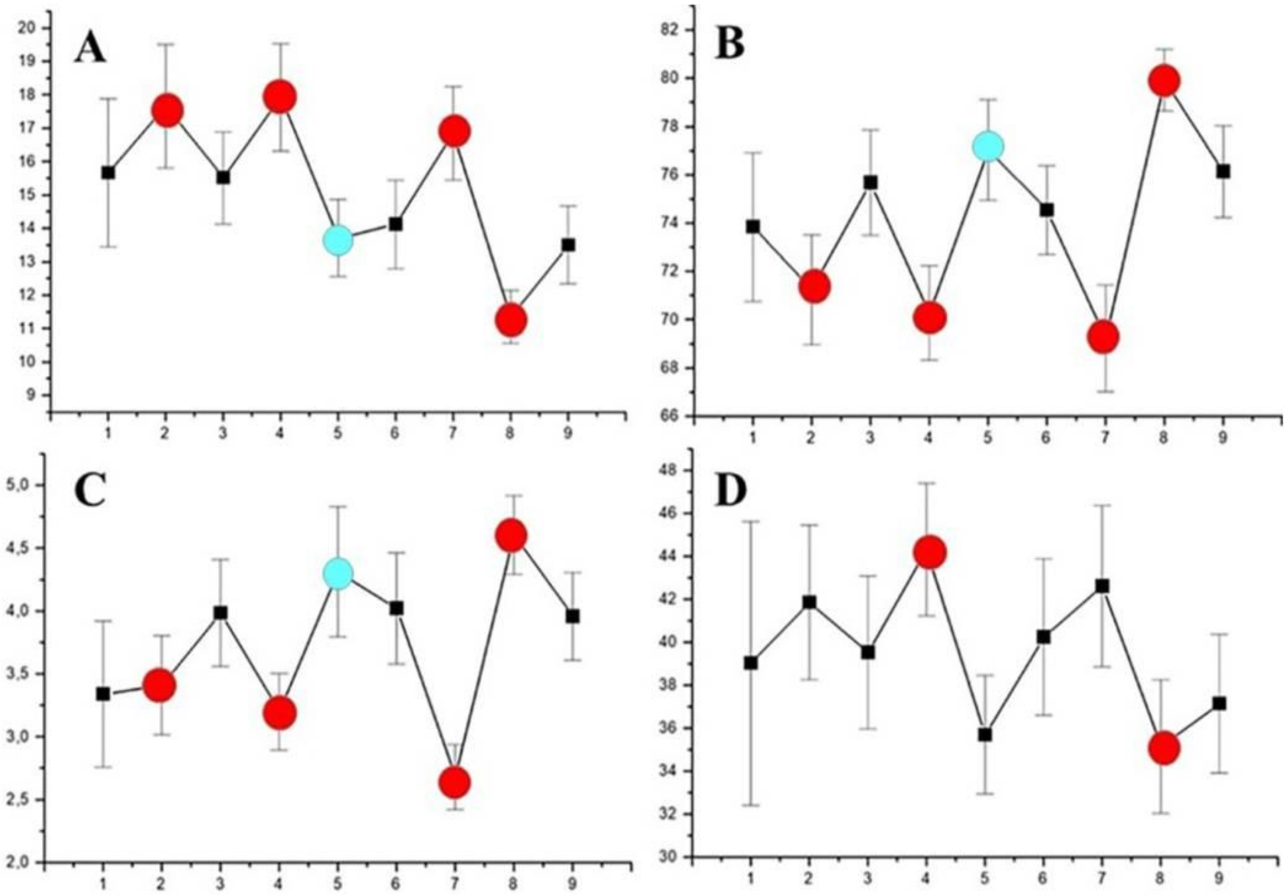

Figure 3. **Monthly averages of HF% (A), LFnu (B), LF/HF(C), RMSSD (D) indices in adolescents. The x-axis represents the months of the year, where 1=April, 2=September, 3=October, 4=November, 5=December (2013), 6=January, 7=February, 8=March, 9=April (2014). The y-axis represents values of indices (M±m). The red circles indicate statistically significant differences (p<0.05) between corresponding indices in March. The cyan circles indicate statistically significant differences (p<0.05) between the November and December, and December and February values of the indices.**
HF, contributions of discrete frequency components to PSD; LFnu, normalized units of HF; LF/HF, relative contribution of sympathetic and parasympathetic influence on HRV; RMSSD, standard deviation of RR-interval differences from their arithmetic mean.

Table 4. The statistical values of HRV indices obtained based on the daily measurements (n=278) of the corresponding indices for each subject. The table includes the mean and standard deviation (M±SD), minimum and maximum values (min-max), median (Me), lower and upper quartiles (25-75), and coefficient of variation (Coef.var.)

HRV Indices	*M±SD*	*Min-max*	*Me*	*25-75*	*Coef. var*
HR. bpm	87.9±12.9	59-120.0	87.5	80-98.0	14.6
D. a.u.	65.1±18.7	10.5-100.0	67.5	54.4-77.7	28.7
R-R. ms	693.3±106.5	496.0-1009.4	681.5	612.2-749.8	15.4
SI. a.u.	124.4±110.2	12.5-632.4	86.6	48.5-166.7	*88.5*
R-R(Mo). ms	664.7±115.7	480-1,120.0	640.0	560.0-720.0	17.4
RMSSD. ms	39.8±19.9	8.6-103.1	36.2	24.7-50.4	50.0
PSD. ms^2	3,493.7±2,945.5	273.6-18,585.2	2726.2	1,385.9-4,723.6	*84.3*
HF. ms^2	540.2±557.7	14.5-3,299.0	348.0	168.1-711.9	*103.3*
LF. ms^2	1,391.9±1,013.8	81.1-5,619.2	1,164.8	585.9-2,041.0	*72.8*
LF/HF	3.8±2.3	0.5-15.2	3.3	1.9-5.2	61.6
VLF. ms^2	1,561.6±1,736.7	120.0-11,696.3	1,007.2	515.1-1,787.5	*111.2*
HFnu	25.9±11.9	6.2-67.1	23.2	16.2-34.3	45.8
LFnu	74.1±11.9	32.9-93.8	76.8	65.7-83.8	16.0
HF%	15.2±8.6	2.6-55.5	13.1	9.1-19.2	56.6
LF%	42.7±11.8	14.1-68.2	43.1	34.2-51.9	27.6
VLF%	42.1±13.6	13.7-79.7	41.7	31.6-51.3	32.2

HR, heart rate; D, psychoemotional index; RR, duration of cardiac intervals; SI, stress index of regulatory systems; RMSSD, standard deviation of RR-interval differences from their arithmetic mean; PSD, power spectral density; HF, (breathing waves) power of the high-frequency component of PSD; LF, power of the low-frequency component of PSD; LF/HF, relative contribution of sympathetic and parasympathetic influence on HRV; VLF, power of the very low-frequency component of PSD; HFnu and LFnu, normalized units of HF and LF; HF%, LF%, VLF%, contributions of respective frequency components to PSD.

Table 5. The correlation coefficients between the daily average values (n=36) of the HRV indicators

	HR	*D*	*RR*	*SI*	*RMSSD*	*HF*	*LF*	*LF/HF*	*PSD*	*VLF*	*HF%*	*LF%*	*VLF%*
HR	1.00	-0.67*	-0.99*	0.85*	-0.66*	-0.54*	-0.52*	0.42*	-0.59*	-0.49*	-0.54*	0.14	0.23
D	-0.67*	1.00	0.61*	-0.86*	0.71*	0.50*	0.87*	-0.07	0.72*	0.52*	0.27	0.28	-0.51*
RR	-0.99*	0.61*	1.00	-0.80*	0.66*	0.58*	0.47*	-0.47*	0.58*	0.49*	0.59*	-0.20	-0.20
SI	0.85*	-0.86*	-0.80*	1.00	-0.65*	-0.46*	-0.70*	0.17	-0.65*	-0.52*	-0.34*	-0.06	0.31
RMSSD	-0.66*	0.71*	0.66*	-0.65	1.00	0.89*	0.74*	-0.56*	0.85*	0.68*	0.65*	-0.23	-0.21
HF	-0.54*	0.50*	0.58*	-0.46*	0.89*	1.00	0.58*	-0.65*	0.78*	0.63*	0.78*	-0.35*	-0.17
LF	-0.52*	0.87*	0.47*	-0.70*	0.74*	0.58*	1.00	-0.08	0.83*	0.59*	0.21	0.26	-0.43*
LF/HF	0.42*	-0.07	-0.47*	0.17	-0.56*	-0.65*	-0.08	1.00	-0.37*	-0.34*	-0.82*	0.70*	-0.19
PSD	-0.59*	0.72*	0.58*	-0.65*	0.85*	0.78*	0.83*	-0.37*	1.00	0.93*	0.41*	-0.21	-0.06
VLF	-0.49*	0.52*	0.49*	-0.52*	0.68*	0.63*	0.59*	-0.34*	0.93*	1.00	0.30	-0.39*	0.22
HF%	-0.54*	0.27	0.59*	-0.34*	0.65*	0.78*	0.21	-0.82*	0.41*	0.30	1.00	-0.46*	-0.21
LF%	0.14	0.28	-0.20	-0.06	-0.23	-0.35	0.26	0.70*	-0.21	-0.39*	-0.46*	1.00	-0.77*
VLF%	0.23	-0.51*	-0.20	0.31	-0.21	-0.17	-0.43*	-0.19	-0.06	0.22	-0.21	-0.77*	1.00

* The correlation coefficients in bold italics are shown at the significance level of p<0.05. HR, heart rate; D, psychoemotional index; RR, duration of cardiac intervals; SI, stress index of regulatory systems; RMSSD, the square root of the mean of the squares of the successive differences between adjacent NN intervals; PSD, power spectral density; HF, (breathing waves) power of the high-frequency component of PSD; LF, power of the low-frequency component of PSD; LF/HF, relative contribution of sympathetic and parasympathetic influence on HRV; VLF, power of the very low-frequency component of PSD; HF%, LF%, VLF%, contributions of respective frequency components to PSD.

The percentile values for the monthly average of the StA and TrA are provided in *Table 2*, while the corresponding values for the SeH, the Act, and the Md are presented in *Table 3*. As illustrated in *Table 2*, elevated StA (above the normal range) was observed in 25% of participants from October until April, with the levels remaining high throughout this period. Furthermore, in 10% of participants, anxiety manifests as a basic state present irrespective of season. The StA on the median level (50% of cases) reaches high levels in December and in April. For TrA, 25% of participants showed elevated scores from November to April, with 10% showing above-normal scores from September to April.

Table 3 illustrates the percentile monthly average values of SeH, Act, and Md scores. A decrease in SeH scores was observed in 25% of cases, commencing in October and persisting below the norm (5.0-5.5 points) until April. The Act is observed to be low in 25% of cases from September through April, and in 50% of cases, it is lowest in November and December. The Md is found to correspond to low values in all months in 10% of cases, and in 25% of cases, it is the lowest in November. In general, SeH and Md in 50% and Act in 25% of cases are consistent with the norm across all tested months.

Nonparametric Mann-Whitney and Kolmogorov-Smirnov tests were used to assessing the significance of differences in monthly average mental state indicators. Significant differences (p<0.05) were observed between the September averages and those of other months for both StA and TrA. Specifically, StA averages in December, February, March, and April were significantly higher than in September (*Figure 2A*); TrA averages in December, January, and April were significantly higher (p<0.05) than in September (*Figure 2B*). This indicates an increase in anxiety from October, peaking in December and persisting until April. The concurrent increase in StA and TrA with decreasing daylight hours suggests a relationship with photoperiodicity.

Significant differences (p<0.05) were also found in average monthly Act levels in November and December compared to September (*Figure 2C*). Activity levels decreased from October, reaching a minimum in November and remaining low throughout the polar night. *Figure 2D* clearly illustrates a decrease in average monthly Md scores from October to January, although no statistically significant (p<0.05) differences were found within the period of darkness. No significant differences were observed for SeH, either. Overall, StA, TrA, and Act demonstrated seasonal variations associated with the polar night. However, the reasons for the elevated anxiety levels in April remain unclear.

Heart Rate Variability

Table 4 presents descriptive statistics for heart rate variability (HRV) indices calculated from daily measurements for each participant.

Table 5 displays correlations among the daily average HRV indices (n=36). While all indices showed significant intercorrelations ($p<0.05$), statistically significant monthly variations ($p<0.05$) were observed solely for HF, LF/HF, HFnu, LFnu, HF%, LF%, and RMSSD.

Significant differences were found between average monthly values for several heart rate variability (HRV) indices and their March counterparts. These differences were observed in:

- September: HF, LF/HF, HFnu, LFnu, HF% and LF/HF, HFnu, LFnu, HF%.
- November: RMSSD, HF, LF/HF, HFnu, LFnu, HF%, and LF%.
- February: HF, LF/HF, HFnu, and LFnu.

The aforementioned differences were assessed using the Mann=Whitney and Kolmogorov-Smirnov tests, respectively. However, when applying these two nonparametric criteria simultaneously, only the average monthly values of LF/HF, HFnu, and LFnu showed a significant distinction compared to their values in March across both tests. These results suggest that LFnu, HFnu, and their LF/HF ratio are key determinants of seasonal HR regulation; HF, HF%, and RMSSD also contributed notably. However, absolute HRV index values revealed no seasonal or photoperiodic associations.

The percentiles for average monthly values of LF/HF, HFnu, and LFnu, based on the averaging of their within-monthly daily means, are presented in Table 6.

Due to the lack of available comparable HRV norms for adolescents living beyond the Arctic Circle, data from 14-year-old adolescents in the Arkhangelsk region, Russia (64°33′ N, 40°32′ E) served as a reference [49]. Our participants exhibited significantly higher LF/HF values (median 3.5; percentiles 1.5, 2.0, 5.0, 6.6) compared to the reference values from Arkhangelsk (median 1.85; percentiles 0.65, 1.02, 3.11, 4.41).

This suggests a greater predominance of sympathetic HR regulation in adolescents residing beyond the Arctic Circle compared with those in subpolar areas. Furthermore, the shift in HR regulation towards a greater sympathetic branch contribution is most evident in December and March.

The relative contribution of HFnu and LFnu in HR regulation is corroborated by the prevalence of LFnu over HFnu in 75% of cases, which is derived from the percentile distribution (Table 6).

Figure 3 depicts the fluctuations in the monthly average values of HF% (A), LFnu (B), LF/HF (C), and RMSSD (D). Higher HF% and lower LF/HF and LFnu values were observed in September, November, and February, contrasting with the pattern seen in March (Figure 3, red circles). December values (cyan circles) differed significantly from November and February values for HF%, LFnu, and LF/HF.

This indicates more substantial parasympathetic ANS contribution to HR regulation in September, November, and February Conversely, sympathetic dominance occurred in December and March.

Only average monthly RMSSD values in November differed significantly ($p < 0.05$) from those in March. Hence, the greatest tension in HR regulation in adolescents appears to occur in December and March.

Average monthly values of HR, RR, PSD, LF, VLF, SI, and D indices of the HRV indices demonstrated a negligible correlation with high-latitude photoperiodicity associated with the polar night and polar day.

Seasonal variations were thus observed only in the relative contributions of the sympathetic and parasympathetic branches of the autonomic nervous system (ANS) to HR regulation. Notably, RMSSD (a marker of parasympathetic HRV contribution) peaked at the onset of polar night (November) and reached its nadir after the polar night (March), suggesting March may represent the least favorable month for adolescent health, based on these HRV data.

Table 6. Presents the percentiles for the monthly averages of LF/HF, HFnu, and LFnu

Months, n	*LF/HF*					*HFnu*					*LFnu*				
	10	25	50	75	90	10	25	50	75	90	10	25	50	75	90
Apr (9)	1.4	2.3	2.9	4.1	6.7	13.0	19.7	25.8	30.6	41.9	58.1	69.4	74.2	80.3	87.0
Sep (36)	1.0	1.6	3.0*	4.4	6.5	13.4	18.7	25.0*	37.8	49.9	50.1	62.2	75.0*	81.3	86.6
Oct (28)	1.4	2.2	3.8	5.6	6.2	13.9	15.3	20.8	31.7	41.9	58.1	68.3	79.2	84.7	86.1
Nov (48)	1.1	1.6	2.7*	4.5	5.8	14.6	18.1	27.2*	39.1	48.6	51.4	60.9	72.8*	81.9	85.4
Dec (26)	1.7	2.2	3.7	5.9	8.8	10.2	14.4	21.2	31.2	36.5	63.5	68.8	78.8	85.6	89.8
Jan (41)	1.5	1.7	3.6	5.1	7.6	11.7	16.5	21.9	36.8	40.4	59.6	63.2	78.1	83.5	88.3
Feb (25)	1.1	1.5	2.4*	3.7	4.5	18.2	21.2	29.2*	40.4	47.8	52.2	59.6	70.8*	78.8	81.8
Mar (34)	2.1	2.9	4.7*	5.9	6.7	12.9	14.6	17.6*	25.4	32.5	67.5	74.6	82.4*	85.4	87.1
Apr (31)	1.9	2.3	4.3	5.6	6.4	13.6	15.2	18.8	29.9	34.8	65.2	70.1	81.2	84.8	86.4
Mean	1.5	2.0	3.5	5.0	6.6	13.5	17.1	23.1	33.7	41.6	58.4	66.3	76.9	82.9	86.5

* The values indicate significant differences between the monthly averages of the median LF/HF, HFnu, and LFnu in comparison to their values in March. LF/HF, relative contribution of sympathetic and parasympathetic influence on HRV; VLF, power of the very low-frequency component of PSD; HFnu and LFnu, normalized units of HF and LF.

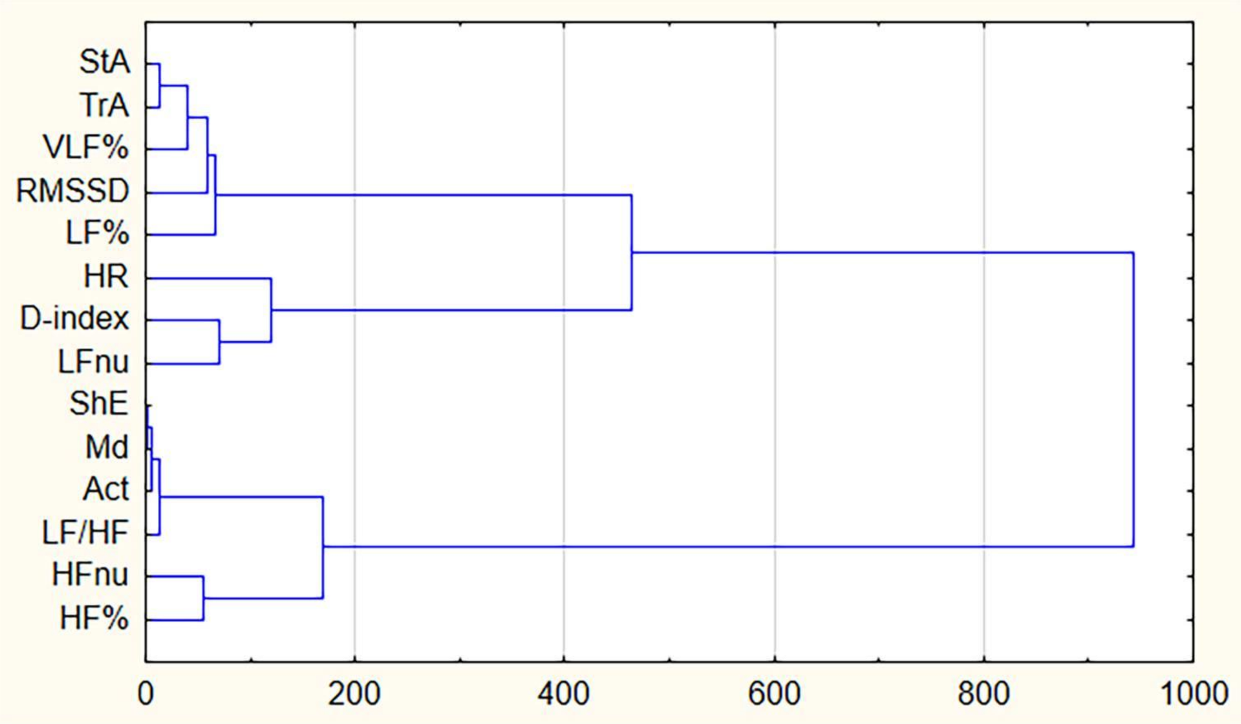

Figure 4. The dendrogram for 14 variables. Ward's method. The abscissa axis represents the Euclidean distance.

StA, state anxiety; TrA, trait anxiety; VLF%, very low frequency (contribution to Total Power Spectral Density (PSD), %); RMSSD (ms), the square root of the mean of the squares of the successive differences between adjacent NN intervals; LF%, low frequency (contribution to PSD), %); HR, heart rate; D, index of psychoemotional state; Lfnu, low frequency (normalized units); SeH, self-esteem of health; Md, mood, Act, activity; LF/H, ratio of LFnu to Hfnu; Hfnu, high frequency (normalized units); HF%, high frequency (contribution to PSD, %).

Association of Mental State with HRV

Pairwise and Spearman rank correlations for the evaluation of the closeness of the relationship between the mental and HRV indicators revealed significant associations only between activity (Act) and LF% (r=0.42, p<0.05) and between activity (Act) and VLF% (r=-0.66, p<0.05). The application of multidimensional cluster analysis to the data set yielded more intricate associations between mental and HRV indices. The results were presented in the form of a hierarchical classification based on Ward's association rule. The results yielded two clusters. The first cluster comprised two subclusters: one including TrA, StA, LF%, RMSSD, and VLF%; the other, including HR, D-index, and LFnu. The second cluster similarly comprised two subclusters: one including SeH, Md, Act, and LF/HF; the other, including HFnu and HF% (*Figure 4*). The matrix of distances between variables is provided in *Supplementary 2*.

This means that the state of anxiety appears linked to fundamental characteristics of metabolism in the human body (VLF%), the contribution of the sympathetic component in the regulation of HR (LF%), and HR variability range (RMSSD). Furthermore, anxiety severity correlated with the current psycho-emotional state (D-index), as reflected in heart rate (HR) modulated by the relative sympathetic nervous system (SNS) contribution to HR regulation (LFnu). SeH, Md, and Act formed a separate cluster, indicating their dependence on parasympathetic influence on heart rate regulation (HFnu, HF%), as determined by the sympathetic-to-parasympathetic ratio (LF/HF) in heart rate variability (HRV) regulation. Multidimensional analysis revealed a complex, nonlinear relationship between mental state and HRV, explaining the absence of significant correlations (p<0.05) between individual indices. However, this analysis allowed for the identification of the dominant contributions of sympathetic and parasympathetic regulation to specific mental states.

Discussion

Mental State

This study examined seasonal variations in mental state and heart rate variability among healthy adolescents residing beyond the Arctic Circle.

We found that average monthly scores for StA, TrA, and Act correlated with photoperiodicity in regions beyond the Arctic Circle. Specifically, as the duration of darkness increased, StA and TrA rose concurrently, peaking during the period of continuous darkness at the latitude of Apatity, Russia (December 15–28). Conversely, Act and Md scores decreased, reaching their nadir in November.

The percentile analysis of StA and TrA revealed that elevated anxiety (above reference values) affected 10% of participants as early as September, persisting through March. This elevated anxiety was observed in 25% of participants from October through March.

StA typically stems from stressful situations and is characterized by subjective discomfort, tension, anxiety, and autonomic arousal. TrA, conversely, represents a predisposition to perceive threats across various situations [44]. High TrA increases the likelihood of stressful responses and anxiety in these situations. Extremely high TrA scores are strongly associated with neurotic conflict, emotional and neurotic breakdowns, and psychosomatic illnesses [35, 50, 51, 52].

We hypothesize that the high severity of StA and TrA in adolescents may manifest as a symptom of SAD, particularly during the extreme conditions of the polar night. Moreover, high baseline anxiety (above the 75th percentile) correlated with low Act (below the 25th percentile) and, from October onward, with low subjective well-being (SeH) (below the 25th percentile). This suggests that reduced Act and SeH may act as cofactors in triggering SAD symptoms, in addition to the high anxiety levels prevalent during the polar night.

Our findings underscore the importance of high-latitude photoperiodicity as a seasonal factor potentially contributing to the onset and prevalence of SAD in high-latitude adolescents. This is supported indirectly by the works of Ponomarev and Gribanov et al., who demonstrated a correlation between winter sunlight deficits and increased state-trait anxiety in Arctic residents [53], and by evidence indicating that photoperiodicity significantly affects brain bioelectrical activity in northern schoolchildren [54].

High levels of anxiety in adolescents, independent of seasonal photoperiodicity, may indicate underlying psychopathology warranting further investigation. The increase in anxiety severity associated with seasonal photoperiodicity might be amenable to light therapy; however, we are unaware of any studies applying this approach to seasonal mental disorders in adolescents. This area requires further research.

Heart Rate Variability

Our HRV data, specifically the average monthly LF/HF, LFnu, and HFnu values, differed significantly from the previously published findings. For example, only 10% of our participants' seated LF/HF values (median 1.5) fell within the ranges reported by Acharya et al. (1.33±1.36) and Farah et al. (1.4±1.0) [55, 56]. Our study's median LF/HF value (3.3) was substantially higher than that reported in adolescents from the Arkhangelsk region (1.85) [49] and the mean of 1.18 reported by Mikhayjlov et al. in calmly seated adolescents [57].

These discrepancies extended to other HRV indicators, with median RMSSD values higher in Arkhangelsk adolescents (52.7) than in our participants (36.2), and also higher in seated young adults in Singapore (73.78±53.31) and Brazilian adolescents (55.5±29.0) [49, 55, 56]. Furthermore, the contributions of spectral components to HRV differed significantly: in Arkhangelsk adolescents, HF%, LF%, and VLF% contributed 49.89±13.72%, 32.2±10.52%, and 17.95±7.29%, respectively [49], while in our study these values were 15.2±8.6%, 42.7±11.8%, and 42.1±13.6%, respectively.

Similar inconsistencies were observed when comparing the SI index, PSD, HF, LF, VLF, and the relative contributions of the sympathetic and parasympathetic components of the ANS to HR regulation (LF/HF, HFnu, LFnu, HF%, LF%, VLF%) [49, 56, 58, 59]. Moreover, the HF component's contribution to PSD was significantly lower than that of LF and VLF components in our study compared to others.

Reduced parasympathetic and increased sympathetic influence on HRV suggests heightened cardiovascular tension in adolescents residing beyond the Arctic Circle. This tension appeared independent of seasonal photoperiodicity, as LFnu exceeded HFnu in 75% of cases across all months under consideration. As Porges notes, low cardiac vagal tone is common to a broad range of maladaptive conditions [60]. Therefore, December and March represent the most vulnerable months for cardiovascular health, given the lowest average monthly HF% and the most substantial risk of health disorders.

Therefore, seasonal variations in HRV appear confined to the regulatory mechanisms governed by the relative contributions of HF and LF power to HR regulation. Moreover, these contributions are relatively independent of photoperiodicity, as evidenced by the alternation of dominance of HF%, LFnu, and, respectively, values of LF/HF every month. The high coefficients of variation for HFnu (45.8), LFnu (16.0), HF% (56.6), and LF% (27.6) suggest that the observed seasonal fluctuations in HR may be mitigated by enhancing the parasympathetic contribution of ANS to HR regulation. This could be achieved by reducing the energy expenditure required for adaptation to environmental stressors.

Association of Mental State with HRV

Our findings demonstrate that high levels of StA and TrA, exceeding normal values, were observed in 25% of participants from October to April. A smaller subset (10%) exhibited persistently high anxiety levels high anxiety levels, irrespective of seasonal variations. The severity of both StA and TrA increased concurrently with decreasing daylight hours, peaking in December and remaining elevated until April.

Concurrently, we observed a significantly lower contribution of HFnu (25.9±11.9; range 6.2-67.1) to HRV during the study period compared to values reported by Vanderlei et al. (48.28±12.34; range 49.3-71.5) in 14-year-old Brazilian adolescents [61]. This discrepancy suggests that the polar environment acts as a significant stressor, resulting in decreased HF and increased LF contributions to HRV. Multidimensional cluster analysis revealed strong associations between TrA and StA and LF%, RMSSD, VLF%, and LFnu. *Figure* 3 (B, D) illustrates the strong association between TrA, StA, LF power, and RMSSD, showing the highest LFnu and lowest RMSSD values during December and March, when anxiety peaked. The association of SeH, Md, and Act with LF/HF ratio suggests instability in these states due to variable LF and HF contributions to LF/HF (Fig. 3C).

We hypothesize that the predominance of LF% (Lnu) in HRV contributes to the dominance of excitatory over inhibitory processes, potentially promoting high anxiety. The decreased HF contribution to HRV could represent a physiological manifestation of polar tension syndrome (PTS).

Our results align with the established understanding that vagal withdrawal is a key feature of stress responses [62], a notion generally supported by research on HRV responses to stressors [50, 63]. Porges suggests that vagally mediated HRV indexes CNS-ANS integration and thus serves as a psychophysiological marker of adaptive environmental engagement [60]. Low vagal tone has been associated with poor emotion regulation, reduced reactivity to stimuli, and stress vulnerability in infancy and childhood [62], delinquency risk in pre-adolescent boys [64], and both anxiety and antisocial behavior in adolescents [65].

In conclusion, our findings suggest that mental state, as manifested through anxiety and activity levels, is significantly influenced by both HRV and environmental factors, with seasonal photoperiodicity performing a substantial role.

Conclusion

This study is the first to demonstrate a correlation between state and trait anxiety (StA and TrA) in adolescents living beyond the Arctic Circle and seasonal photoperiodicity. Anxiety levels increased with decreasing daylight, peaking in December during the polar night. Reduced HF and increased LF contributions to heart rate regulation during this period may represent a physiological mechanism underlying both the manifestation of PTS and SAD, both of which are associated with elevated anxiety.

HRV indicators showed a minimal association with photoperiodicity, except for the HF and LF contributions to heart rate regulation.

This study uniquely reveals the monthly fluctuation in the dominance of parasympathetic (HF) and sympathetic (LF) links of the ANS in the regulation of heart rhythm. The results demonstrate that the sympathetic branch plays a predominant role during the polar night and in March.

Our findings indicate that March was the most detrimental month for adolescent health, showing the greatest decrease in HF contribution to HRV and RMSSD values, alongside a concomitant increase in LF contribution to heart rate regulation.

Limitations

This study has several limitations. The limited sample size resulted from challenges in obtaining informed consent. Methodological limitations stem from the use of a questionnaire format that did not permit direct ascertainment of the incidence of SAD in adolescents. Nonetheless, the observed seasonal increase in anxiety above reference values in healthy adolescents suggests that prolonged darkness and the polar night may contribute to SAD prevalence. Further research is required to expand the sample size to include a greater number of children and adolescents, thus enhancing the reliability and generalizability of the findings. Subsequent studies will expand participant enrollment to identify potential risk groups for SAD and to validate interventions aimed at mitigating this condition.

Ethical Approval

This study adhered to the principles of the Declaration of Helsinki (2013 revision) and received ethical approval from the Russian Academy of Sciences' Institutional Bioethics Committee (January 18, 2017). All parents provided written informed consent after being fully apprised of the study's purpose and procedures.

Conflict of Interest

The authors declare no potential conflict of interest.

Funding

This study was conducted under state assignment FMEZ-2022-0012 and funded by West-Siberian Science and Education Center, Government of Tyumen District, Decree of 20.11.2020: No. 928-rp.

References

1. Rozhkov VN, Belisheva NK, Martynova AA, Soroko SI. Psychophysiological and cardiohemodynamic effects of solar, geomagnetic and meteorological factors in man living in Arctic area. *Fiziol Cheloveka* 2014 Jul-Aug;40(4):51-64. Russian. https://pubmed.ncbi.nlm.nih.gov/25707219.
2. Belisheva NK. The Effect of Space Weather on Human Body at the Spitsbergen Archipelago. In: Kanao M, Kakinami Y, and Toyokuni G, Eds. Arctic Studies – A Proxy for Climate Change. Rijeka, Croatia: IntechOpen. 2019. http://doi.org/10.5772/intechopen.85021.
3. Usui A, Obinata I, Ishizuka Y, Okado T, Fukuzawa H, Kanba S. Seasonal changes in human sleep-wake rhythm in Antarctica and Japan. *Psychiatry Clin Neurosci* 2000; 54(3): 361-362. https://doi.org/10.1046/j.1440-1819.2000.00715.x.
4. Francis G, Bishop L, Luke C, Middleton B, Williams P, Arendt J. Sleep during the Antarctic winter: preliminary observations on changing the spectral composition of artificial light. *J Sleep Res* 2018; 17(3), 354-360. https://doi.org/10.1111/j.1365-2869.2008.00664.x
5. Arendt J. Biological Rhythms During Residence in Polar Regions. *Chronobiol Int* 2012; 29(4): 379-394. https://doi.org/10.3109/07420528.2012.668997.
6. Arendt J, Middleton B. Human seasonal and circadian studies in Antarctica (Halley, 75°S). *Gen Comp Endocrinol* 2018, 258: 250-258. https://doi.org/10.1016/j.ygcen.2017.05.010.
7. Kaznacheev VP. Contemporary Aspects of Adaptation. Novosibirsk: Nauka. 1980; 189 p. Russian. https://rusneb.ru/catalog/002072_000044_ARONB-RU_Архангельская+ОНБ_DOLIB_612.017.2_К+148-790819.
8. Panin AE, Sokolov VP. Psychosomatic relationships in chronic emotional stress. Novosibirsk: Nauka. 1981; 179 p. Russian.
9. Hasnulin VI. Human health and cosmogeophysical north factors. Human Ecology 2013; 20(12): 3-13. Russian. https://doi.org/10.17816/humeco17277.
10. Hasnulin VI, Hasnulin PV. Modern ideas about the mechanisms of northern stress formation in humans at high latitudes. Human Ecology 2012; 19(1): 3-11. Russian. https://doi.org/10.17816/humeco17512.
11. Rosenthal NE, Sack DA, Gillin JC, Lewy AJ, Goodwin FK, Davenport Y, et al. Seasonal affective disorder. A description of the syndrome and preliminary findings with light therapy. *Arch Gen Psychiatry* 1984; 41(1): 72-80. https://doi.org/10.1001/archpsyc.1984.01790120076010.
12. Kasper S, Wehr TA, Bartko JJ, Gaist PA, Rosenthal NE. Epidemiological findings of seasonal changes in mood and behavior. A telephone survey of Montgomery County, Maryland. *Arch Gen Psychiatry* 1989; 46(9): 823-833. https://doi.org/10.1001/archpsyc.1989.01810090065010.
13. Fonte A, Coutinho B. Seasonal sensitivity and psychiatric morbidity: study about seasonal affective disorder. *BMC Psychiatry* 2021; 21(1): 317. https://doi.org/10.1186/s12888-021-03313-z.
14. Rosenthal NE Seasons of the mind: why you get the winter blues and what you can do about it. New York: Bantam Books. 1989; 278 p. https://archive.org/details/seasonsofmindwhy0000rose_n1b5.
15. Bundzen PV. Light regime effect in the Antarctic continent on the state of autoregulating functions in the human brain. *Fiziol Zh SSSR Im I M Sechenova* 1969; 55(8): 929-939. Russian. https://pubmed.ncbi.nlm.nih.gov/5357475.
16. Collet G, Mairesse O, Cortoos A, Tellez HF, Neyt X, Peigneux P, et al. Altitude and seasonality impact on sleep in Antarctica. *Aerosp Med Hum Perform* 2015; 86(4): 392-396. https://doi.org/10.3357/amhp.4159.2015.
17. Pattyn N, Van Puyvelde M, Fernandez-Tellez H, Roelands B, Mairesse O. From the midnight sun to the longest night: Sleep in Antarctica. *Sleep Med Rev* 2018; 37: 159-172. https://doi.org/10.1016/j.smrv.2017.03.001.
18. Kang JM, Cho SJ, Cho SE, Bang T, Chae BD, Yi E, et al. Mood and Sleep Status and Mental Disorders During Prolonged Winter-Over Residence in Two Korean Antarctic Stations. *Nat Sci Sleep* 2022; 14: 1387-1396. https://doi.org/10.2147/nss.s134864.
19. Lingjærde O, Bratlid T, Hansen T. Insomnia during the "dark period" in northern Norway: An explorative, controlled trial with light treatment. *Acta Psychiatr Scand* 1985; 71(5): 506-512. https://doi.org/10.1186/1471-244X-12-225.
20. Rosen LN, Targum SD, Terman M, Bryant MJ, Hoffman H, Kasper SF, et al. Prevalence of seasonal affective disorder at four latitudes.

Psychiatry Res 1990; 31(2): 131-144 https://doi.org/10.1016/0165-1781(90)90116-m.

21. Rosen L, Knudson KH, Fancher P. Prevalence of seasonal affective disorder among U.S. Army soldiers in Alaska. *Mil Med* 2002; 167(7): 581-584. https://pubmed.ncbi.nlm.nih.gov/12125852.
22. Hansen V, Jacobsen BK, Husby R. Mental distress during winter. An epidemiologic study of 7759 adults north of arctic circle. *Acta Psychiatr Scand* 1991; 84(2): 137-141. https://doi.org/10.1111/j.1600-0447.1991.tb03117.x.
23. Partonen T, Partinen M, Lonnquist J. Frequencies of seasonal major depressive symptoms at high latitudes. *Eur Arch Psychiat Clin Neurosci* 1993; 243(3-4): 189-192. https://doi.org/10.1007/BF02190726.
24. Mersch PP, Middendorp HM, Bouhuys AL, Beersma DG, van den Hoofdakker RH. The prevalence of seasonal affective disorder in the Netherlands: a prospective and retrospective study of seasonal mood variation in the general population. *Biol Psychiatry* 1991; 45(8): 10131022. https://doi:10.1016/s0006-3223(98)00220-0.
25. Haggarty JM, Cernovsky Z, Husni M. The limited influence of latitude on rates of seasonal affective disorder. *J Nerv Ment Dis* 2001; 189(7): 482-484. https://doi:10.1097/00005053-200107000-00011.
26. Nillni YI, Rohan KJ, Rettew D, Achenbach TM. Seasonal trends in depressive problems among United States children and adolescents: a representative population survey. *Psychiatry Res* 2009; 170(2-3): 224-228. https://doi.org/10.1016/j.psychres.2008.07.011.
27. Grimaldi S, Partonen T, Haukka J, Aromaa A, Lönnqvist J. Seasonal vegetative and affective symptoms in the Finnish general population: testing the dual vulnerability and latitude effect hypotheses. *Nord J Psychiatry* 2009; 63(5): 397-404. https://doi.org/10.1080/08039480902878729.
28. Marqueze EC, Vasconcelos S, Garefelt J, Skene DJ, Moreno CR, Lowden A. Natural light exposure, sleep and depression among day workers and shiftworkers at arctic and equatorial latitudes. *PLoS One* 2015; 10(4): e0122078. https://doi:10.1371/journal.pone.0122078.
29. Patten SB, Williams JV, Lavorato DH, Wang JL., Bulloch AG. Major Depression Prevalence Increases with Latitude in Canada. *Can J Psychiatry* 2017; 62(1), 62-66. https://doi.org/10.1177/0706743716673323.
30. Simutkin GG, Popova NM. Seasonal affective disorder in children and adolescents. *Rossiiskii psikhiatricheskii zhurnal* 2008; (4): 74-78. Russian. https://elibrary.ru/item.asp?id=11630849.
31. Carskadon MA, Acebo C. Parental Reports of Seasonal Mood and Behavior Changes in Children. *J Am Acad Child Adolesc Psychiatry* 1993; 32(2): 264-269. https://doi:10.1097/00004583-199303000-00005.
32. Sourander A, Koskelainen M, Helenius H. Mood, latitude, and seasonality among adolescents. *J Am Acad Child Adolesc Psychiatry* 1999; 38(10): 1271-1276. https://doi.org/10.1097/00004583-199910000-00016.
33. Gruber NP, Dilsaver SC. Bulimia and anorexia nervosa in winter depression: lifetime rates in a clinical sample. *J Psychiatry Neurosci* 1996; 21(1): 9-12. https://pubmed.ncbi.nlm.nih.gov/8580121.
34. Langevin R, Ramdé J. Attention deficit hyperactivity disorder (ADHD) in children, seasonal photoperiods, nocturnal movements and diurnal agitation. *J Can Acad Child Adolesc Psychiatry* 2012; 21(1): 53-58. https://pubmed.ncbi.nlm.nih.gov/22299015.
35. Chang HA, Chang CC, Tzeng NS, Kuo TB, Lu RB, Huang SY. Generalized anxiety disorder, comorbid major depression and heart rate variability: a case-control study in Taiwan. *Psychiatry Investig* 2013; 10(4): 326-335. https://doi.org/10.4306/pi.2013.10.4.326.
36. Cheng YC, Su MI, Liu CW, Huang YC, Huang WL. Heart rate variability in patients with anxiety disorders: A systematic review and meta-analysis. *Psychiatry Clin Neurosci* 2022; 76(7): 292-302. http://doi/10.1111/pcn.13356/full.
37. Levine JC, Fleming R, Piedmont JI, Cain SM, Chen WJ. Heart rate variability and generalized anxiety disorder during laboratory-induced worry and aversive imagery. *J Affect Disord* 2016; 205: 207-215. https://doi:10.1016/j.jad.2016.07.019.
38. Thayer JF, Lane RD. A model of neurovisceral integration in emotion regulation and dysregulation. *J Affect Disord* 2000; 61(3): 201-216. https://doi.org/10.1016/s0165-0327(00)00338-4.
39. Appelhans BM, Luecken LJ. Heart rate variability as an index of regulated emotional responding. *Rev Gen Psychol* 2006; 10(3): 229-240. https://doi.org/10.1037/1089-2680.10.3.229.
40. Austin MA, Riniolo TC, Porges SW. Borderline personality disorder and emotion regulation: insights from the Polyvagal Theory. *Brain Cogn* 2007; 65(1): 69-76. http://doi.org/10.1016/j.bandc.2006.05.007.
41. Porges SW. The polyvagal perspective. *Biol Psychol* 2007; 74(2): 116-143. https://doi.org/10.1016/j.biopsycho.2006.06.009.
42. Beauchaine TP, Thayer JF. Heart rate variability as a transdiagnostic biomarker of psychopathology. *Int J Psychophysiol* 2015; 98(2 Pt 2): 338-350. https://doi.org/10.1016/j.ijpsycho.2015.08.004.
43. Doskin VA, Lavrent'eva NA, Strongina OM, & Sharaĭ VB. "SAN" psychological test applicable to studies in the field of work physiology]. Gigiena truda i professional'nye zabolevaniia 1975; 5: 28-32. https://www.semanticscholar.org/paper/%5B"SAN"-psychological-test-applicable-to-studies-in-Doskin-Lavrent'eva/4b59374fca3bb964f7fc9f3b00fe5abe292f7df1.
44. Spielberger CD, Sydeman SJ. State-Trait Anxiety Inventory and State-Trait Anger Expression Inventory. In: Maruish ME, Ed. The Use of Psychological Testing for Treatment Planning and Outcome Assessment. Hillsdale, NJ, USA: L. Erlbaum Associates. 1994: 292-321. https://www.scirp.org/reference/referencespapers?referenceid=1585180.
45. 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. *Circulation.* 1996; 93(5): 1043-1065. https://pubmed.ncbi.nlm.nih.gov/8598068.
46. Stein PK, Kleiger RE. Insights from the study of heart rate variability. *Annu Rev Med* 1990; 50: 249-261. https://doi.org/10.1146/annurev.med.50.1.249.
47. Baevsky RM, Ivanov GG, Chireikin LV, Gavrilushkin AP, Dovgalevsky PYa, Kukushkin YuA, et al. Analysis of heart rate variability using various electrocardiographic systems (part 1). *Journal of Arrhythmology* 2002; (24): 65-87. Russian. https://elibrary.ru/item.asp?id=9166688.
48. Sharma VK, Subramanian SK, Arunachalam V, Rajendran R. Heart Rate Variability in Adolescents – Normative Data Stratified by Sex and Physical Activity. *J Clin Diagn Res* 2015; 9(10): CC08-CC13. https://doi.org/10.7860/JCDR/2015/15373.6662.
49. Nazarenko SYu. Heart rate in adolescents in the Arkhangelsk region. PhD Dissertation. Arkhangelsk, Russia. 2007; 134 p. Russian. https://elibrary.ru/item.asp?id=19198242.
50. Friedman BH. An autonomic flexibility – neurovisceral integration model of anxiety and cardiac vagal tone. *Biol Psychol* 2007; 74(2): 185-199. https://doi:10.1016/j.biopsycho.2005.08.009.
51. Abushalbaq OM, Khdour HY, Abo Hamza EG, Moustafa AA, Herzallah MM. Investigating principal working memory features in generalized, panic, and social anxiety spectrum disorders. *Front Psychiatry* 2021; 12: 701412 https://doi.org/10.3389/fpsyt.2021.701412.
52. Wang Z, Luo Y, Zhang Y, Chen L, Zou Y, Xiao J, et al. Heart rate variability in generalized anxiety disorder, major depressive disorder and panic disorder: A network meta-analysis and systematic review. *J Affect Disord* 2023; 330: 259-266. https://doi.org/10.1016/j.jad.2023.03.018.
53. Ponomarev VV. The impact of sunlight deficit on the anxiety level of the indigenous population in the Arctic. *Scientific Bulletin of the Yamal-Nenets Autonomous District* 2022; (4): 108-119. Russian. https://doi.org/10.26110/ARCTIC.2022.117.4.006.

54. Gribanov AV, Dzhos YS, Bagretsova TV, Biruykov IS. Photoperiodism and changes in brain bioelectric activity in schoolchildren in the arctic zone. *Hum Physiol* 2016; 42: 128-136. Russian. https://doi.org/10.1134/S0362119716020067.
55. Rajendra Acharya U, Kannathal N, Mei Hua L, Mei Yi L. Study of heart rate variability signals at sitting and lying postures. *Journal of Bodywork and Movement Therapies* 2005, 9(2): 134-141 https://doi.org/10.1016/j.jbmt.2004.04.001.
56. Farah BQ, Andrade-Lima A, Germano-Soares AH, Christofaro DGD, Gomes de Barros MV, Luiz do Prado W, et al. Physical Activity and Heart Rate Variability in Adolescents with Abdominal Obesity. *Pediatr Cardiol* 2018; 39(3): 466-472. https://doi.org/10.1007/s00246-017-1775-6.
57. Mikhayjlov VM, Fil'kina OM, Shanina TG. Heart Rate Variability Physiological Norm Parameters Limits in Healthy Teenagers in Dependence of Sex and Training Level. *Ultrasound and Functional Diagnostics* 2009; (3): 67-73. Russian. https://elibrary.ru/item.asp?id=12931287.
58. Shlyk NI. The heart rate and regulation type of children, teenagers and sportsmen. Izhevsk: «Udmurt university», 2009; 254 p. Russian. https://elibrary.ru/item.asp?Id=19551410.
59. Krivonogova O, Krivonogova E, Poskotinova L. Heart rate variability, time estimation and internet-dependent behaviour in 16-17-year-old adolescents: A study in russian arctic. *Life (Basel)* 2021; 11(6): 497. https://doi.org/10.3390/life11060497.
60. Porges SW. Physiologic regulation in high-risk infants: a model for assessment and potential intervention. *Development and Psychopathology* 1996; 8(1): 43–58. https://doi.org/10.1017/S0954579400006969.
61. Vanderlei FM, Rossi RC, de Souza NM, de Sá DA, Gonçalves TM, Pastre CM, et al. Heart rate variability in healthy adolescents at rest. *J Hum Growth Dev* 2012; 22(2): 173-178 http://hdl.handle.net/11449/73743.
62. Porges SW. Vagal tone: a physiologic marker of stress vulnerability. Pediatrics 1992; 90(3 Pt 2): 498-504. https://pubmed.ncbi.nlm.nih.gov/1513615.
63. Lombardi F, Malliani A, Pagani M, Cerutti S. Heart rate variability and its sympatho-vagal modulation. *Cardiovasc Res* 1996; 32(2): 208-216. https://doi:10.1016/0008-6363(96)00116-2.
64. Pine DS, Wasserman GA, Miller L, Coplan JD, Bagiella E, Kovelenku P, et al. Heart period variability and psychopathology in urban boys at risk for delinquency. *Psychophysiology* 1998; 35(5): 521-529. https://doi.org/10.1017/s0048577298970846.
65. Mezzacappa E, Tremblay RE, Kindlon D, Saul JP, Arseneault L, Seguin J, et al. Anxiety, antisocial behavior, and heart rate regulation in adolescent males. *J Child Psychol Psychiatry* 1997; 38(4): 457-469. https://doi.org/10.1111/j.1469-7610.1997.tb01531.x.
66. Karelin A. Big encyclopaedia of psychological tests. Moscow, Russia: Eksmo. 2007: 36-38.
67. Collection of psychological tests. Part I: Handbook. Compiled by E. E. Mironova. Minsk: Women's Institute ENVILA. 2005: 19-20.
68. The Scales, Tests and Questionnaires for Medical Rehabilitation. Moscow, Russia: Antidor, 2002: 71.

Authors:
Natalia K. Belisheva – MD, DSc, Corresponding member of International Academy of Ecology, Man and Nature Protection Sciences, Chief Researcher in Arctic Human Adaptation Laboratory, Kola Science Centre of the Russian Academy of Science, Apatity, Russia. https://orcid.org/0000-0002-5504-2983.
Alla A. Martynova – PhD, Head of the Arctic Human Adaptation Laboratory, Kola Science Centre of the Russian Academy of Science, Apatity, Russia. https://orcid.org/0000-0002-0701-8698.
Sergei N. Kolomeichuk – PhD, Head of the Laboratory of Genetics, Proteomics and Metabolomics University Research Institute of Biotechnology, Tyumen, Russia. https://orcid.org/0000-0003-3104-3639.

ISSN 2304-3415, Russian Open Medical Journal
2024. Volume 13. Issue 4 (December). Article CID e0416
DOI: 10.15275/rusomj.2024.0416

Supplementary 1. Questionnaire SAM

Questionnaire SAM [43, 66-68]

Used to assess Self-Esteem of health (SeH), Activity (Act) and Mood (Md).

Purpose: to determine how favorable the state of SeH, Act, Md of the respondent.

Description of the method: the questionnaire consists of 30 pairs of opposite characteristics, on which the respondent is asked to assess his or her own well-being. Each pair represents a scale, in according to a person marks the degree of actualization of this or that characteristic state.

Processing and evaluation of results: when counting, the extreme degree of expression of a pair's negative pole is scored one point, and the extreme expression of a pair's of the positive pole of the couple is seven points. It should be taken into account that the poles of the scales constantly change, but positive states always get high scores, and negative ones get low scores.

The resulting scores are grouped according to the key into three categories and the number of points for each of them is calculated.

Self-Esteem of health (sum of points on the scales): 1, 2, 7, 8, 13, 14, 19, 20, 25, 26.

Activity (sum of points on scales): 3, 4, 9, 10, 15, 16, 21, 22, 27,28.

Mood (sum of points on scales): 5, 6, 11, 12, 17, 18, 23, 24, 29, 30.

The results obtained for each category are divided by 10. The scores exceeding 4 points indicate a favorable state of the examinee, scores below 4 indicate the opposite. Normal state scores lie in the range 5.0 - 5.5 points.

It should be taken into account that when analyzing the functional condition it is not only the values of its individual parameters that are important, but also their correlation.

Instructions: You are offered to describe your current state of health with the help of a table, consisting of 30 polar signs. You must, in each pair, choose the characteristic that most accurately describes your condition and mark the number that corresponds to the degree (strength) of expression of this characteristic.

1. Feeling good	3210123	Feeling bad
2. Feeling strong	3210123	Feeling weak
3. Passive	3210123	Active
4. Sedentary (Low mobility)	3210123	Mobility
5. Funny	3210123	Sad
6. Good mood	3210123	Bad mood
7. Employable	3210123	Broken
8. Full of energy	3210123	Exhausted
9. The Slow	3210123	Fast
10. Inactive	3210123	Active
11. Happy	3210123	Unhappy
12. Vivacious	3210123	Gloomy
13. Tense	3210123	Relaxed
14. Healthy	3210123	Sick
15. Uninvolved	3210123	Passionate
16. Indifferent	3210123	Excited
17. Enthusiastic	3210123	Dull
18. Joyful	3210123	Sad
19. Rested	3210123	Tired
20. Fresh	3210123	Weary
21. Sleepy	3210123	Arousaled
22. Desire to rest	3210123	Desire to work
23. Calm	3210123	Concerned
24. Optimistic	3210123	Pessimistic
25. Hardy	3210123	Tired
26. Cheerful	3210123	Sluggish
27. Thinking is hard	3210123	Thinking is easy
28. Distracted	3210123	Attentive
29. Full of hope	3210123	Disappointed
30. Satisfied	3210123	Dissatisfied

ISSN 2304-3415, Russian Open Medical Journal
2024. Volume 13. Issue 4 (December). Article CID e0416
DOI: 10.15275/rusomj.2024.0416

Supplementary 2. The matrix of distances between variables

Euclidean distance

	StA	*TrA*	*ShE*	*Act*	*Md*	*HR*	*D-index*	*RMSSD*	*LF/HF*	*HFnu*	*LFnu*	*HF%*	*LF%*	*VLF%*
StA	0	13	163	168	163	231	123	44	169	79	169	120	46	32
TrA	13	0	160	164	160	235	129	47	166	74	174	116	50	34
ShE	163	160	0	5	2	392	280	159	10	103	327	50	182	175
Act	168	164	5	0	5	396	284	163	9	108	332	54	186	180
Md	163	160	2	5	0	392	280	159	11	103	328	50	182	175
HR	231	235	392	396	392	0	135	248	397	301	81	348	218	222
D-index	123	129	280	284	280	135	0	128	285	192	70	237	107	121
RMSSD	44	47	159	163	159	248	128	0	165	73	185	114	67	54
LF/HF	169	166	10	9	11	397	285	165	0	111	332	59	186	181
HFnu	79	74	103	108	103	301	192	73	111	0	243	54	110	87
LFnu	169	174	327	332	328	81	70	185	332	243	0	286	148	163
HF%	120	116	50	54	50	348	237	114	59	54	286	0	143	132
LF%	46	50	182	186	182	218	107	67	186	110	148	143	0	60
VLF%	32	34	175	180	175	222	121	54	181	87	163	132	60	0

Spearman rank correlations

	StA	*TrA*	*ShE*	*Act*	*Md*	*HR*	*D-index*	*RMSSD*	*LF/HF*	*HFnu*	*LFnu*	*HF%*	*LF%*	*VLF%*
StA	1.00	**0.76**	-0.23	-0.33	0.08	0.20	0.04	0.15	-0.06	0.12	-0.12	0.15	-0.18	0.16
TrA	**0.76**	1.00	-0.39	-0.15	-0.07	0.34	-0.28	-0.11	-0.19	0.24	-0.24	0.24	-0.29	0.16
ShE	-0.23	-0.39	1.00	0.42	**0.60**	0.02	0.01	0.00	-0.02	-0.02	0.02	-0.07	0.11	-0.15
Act	-0.33	-0.15	0.42	1.00	0.29	-0.11	0.10	-0.19	0.06	-0.15	0.15	0.01	0.42	**-0.66**
Md	0.08	-0.07	**0.60**	0.29	1.00	-0.06	-0.10	0.09	-0.20	0.22	-0.22	0.17	-0.14	-0.06
HR	0.20	0.34	0.02	-0.11	-0.06	1.00	**-0.65**	**-0.62**	0.24	-0.19	0.19	-0.19	0.09	0.08
D-index	0.04	-0.28	0.01	0.10	-0.10	**-0.65**	1.00	**0.65**	0.07	-0.14	0.14	-0.02	0.26	-0.33
RMSSD	0.15	-0.11	0.00	-0.19	0.09	**-0.62**	**0.65**	1.00	**-0.47**	**0.46**	**-0.46**	**0.43**	-0.35	0.14
LF/HF	-0.06	-0.19	-0.02	0.06	-0.20	0.24	0.07	**-0.47**	1.00	**-0.95**	**0.95**	**-0.90**	**0.78**	-0.31
HFnu	0.12	0.24	-0.02	-0.15	0.22	-0.19	-0.14	**0.46**	**-0.95**	1.00	-1.00	**0.93**	**-0.86**	0.37
LFnu	-0.12	-0.24	0.02	0.15	-0.22	0.19	0.14	**-0.46**	**0.95**	-1.00	1.00	**-0.93**	**0.86**	-0.37
HF%	0.15	0.24	-0.07	0.01	0.17	-0.19	-0.02	**0.43**	**-0.90**	**0.93**	**-0.93**	1.00	**-0.65**	0.06
LF%	-0.18	-0.29	0.11	**0.42**	-0.14	0.09	0.26	-0.35	**0.78**	**-0.86**	**0.86**	**-0.65**	1.00	**-0.75**
VLF%	0.16	0.16	-0.15	**-0.66**	-0.06	0.08	-0.33	0.14	-0.31	0.37	-0.37	0.06	**-0.75**	1.00

Missing data removed pairwise. Marked correlations are significant at p<0.05.