Chapter 37

Prospect of Creating a Virtual Reality System with Feedback for the Correction of the Patient's Psychological State Based on the Results of the Analysis of Arterial Pulsations Registered during Blood Pressure Measurement Using the Oranta-AO Information System

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Abstract

Introduction: Nowadays, the timely diagnosis of anxiety levels and its psychotherapeutic correction is an important issue.
Objective: To investigate the impact of video imagery of "sound of water" on vegetative balance for the purpose of creating a virtual reality system for psychological rehabilitation.
Materials and Methods: 80 students aged 18-23 were examined before and after 5 minutes of viewing the video composition "sound of water." As an audiovisual influence, a patient rehabilitation module with virtual reality was integrated into the medical information system Oranta-MIS. The cardiovascular system, autonomic nervous system, and their regulatory mechanisms were studied using proposed methods through time and spectral analysis of arterial oscillations (AO). The level of personal anxiety was determined using the method of C.D. Spielberger, and the degree of neuroticism was assessed using G. Eysenck's method.
Results: Some strong correlation links were observed between the level of personal anxiety and indicators of heart rate variability, reflecting the state of sympathetic and parasympathetic branches of the autonomic nervous system. These correlations have allowed us to the predict a person's stress level. A positive and calming impact of viewing "sound of water" compositions on the state of the autonomic nervous system and the psycho-emotional status of the subjects was registered.
Conclusions: The application of "sound of water " listening within virtual reality systems with biofeedback is effective and can be helpful in controlling the anxiety levels and conducting psychotherapeutic correction. The analysis of arterial oscillations in a virtual reality setting could serve as a marker in assessing a person's psycho-emotional state.

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1. Introduction

The modern pace of life, the psychological consequences of the COVID-19 pandemic, social and economic changes contribute to an increase in the level of anxiety and depressive disorders, psychoemotional stress, psychological maladjustment, and reduced stress resistance. Among these issues, the prevalence of these problems among students is also on the rise (Frankov, 2006). Timely diagnosis of anxiety levels and its psychotherapeutic correction are important challenges in today's conditions.

Assessment of heart rate variability allows us to determine the state of the autonomic nervous system (ANS) (Bayevsky et al., 2001; Heart, 1996 & Kifer et al. 2019). After all, heart rate variability characterizes the variability of time intervals between heart contractions, and accordingly, its analysis reflects the state of regulatory mechanisms and their resistance to the influence of physical and psychoemotional factors (Bayevsky et al., 2001; Heart, 1996). Therefore, this technique serves as an indicator of psychoemotional maladjustment and is used for rapid diagnosis of the functional state of the body. Increased activity of the parasympathetic division of the autonomic nervous system is considered a marker of stress resistance. In recent years, scientists have been interested in arterial oscillography as a promising simple and highly informative method for assessing the variability and quality of adaptation.

The authors Vakulenko D. & Vakulenko L. (Selskyy et al., 2018; Romaniv et al., 2022; Martseniuk et al., 2007, 2018, 2020, 2021, 2022; Mintser et al., 2020 & Vakulenko et al., 2015, 2017 - 2022) developed a program for using electrocardiogram indicators in the analysis of pulse oscillations of peripheral vessels on arterial oscillograms recorded during blood pressure measurement. Since the amplitude of the pulse wave is proportional to the lumen of the vessel, the use of this method allows to estimate peripheral blood flow. By performing mathematical analysis of oscillograms using time and spectral methods, it is possible to estimate the relationship between the sympathetic and parasympathetic parts of the autonomic nervous system and, accordingly, their role in vascular tone (Vakulenko et al., 2015, 2019, 2022).

Some researchers have found a clear association between neuropsychological status and heart rate variability characteristics (Golukhova et al. 2012). Despite these points, an important issue to address the correction of disorders caused by stress and anxiety-depressive disorders is the method of biofeedback on heart rate variability parameters. Today, trainings aimed at increasing parasympathetic tone are relevant, as they have a positive effect on people's health, prevent the occurrence of cardiovascular disease and various kinds of neuroses. Differentiated relaxation techniques can solve the problem of stress resistance in the future (Paul et al., 2012; Kovaleva et al., 2013).

There are a number of scientific papers devoted to this topic, but the effect of watching video fragments on the state of vascular tone has not been studied. Accordingly, assessing the state of stress resistance by the parameters of the data of mathematical analysis of arterial oscillograms, it is possible to analyze the initial psychological state of the subject and, using a feedback system, directly influence it by selecting pictures and video fragments that can evoke

positive emotions. It is an undeniable fact that viewing images causes the emergence of peculiar emotions that can be reflected both in the variability of the heart rate and in the electroencephalogram (EEG). In particular, viewing images with different emotional colors causes changes in EEG rhythms (Kovaleva et al., 2012), with a number of authors emphasizing the beta range (Miskovic et al., 2010).

Our attention has been drawn to a number of scientific publications that emphasize the calming effect of exposure to natural sounds (the sound of a waterfall, rain, wind, birds chirping, etc.) (Alvarsson et al., 2010). For example, (Ulrich, 2020) highlighted in his research that exposure to the natural environment has a restorative effect and evokes positive emotions. According to his research, watching videos depicting nature contributed to faster recovery from stress. The advantage of exposure to favorable sounds (50 dBA) of the natural environment over the noise of the urban environment and their advantage in recovering from stress was also studied. In this case, variability indicators were often used (Alvarsson et al., 2010). There is evidence that the sounds of wind and birds chirping significantly reduce the activity of salivary gland amylase, which serves as a marker of psychoemotional stress (Vakulenko et al., 2015, 2021). In fact, influencing with the help of a virtual environment, using the sounds of nature, natural landscapes, and other imitations, is a very promising idea that requires more detailed study.

Virtual reality (VR) is a three-dimensional model of reality created by computer and creating the effect of human presence in it. Virtual reality, by affecting the sensory system, can cause unconditional emotional reactions. The study of the impact of VR systems on humans and, in particular, on anxiety disorders is considered a promising area (Diemer et al., 2014 & Lindner et al., 2017). If earlier virtual reality helmets were used as entertainment, today the head-mounted displays of Oculus RIFT, HTC Vive and others are equipped with various sensors built into the helmet and connected to other devices and sensors that monitor the physiological state of systems and organs.

Accordingly, the impact of visual and sound virtualization on a biological object and, accordingly, the further use of this impact to correct anxiety disorders is quite promising.

The information capabilities of the blood pressure measurement procedure are endless. From 2010 to 2023, the authors of the study went from an idea to the development and implementation of an information system for conducting scientific research aimed at studying, substantiating and implementing into practice methods for analyzing arterial pulsations recorded during blood pressure measurement in 2000 patients (more than 4000 AO).

In 2021, clinical trials were conducted, and the Oranta-AO information system was certified as a medical device for implementation in various fields of medicine, rehabilitation, sports, education, in a telediagnostic information system and tele-rehabilitation with feedback.

The results of the research are reflected in publications (Selskyy et al., 2018; Romaniv et al., 2022; Martseniuk et al., 2007, 2018, 2020, 2021, 2022; Mintser et al., 2020 & Vakulenko et al., 2015, 2017 - 2022) and in sections of the monograph Arterial oscillography: New capabilities of the blood pressure monitor with the Oranta-AO information system (Vakulenko D. et al., Chapter 1-43, 2023). This Chapter presents a fragment of the results of our latest research.

2. Objective

The aim of our work was to study the effect of the video image of "murmuring water" on the autonomic balance with the prospect of creating a VR system for psychological rehabilitation. To achieve this goal, we studied the state of the autonomic system in students, as they are at risk of stressing their regulatory systems, which is associated with exam stressful situations, unusual, for their perception, distance learning in a pandemic. It is indisputable that the prevalence of maladaptive disorders among students ranges from 5.8 to 61.35% (Frankov, 2006).

3. Materials and Methods

We examined 80 students (45 males, 35 females) of TNTU named after I. Puluj and I. Gorbachevsky TNMU in Ternopil, Ukraine. The study was conducted in two stages. At the first stage, the level of anxiety was determined and the parameters of heart rate variability at rest were evaluated; at the second stage, the similar parameters were determined after a five-minute exposure to the video composition "murmur of water," which reflected the murmur of water in streams. As an audiovisual impact, the patient rehabilitation module using virtual reality, which is integrated into the Oranta-MIS medical information system, was used (Figure 1). This rehabilitation tool is a component of the rehabilitation program.

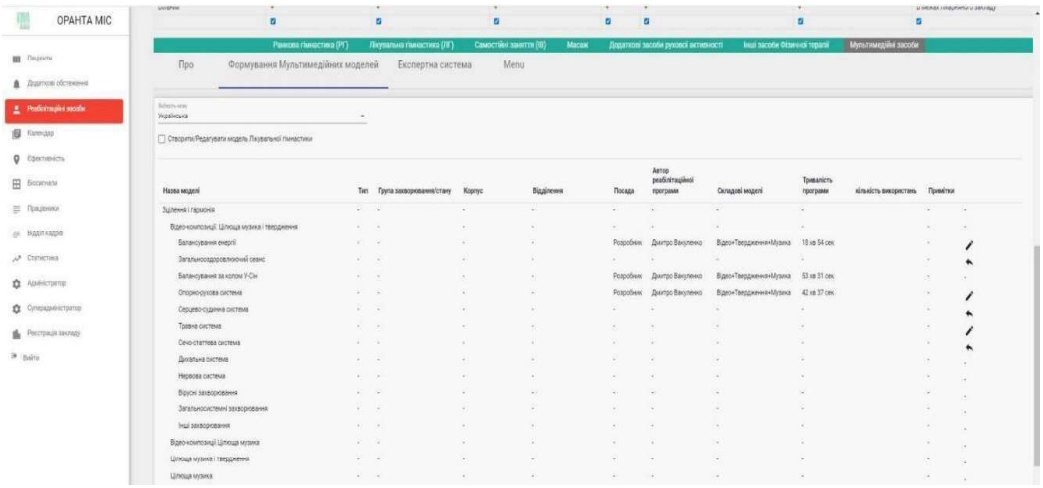

Figure 1. Web interface for the formation of a rehabilitation program based on the virtual reality environment.

The state of the autonomic nervous system was assessed by the indicators of the arterial oscillogram recorded during the measurement of blood pressure by an electronic blood pressure monitor VAT 41-2. The arterial oscillograms were analyzed using special computer programs developed by Vakulenko D. & Vakulenko L. (Selskyy et al., 2018; Romaniv et al., 2022; Martseniuk et al., 2007, 2018, 2020, 2021, 2022; Mintser et al., 2020 & Vakulenko et al., 2015, 2017 - 2022). Pulsation indices of oscillograms were evaluated by maximum (positive)

extremes - max (during the passage of the systolic wave, cardiac component) and minimum (negative) extremes - min (during diastole, vascular component).

The state of vegetative balance and levels of control of the cardiovascular system were assessed by the indicators of time and spectral analysis of arterial oscillograms. The time indices of the oscillograms were studied in the form of IN, IVR, BP, RMSSD, where IN is the stress index, IVR is the autonomic balance index, BP is the autonomic rhythm index, and RMSSD is the square root of the average sum of squares of differences between adjacent NN intervals. IVR was estimated as an index equal to the ratio of the amplitude of the mode of the histogram of the distribution of cardiac integrals to the difference between the maximum and minimum cardiac intervals in the sample. This index depends on the ratio between the activity of the sympathetic and parasympathetic parts of the autonomic nervous system. In turn, BP and RMSSD indicators characterize the degree of influence of the parasympathetic link of regulation, the lower the BP, the more parasympathetic regulation prevails, and RMSSD reflects the ability of the sinus node to concentrate the heart rate. An indicator sensitive to the increase in the tone of the sympathetic link of the autonomic circuit is IN, which reflects the degree of tension of the regulatory systems and the predominance of the activity of central regulatory mechanisms over autonomic ones.

The physiological meaning of the spectral analysis of the arterial oscillogram (by analogy with the variability of the heart rate of the electrocardiogram) is that it assesses the relationship of individual levels of control over both the heart rhythm (Opanasiuk, 2011) and vascular activity (Vakulenko et al., 2015, 2019 - 2022). The spectral indices were evaluated: ULF, VLF, LF, HF. Accordingly, ULF are ultra-low frequency waves (less than 0.0033 Hz), VLF are very low frequency waves (0.04 - 0.0033 Hz), LF is the low-frequency component of the spectrum (0.04-0.15 Hz) and HF is the high-frequency component of the spectrum (0.15 - 0.4 Hz). At the same time, LF and VLF characterize the sympathetic tone, and HF characterizes the parasympathetic tone (Fazekas et al., 1993 & Alvarsson et al., 2010). The exact origin of ULF remains unknown; it is believed that this range reflects the activity of the higher centers of heart rate regulation. An increase in this indicator is characteristic of a failure of heart rate adaptation.

The level of personality anxiety was determined by the method of C.D. Spielberger, the degree of neuroticism was determined by the method of G. Eysenck, using 23 questions on the neuroticism-stability scale (Diemer et al., 2014).

Statistical analysis of the results was performed using the software package “OscEcgReoPuls.” The statistical evaluation of the reliability of the indicators was carried out using the Student's criterion.

4. Results

Among the examined students, 30 (37.5%) had a level of personal anxiety of more than 45 points, and 25 (31, 25%) had a high degree of neuroticism. Still, the samples with low and moderate levels of personality anxiety remained dominant. These indicators were especially closely correlated with the indicators of spectral analysis, such as LF and HF. In fact, there was a close negative correlation between HF and anxiety, while LF showed a close positive correlation. The LF index has been repeatedly described in the scientific literature as stress-regulating, because it is a well-known fact that high levels of anxiety are associated with

activation of the sympathetic nervous system. An increase in HF indicates an increase in adaptive reserves, so this indicator was significantly higher in students with low and moderate anxiety.

As you can see from Table 1, viewing the video composition "murmuring water" caused a significant and reliable dynamics of the studied indicators both in the group with and without an initial high level of anxiety. In the general sample of students, during the time analysis of arterial oscillograms by maximum (positive) extremes, a sharp increase in IN (activity of the central control circuit), IVR (activity of the sympathetic part of the ANS) and a decrease in BP, RMSSD (activity of its parasympathetic part) were recorded. The above indicates that watching the video composition "Water" contributes to an increase in the centralization of the effect on heart activity, and cerebral ergotropic effects increase. At the same time, the vascular component reacted differently, there was a significant decrease in the influence of the sympathetic link of the ANS on the state of the vessels (Kifer et al. 2019; Martseniuk et al., 2007, 2018 & Vakulenko et al., 2015, 2019 - 2022). This is evidenced by the indicators registered by the minimum (negative) extremes: a significant decrease in IN, IVR and an increase in BP ($P<0.05$). In fact, the vascular component of the effect was manifested by a sharp decrease in sympathicotonia (Table 1).

Table 1. Temporal analysis of heart rate variability by the indicators of maximum (pos) and minimum (neg) extremes of arterial oscillograms recorded before the examination and after watching the video composition "murmur of water" (n=80)

Indicator.	At rest	After visualization
IN-pos	17.61±1.642	33.35±9.673*
IVR-pos	44.7±3.27	108.64±17.384*
BPpos.	0.71±0.048	0.2928±0.028*
RMSSD	0.12±0.019	0.075±0.006*
AMo- neg	43.05±2.480	25.05±2.113*
IN- neg	45.29±4.034	10.89±0.810*
IVR-neg	109.45±10.781	29.45±2.372*
BP-neg	0.31±0.043	0.857±0.018*

Note: * - $p<0.05$ - significant changes between the initial state and water.

The obvious difference between the indicators of time analysis by positive and negative extremes confirms the ambiguous effect of visualization of video fragments on both the central and vascular circuits. In fact, the sympathetic link of the autonomic nervous system increased in the central circuit, while in the vascular circuit it decreased and the balance shifted toward the parasympathetic.

The spectral analysis (Table 2) of arterial oscillograms made it possible to study and evaluate the effect of different levels of regulation of the cardiovascular system, namely, directly on the state of the vessels. The reliable dynamics of all the studied indicators when the subjects were "immersed" in virtual reality with the help of the video composition "water murmur" is noteworthy. In the course of the study, there was a significant increase in HF(%) and LF(%). Moreover, the increase in the HF component was dominant, which indicates a favorable effect of the video composition on the autonomic balance and fully coincides with the fact that the HF component plays a role in the ability to self-regulation, to optimal autonomic regulation (Chamos et al., 2013). In contrast to the above HF and LF indicators, the percentage of oscillations of the very low frequency VLF in the total spectrum power and the

ultra-low frequency ULF significantly decreased to almost the same extent (-51% and -53%). The decrease in VLF power also indicated a decrease in humoral regulation and the activity of the sympathetic component of regulation.

Table 2. Spectral analysis of arterial oscillograms recorded by the total power of the signal spectrum recorded before the examination and after watching the video composition "murmur of water" (n=80)

	At rest	After visualization	
%ULF	2.33±0.104	1.14±0.25*	-51%
%VLF	35.98±6.63	17.03±1.96*	-53%
%LF	13.56±1.23	16.25±1.54*	+20%
%HF	48.13±5.81	64.63±3.43*	+34%

Note: * - $p<0.05$ - significant changes between the initial state and water.

Thus, watching the video composition "murmur of water" contributed to a decrease in the influence of the sympathetic part of the ANS on the state of blood vessels, reducing psychoemotional stress. This is evidenced by a decrease in the percentage of ULF and VLF in the total frequency spectrum and a pronounced increase in HF (high-frequency component of the spectrum, which corresponds to the level of activity of the parasympathetic link of regulation).

Thus, an automated system for forming a component of a patient's rehabilitation program using virtual reality with feedback to correct the patient's psychophysiological state should include a unit for taking an arterial oscillogram, a data processing unit, and a unit for audiovisual impact.

Feedback involves the assessment of the time and spectral characteristics of the arterial oscillogram and the tracking of their changes under the audiovisual influence of the multimedia environment. Particular attention is paid to the indicators characterizing the state of the sympathetic link by time IN and spectral LF and VLF, and, accordingly, the parasympathetic link by time BP, RMSSD and spectral HF. The video image will be presented under the control of achieving vegetative equilibrium. VR glasses can be used as a block for audiovisualization.

Conclusion

The frequency analysis of heart rate variability serves as an indicator of the state of regulatory mechanisms, including the nervous system and psychological state. There are close correlations between the level of personal anxiety and indicators of heart rate variability, which reflect the state of the sympathetic and parasympathetic parts of the autonomic nervous system and can be used to predict the level of stress in a person. The analysis of heart rate variability under the influence of viewing "water murmur" compositions by time and spectral methods showed a positive calming effect and the feasibility of using this technique in virtual reality systems with feedback, which will help control the level of stress and influence the appropriate video fragments. The selection and analysis of the arterial oscillogram in such a virtual reality system will serve as a marker in assessing the psychological state of a person, and the video image of the composition "Murmur of Water" will allow to correct the patient's psychological state.

The prospect of further research is to study the effect of various video fragments on autonomic balance and to develop a rehabilitation automated virtual reality system with feedback based on automated selection and analysis of arterial oscillograms for use in stress management.

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