ORIGINAL ARTICLE

CONTENTS

Structural analysis of prognostic diagnostics of cardiovascular system adaptive capacity and assessment of psycho-physiological resistance to stressogenic cognitive loads

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ABSTRACT

Aim: To conduct a structural analysis of cardiological signs of adaptation to stressogenic cognitive loads by identifying factor features of correlations between heart rate variability (HRV) and coping-testing data indicators.

Materials and Methods: 43 people aged 19.7±1.8 years (23 boys and 20 girls) were monitored for their HRV. Methods included DC-06000 portable ECG recorder, 3X series "badge" type (single channel) and COPE Test. The study process includes four stages.

Results: As a result of further factor correlation analysis, it was revealed that Factor 1 "HRV Stress Indicators" has a negative correlation ($p<0.05$) of "moderate" strength $\rho s= -0.363$ with Factor 2 "Strategies to avoid problems and stresses" and a positive correlation of "weak" strength $\rho s=0.167$ with Factor 3 "Psychoemotional Indicators". If two factors correlate with each other, it indicates they are related and can interact, which is important for adequate interpretation of the results of factor analysis.

Conclusions: Structural analysis of the complex of cardiological signs of adaptivity to stressogenic cognitive loads and coping-testing data revealed the existence of three correlated factors: Factor 1 "HRV Stress Scores", Factor 2 "Strategies to avoid problems and stress", Factor 3 "Psychoemotional indicators". The revealed negative correlation of Factors 1 and 2 may indicate that in case the impact of Factor 2 "Strategies to avoid problems and stress" increases, the intensity of Factor 1 "HRV Stress Scores" (i.e., stress signs according to the indicators of heart rate variability) may decrease.

KEY WORDS: medicine, students, electrocardiography, heart rate, cognition

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INTRODUCTION

An assessment of a person's resilience to stress can be performed by analyzing coping strategies. Coping strategies are the ways people, consciously or unconsciously, choose to minimize the impact of stress and/or overcome it [1]. There are many various coping strategies, but they can be summarized in several groups such as: (a) problem-oriented strategies, which are aimed at solving the problems that caused stress, including planning, information searching, problem diagnosing and developing strategies to solve it; (b) emotionally-oriented strategies, which are aimed at reducing emotional tension resulted from stress, including relaxation, meditation, social support, and search of inner peace; (c) socially oriented strategies, which are aimed at maintaining and increasing social support in difficult life situations, including seeking help, support and participation in group activities; (d) preventive strategies that aim to prevent stress before it occurs, including a healthy lifestyle, healthy diet, physical activity, and other positive behavioral patterns (stereotyped actions).

To assess a person's resilience to stress, one can apply coping strategies study methods, which envisage conducting of coping-tests using different variations of questionnaires, e.g.:

1. Ways of Coping Questionnaire (WAYS) is 66-items standardized questionnaire on coping strategies that people use in different situations, it has been developed in 1988 by S. Folkman and R. Lazarus [2].
2. The Stress Questionnaire allows us to measure the level of stress experienced by a person.
3. The Singapore Women's Health Study questionnaire is used to determine the stress influence on women's health and can be used to compare the results with normative data.
4. The Perceived Stress Scale is a brief 10-items questionnaire allowing us to assess the level of stress perceived by a person [3].

The data from these questionnaires can be collected in the form of national and international databases that contain results of surveys of various population groups, in particular people who are getting education [4-7].

These data can be instrumental in assessment of the extent to the results of a particular survey differ from those that might be expected for the general population. In the process of comparing survey results with normative data, it is important to consider factors such as age, gender, ethnicity, cultural peculiarities and other factors that may affect the survey results.

Several methods can be used to assess a person's resilience to stress, based on the results of analysis of questionnaires on coping strategies:

1. Quantitative data analysis. Coping strategies questionnaire may contain questions allowing us to collect quantitative data that permit to determine which coping strategies a person uses in different situations. These data can be analyzed to investigate which coping strategies are associated with stress levels reduction and improving stress resilience.
2. Qualitative data analysis. The questionnaire may also contain questions allowing us to collect qualitative data on how a person perceives and reacts to stress.
3. Comparison of results. The results of the questionnaire can be compared with normative data to find out the extent a particular individual differs from the general population in terms of use of coping strategies use and stress resilience.
4. Interview and observation. In addition to the questionnaire, other methods such as interviews and observation can be used to collect additional information on how a person responds to stress and how he/she uses coping strategies. These methods can complement and extend the data obtained from the questionnaire.

AIM

To conduct a structural analysis of cardiological signs of adaptation to stressogenic cognitive loads by identifying factor features of correlations between heart rate variability (HRV) and coping-testing data indicators.

MATERIALS AND METHODS

In order to improve the existing methods of prognostic diagnostics of the cardiovascular system adaptability and evaluation of psycho-physiological resilience to stressogenic cognitive loads, 43 people aged (mean ± standard error) 19.7±1.8 years (23 boys and 20 girls) who are getting higher medical education were monitored for their HRV. Data were collected using a DC-06000 portable ECG recorder, 3X series "badge" type (single channel), before and after research application of immersive technology with stressogenic loads on visual-spatial cognitive functions and entered into a computer through "Harmony" specialized software for further streamlining and analysis. Coping-testing data were collected using the COPE Test (Coping Orientation to Problems Experienced Inventory) questionnaire.

The study group inclusion criteria were as follows: previous experience with immersive technologies, written consent to voluntary participation in the examination, absence of contraindications for the examination. Exclusion criteria comprised the following: presence of acute respiratory viral infections (ARVI), presence of significant psycho-physical stress during 8 hours before the study, refusal to be examined after the study start at any of its stages. Taking into account the current legislation requirements, all subjects gave their written consent to participate in the study and consent for personal data processing prior to the study.

The received data received statistical analysis by the licensed software IBM SPSS Statistics Base v.22; sublicense No138 issued on 04.08.2016, licentiate LTD "Prognostic decisions". Correlation analysis is required to establish the presence and determine the strength of linkage between the heart rhythm vegetative stability under stress and the results of measured stress resilience and stress response based on coping-testing indicators. To identify the indicators, that can jointly indicate prognostically significant stress response parameters, the matrix of Spearman's rank correlation ρs coefficient values, which refers to indicators of strength of relationship evaluation (dependence of feature variation). In this case, qualitative characteristic of the correlation is determined using the Chaddock scale (the strength of correlation) and Promax rotation factor correlations. Applicability of the data set for factor analysis has been tested and confirmed using the Kaiser-Meyer-Olkin test (KMO-test). KMO-test yielded a value of 0.612 for the Overall MSA (Measure of sampling adequacy), that is adequate for factor analysis. Additional verification was carried out using p-value Bartlett's test, with a result of $p<0.001$ indicating that factor analysis can be applied to reduce the number of variables to fewer factors explaining most of the variance in the available data.

The study was conducted in compliance with the standards of the Declaration of Helsinki and approved by the independent ethics committee at Bohomolets National Medical University (Kyiv, Ukraine). All students gave their written informed consent to participate in the study. All data from the students were anonymized prior to the analysis.

Institutional Review Board of SI "Public Health Center MoH of Ukraine" gave positive conclusion for bioethics examination #241 from 17 November 2022.

The study process includes four stages. The first stage involved 20 minutes psychological monitoring by means of the automated psychodiagnostic complex "Person Psychological Safety" [8, 9], using the COPE Test questionnaire.

In order to assess a person's resilience to stressful loads based on HRV data, HRV characteristics of a person under stress and in a state of relaxation can be compared. That was the reason why the second stage of the study involved monitoring of HRV indicators in students who were under stress and mobilized their functional reserve prior to conducting a research application of immersive technology with loads on visual-spatial cognitive function [10]. Recording of HRV indicators readings in pre-stress mobilization state was performed with a portable cardiograph (model DC-06000) [11], which recorded ECG indicators in three leads aVR, aVL, aVF (Einthoven triangle) using disposable silicone electrodes. This allowed the research team to reduce the time of an individual examination procedure to 10 minutes, including limb electrodes attaching, HRV indicators recording and electrodes removal, which meets the requirements of a short-term HRV monitoring [12].

Third stage of the study involved introduction of stressogenic load on visual-spatial cognitive function of the participants. Students wore VR glasses (Oculus Quest 2 128Gb model), took two motion controllers (sticks) and were immersed in virtual reality for 10 minutes, interacting with Sharecare You program (Sharecare Inc.) [14], which is used to study fundamental clinical disciplines, in particular human anatomy, with active involvement of immersive technologies. At the fourth stage of the study, having completed the loading process on participants' visual-spatial cognitive function, the students' HRV indicators were repeatedly recorded.

RESULTS

We done correlation analysis between HRV indicators and variables associated with COPE Test methodology. List of designation of variables associated with HRV indicators of study participants included Frequency of heart rate (FHR), Stress index (SI), Functional condition according to Baevsky, The degree of mental stress according to Mashin, Emotional state index (ESI), Psychoemotional index, low frequency/ high frequency (LF/HF), Vegetative balance index (VBI), standard deviation of adjacent RR intervals (SDNN), square root of the average sum of squares of the differences between the following RR-intervals (RMSSD).

Also, list of designation of variables associated with the study participants results of coping-testing applying COPE Test methodology included Positive reformulation and personal growth, Perceived avoidance of a problem, Concentration on emotions and their active expression, Use of instrumental social support, Active coping, Stressful event denial, Evaluation of a problematic situation as useful, Humor as a means of relieving stress and tension, Behavioral avoidance of a problem, Expecting more favorable environment to solve a problem, Use of emotional social support, Sedative drugs use.

Table 1 presents the correlation matrix of specific statistically significant links between variables of HRV indicators and coping strategy characteristics.

As a result of the correlation analysis, the list of specific HRV indicators and coping strategies with correlation links was revealed. In identified cases illustrated in Table 1, the strength of correlation measured with Cheddock scale was "moderate" ($0.3<|\rho s|<0.5$), statistically significant ($p<0.05$) and predominantly negative, i.e., increasing value of one study variable is associated with a decreasing value of the variable correlated with it.

In Table 1 attention should be paid to numerous negative correlations of the HRV indicators of "Vagosympathetic interaction index" LF/HF under pre-stress mobilization state with the following coping strategies: (a) "Perceived avoidance of a problem" ($\rho s=-0.343$); (b) "Concentration on emotions and their active expression" ($\rho s=-0.319$); (c) "Stressful event denial" ($\rho s=-0.356$); (d) "Behavioral avoidance of a problem" ($\rho s=-0.322$) and (e) "Use of emotional social support" ($\rho s=-0.321$). The revealed correlations can be interpreted as possible connection of the stress-induced increase of the value of the vagosympathetic interaction index of LF/HF HRV with relatively low indicators of certain coping strategies that fall into conditional "avoidance-denial" category.

It is under the influence of stressogenic cognitive load, which activates the sympathetic nervous system and consequently affects HRV, that we can expect a moderate increase of LF/HF index, indicating a predominance of sympathetic activation over a parasympathetic one [14]. In our study, the value of LF/HF index in pre-stress mobilization state turned out to be 20 % higher (VBI – vegetative balance index) than LF/HF in the relaxation state. However, the relevant confidence interval (95 % CI) for VBI has a value ranging from -1 to 69 and contains "0" on the left margin, which requires additional clarification of the statistical reliability of the identified difference between LF/HF in the mobilization and relaxation states. LF/HF index is one of numerous HRV indicators [15], it does not fully reflect individual features of cardiovascular system regulation during stress. However, in some cases, an increase of LF/HF index may indicate the effective mobilization of the body resources to overcome stress, which suggests high stress resilience.

Table 1. Correlation matrix of statistically significant links between variables of HRV indicators and coping strategies characteristics

Coping strategies	HRV indicators					
	Frequency of heart rate (FHR)	Stress index (SI)	The degree of mental stress according to Mashin	Emotional state index (ESI)	LF/HF	Vegetative balance index (VBI)
Perceived avoidance of a problem	-	-	-	-	-0,343*	-
Concentration on emotions and their active expression	-	-	-	-	-0,319*	-
Active coping	0,337*	-	0,307*	-	-	-
Stressful event denial	-	-	-	-	-0,356*	-
Evaluation of a problematic situation as useful	-	-	-	-0,302*	-	-
Behavioral avoidance of a problem	-0,329*	-0,327*	-	-	-0,322*	-0,302*
Use of emotional social support	-	-	-	-	-0,321*	-

Note: * – the difference is significant in comparison with the original data ($p<0,05$).

Table 2. Factor loadings Matrix for HRV indicators and coping strategies

Variable	Factor 1	Factor 2	Factor 3
RMSSD	-0.921	-	-
SDNN	-0.910	-	-
Vegetative balance index (VBI)	0.832	-	-
Stress index (SI)	0.812	-	-
Frequency of heart rate (FHR)	0.590	-	-
Perceived avoidance of a problem	-	0.661	-
Behavioral avoidance of a problem	-	0.622	-
Concentration on emotions and their active expression	-	0.582	-
Use of emotional social support	-	0.564	-
Stressful event denial	-	0.499	-
Expecting more favorable environment to solve a problem	-	0.435	-
Emotional state index (ESI)	-	-	0.965
Psychoemotional index	-	-	0.912

To determine the relationships structure of HRV indicators and coping test data in the context of the resilience analysis and adaptive capacity to stressogenic cognitive loads, it is sensible to apply factor analysis, which allows us to find hidden dependencies between the observed variables, conduct reduction of data dimensionality and identify the main factors associated with common properties of aggregated groups of variables, which are significant for predictive evaluation of stress resilience in further research.

Based on the conducted research factor analysis using Promax rotation of combinations of 25 variables, the factor loadings matrix has been formed. Factor loadings matrix presented in Table 2 reflecting the significance of each variable in each of the three determined, but not yet interpreted, factors.

The factor loadings matrix was formed by three factors, which, after data reduction, included 13 most important components amongst the initial 25 variables. Factor 1 has the highest eigenvalue of 4.185 among all factors and explains the highest variance proportion of 27.9 % in the overall variability of all data. Factor 2 has an eigenvalue of 2.131 and explains 14.2 % of the variance in the total variability of the data. Factor 3 has an eigenvalue of 1.640 and explains 10.9 % of the variance in the overall data variability.

Factor Loadings are key factor characteristics that show the correlation degree between each of the vari-

ables and the corresponding factor. Factor Loadings with a value higher than 0.3 is considered sufficiently strong, and a value higher than 0.5 is considered very strong.

Factor 1 is loaded by (i.e., the factor structure contains) the following HRV indicators (in decreasing order of FL and, accordingly, significance of the indicator): RMSSD (FL=-0.921); SDNN (FL=-0.910); Vegetative balance index – VBI (FL=0.832); tension index – TI (FL=0.812) and frequency of heart rate – HR (FL=0.590), which determines the choice to name the Factor 1 – "HRV Stress Scores" (HRVSS). The variable coping strategy "Frequency of heart rate" correlates with the rest of the variables ($p<0.05$) with a "significant" strength of relationship ($0.5<|\rho s|<0.7$ according to the Cheddock scale). Other variables Stress index, Vegetative balance index, SDNN, RMSSD correlate between each other ($p<0.05$) with "high" ($0.7<|\rho s|<0.9$) or "very high" ($0.9<|\rho s|< 0.99$) strength of relationship.

Factor 2 is loaded by (i.e., the factor structure contains) the following coping strategies (in decreasing order of FL): "Perceived avoidance of a problem" (FL=0.661), "Behavioral avoidance of a problem" (FL=0.622), "Concentration on emotions and their active expression" (FL=0.582), "Use of emotional social support" (FL=0.564), "Denial of a stressful event" (FL=0.499), "Waiting for more favorable conditions to solve a problem" (FL= 0.435), which determines the choice of the name for Factor 2 – "Strategies to avoid problems and stress" (APSS).

It should be noted that coping strategy "Perceived avoidance of a problem" with maximum of FL=0.661 is the only one, which moderately correlates with nearly all other variables (except coping strategy "Denial of a stressful event") which load Factor 1, namely: (a) Spearman correlation coefficient with coping strategy "Concentration on emotions and their active expression" $\rho s=0.323$ ($p=0.035$); (b) with coping strategy "Behavioral avoidance of a problem" $\rho s= 0.421$ ($p=0.005$); (c) with coping strategy "Waiting for more favorable conditions to solve a problem" $\rho s= 0.302$ ($p=0.049$) and (d) with coping strategy "Use of emotional social support" $\rho s= 0.361$ ($p=0.018$).

Factor 3 is loaded by the following indicators that are indirectly related to HRV (in decreasing order of FL): emotional state index – ESI (FL=0.965), psychoemotional index (FL=0.912), which determines the choice to name Factor 3 – "Psychoemotional indicators" (PEI).

As a result of further factor correlation analysis, it was revealed that Factor 1 "HRV Stress Indicators" has a negative correlation ($p<0.05$) of "moderate" strength $\rho s= -0.363$ with Factor 2 "Strategies to avoid problems and stresses" and a positive correlation of "weak" strength $\rho s=0.167$ with Factor 3 "Psychoemotional Indicators". If two factors correlate with each other, it indicates they are related and can interact, which is important for adequate interpretation of the results of factor analysis. Factor 2 APSS and Factor 3 PEI have no statistically significant correlation with each other. Negative correlation of Factor 1 and Factor 2 may indicate that in case of increased impact of Factor 2 "Strategies to avoid problems and stress", the intensity of Factor 1 "HRV stress indicators" (i.e., signs of stress by heart rate variability indicators) may decrease.

Based on the results of factor analysis of correlations between the heart rate variability indicators under stressogenic cognitive loads and coping-testing data, the main factors were defined, namely: Factor 1 "HRV stress indicators", Factor 2 "Strategies to avoid problems and stresses", Factor 3 "Psychoemotional indicators" and the relationship between them was described. These outputs may be instrumental for understanding the interaction between physiological and psychological processes and improving the existing methods for prognostic diagnostics of the cardiovascular system adaptivity and evaluation of psychophysiological resilience to stressogenic cognitive loads.

DISCUSSION

HRV indicators and coping testing can be interrelated due to their respective relationship with the functioning of the autonomic nervous system and the specificity of psychophysiological reactions to stressors, which are partially determined by individual preferences regarding coping strategies. The verification of this hypothesis involved the use of correlation matrices and factor analysis by the authors [16] with further interpretation and validity of the obtained results. Our research in practice showed the validity of this hypothesis, by revealing a negative correlation of Factor 1 and Factor 2, and, accordingly, a reduction in signs of stress according to HRV indicators.

A decrease in HRV may be associated with a poor functioning of the autonomic nervous system, which may cause an increase in stress levels and a decrease in stress resistance. Studies have shown that a higher level of stress resistance of a person can be associated with a higher level of HRV [17]. In addition, effective coping with stress can reduce stress levels and improve the functioning of the autonomic nervous system, which in turn can increase HRV.

However, during the analysis of the obtained data, we found that effective coping strategies do not always correspond to positive coping strategies. Thus, Factor 2, which corresponds to coping "Strategy to

avoid problems and stresses", refers to distress and is a manifestation of maladaptation.

Numerous scientific publications investigate various aspects of cognitive loads and their impact on human productivity and health, and also discuss the mechanisms underlying the relationship between cognitive loads and stress [18, 19].

In view of the data published in other sources, we received confirmation that the training and further professional activity of specialists whose functions are related to making quick decisions in conditions of increased responsibility requires an analysis of the potential stressogenic effect of cognitive loads and an analysis of the cardiological signs of adaptation to such stress-induced states. Thus, it is important to improve and optimize tools for diagnosing the adaptive capacity of the cardiovascular system and assessing psycho-physiological resistance to stressful mental and emotional loads.

CONCLUSIONS

1. As a result of the conducted analysis of the data of monitoring of heart rate variability readings and coping testing data in the age category of 19.7±1.8 years, a relevant structure of factor correlations was revealed, and prognostically significant cardiological signs and coping strategies for adaptation to stressogenic cognitive loads were substantiated.
2. Structural analysis of the complex of cardiological signs of adaptivity to stressogenic cognitive loads and coping-testing data revealed the existence of three correlated factors: Factor 1 "HRV Stress Scores", Factor 2 "Strategies to avoid problems and stress", Factor 3 "Psychoemotional indicators".
3. The revealed negative correlation of Factors 1 and 2 may indicate that in case the impact of Factor 2 "Strategies to avoid problems and stress" increases, the intensity of Factor 1 "HRV Stress Scores" (i.e., stress signs according to the indicators of heart rate variability) may decrease. Justification of this correlation provides the prerequisites for improving the prognostic diagnosis of a person's adaptive potential to the impact of stressogenic cognitive loads.
4. In the context of further improvement of techniques applied to evaluate cardiological signs of individual stress resilience, it seems relevant and important to expand the subpopulation of persons who can be involved in the study of the structure of indicators' correlation between heart rate variability and coping testing in the context of immersive technology with loads on visual-spatial cognitive function.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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