IMPACT OF STRESS ON HEART RATE VARIABILITY

Penio Lebamovski[1]

Abstract: The present article traces the impacts of stress on Heart Rate Variability (HRV). The stress can be caused either through sports or a 3D serious game that simulates real life situations. The study aims to perform an analysis and evaluation of HRV in both cases. One approach is to track the impact of running on HRV. It has been found that sport increases HRV by increasing sympathetic activity. At the same time, it has been proven that professional athletes and special forces have both a high sympathetic tone and a higher parasympathetic tone than ordinary people. Another approach to a stressful situation is through Virtual Reality (VR). Not everyone can be subjected to physical exertion for various reasons; therefore the use of virtual reality in medical diagnosis is important. Two virtual reality systems can be used in medical diagnosis: systems with and without immersion. Science has proven that the greater the immersion in virtual reality, the greater the sympathetic tone. Therefore, the sympathetic tone is most active in VR immersion systems such as Head Mounted Display (HMD).

UDC Classification: 616.1; **DOI**: https://doi.org/peb.v3.315

Keywords: HRV, HMD, Poincare plot, running athletes, VR

Introduction

Heart Rate Variability measures the variation between heartbeats, which depends on physical, psychological, and medical conditions etc. (Mirza, 2012). It is essential to monitor the level of HRV of athletes (Morgan et al., 2017). People with high HRV adapt relatively quickly than others to stimuli. Those who lead a sedentary lifestyle have a lower HRV than people with active lifestyles. Regular sports and exercise increase HRV and reduce mortality (Morgan et al., 2017). While analysing the HRV of short, medium, and long distances runners, it was found that their performance is influenced by the audience's behaviour at the stadium. Literature highlights the effect of endurance training on HRV. The level of oxygen saturation is essential here. In athletes, there is an increase in HRV through maximum oxygen uptake. Other factors affecting HRV are genetics, age, gender, diet, sleep, and rest. These factors also affect endurance.

Aim/Purpose The aim of the study was to determine the impact of stress on HRV. HRV was recorded when respondents were at rest, in virtual environment, and while running. The objective of the study was to determine the parasympathetic tone by the Poincare method by one-hour recording using a Holter device.

Literature Review

Autonomic nervous system

The brain controls the cardiovascular system, heart, and blood circulation (Aubert et al., 2003), and the Autonomic Nervous System (ANS) is highly important, as it includes the sympathetic and parasympathetic parts. These two parts of the ANS complement each other, as the sympathetic division increases the heart rate while the parasympathetic division decreases it. Analysis of heart rate variability can be helpful in training athletes (Aubert et al., 2003). It is crucial to determine the sympathetic signal. HRV is the most appropriate method for controlling the sympathetic and parasympathetic parts (Aubert et al., 2003). The anatomical nervous system controls the body's vital functions, such as respiration, digestion, heart rate, blood pressure and the functioning of all organs. On the other hand, the sympathetic nervous system improves the body's physiological activities, especially under stress. Stress could be caused either in sports or through 3D simulation through serious 3D game. When the parasympathetic division of the autonomic nervous system is activated, the body should rest and recover. During sports exercises, the athlete goes through the following three stages: stage of anxiety, phase of resistance, and overtraining stage. To avoid the third stage in running training, it is necessary to create a program for the athlete to prevent injuries and improve athletic performance. The anatomical nervous system has two subsystems: the sympathetic and parasympathetic nervous system. Depending on the situation, the sympathetic nervous system, gives the signal to "escape" or "fight." It determines the difference between the champion and the participant. It improves the physiological activity of the body under stress. The second subsystem, parasympathetic, counteracts the body's response to the sympathetic nervous system's signal and helps create favorable conditions for rest and recovery. Compared to ordinary people, athletes at the Olympic level and Special Forces have a stronger sympathetic reaction during the

[1] Bulgarian Academy of Sciences, Institute of Robotics, Bulgaria; p.lebamovski@abv.bg, penko_13a@abv.bg

competition and a more vital parasympathetic impulse during rest. "Anxiety stage" is the first reaction of a healthy body to a new stimulus. The next stage is the "Overstrain" or "Resistance Stage," which is the body's response to the imbalance between exercise stress and recovery. The third stage is called "Chronic stress," "Overtraining stage," or "exhaustion." This stage occurs if the body does not adapt to chronic stress for a long time.

3D in Heart Rate Variability

Today, 3D stereoscopic visualization technology is mainly used in the entertainment and film industry (Jinwu, 2014). With the development of computer graphics, technologies for 3D stereoscopic visualization, and 3D stereo television, it should be expected to find widespread application in several other fields, such as medicine, architecture, education, and others (Bogdanova G. N., 2019) (Bogdanova G. T., 2013). 3D technologies can be used to apply VR to create stressful situations, which combined with combination with analytical methods, will provide researchers with new opportunities to analyse HRV in various physiological, pathological, and stressful conditions. Immersion and non-immersion are two types of stereoscopic virtual reality systems. Immersion systems require considerable resources for equipment and machinery, for e.g. Cave Automatic Virtual Environment (CAVE) and Head Mounted Display (HMD) (Figure 2). Immersion-free systems, such as 3D monitors and virtual reality glasses, are relatively inexpensive, offering features like immersion systems. Immersion systems (CAVE) are projection systems that use techniques to project images onto the walls, ceiling, and floor, in a cube-sized room. Subsequently, one can walk around the room using special stereo glasses, after which the system provides information about the image (Minkovska, 2013). While using this system, it was found that its sympathetic activity is significantly higher than in other systems (Malinska, 2015). Immersion-free systems are desktop computers in which the virtual world is displayed on a specialized stereoscopic monitor, and the user should be equipped with active 3D glasses (Minkovska, 2013). With these systems, virtual reality's effect is significantly smaller than immersive systems. The advantage of these systems is that they are more affordable to use because they are relatively inexpensive. There is also the possibility of 3D traditional visualization, which does not depend on additional hardware and software, and can be implemented on any computer. VR is a computer-based technology for simulating the effects (visual, auditory, tactile) of an artificially generated environment on the human senses, giving the individual an impression that he or she is "immersed" in reality (LaValle, 2016; Piovesan, 2012; Petkov, 2010; Pantelidis, 2009). The main difference of VR from other computer technologies for displaying information (for example, large displays, screens, etc.) is that there is "feedback" on human influences on it, i.e. the virtual environment changes adequately to an individual’s reactions through interactivity. The term “augmented reality” is a technology that expands the possibilities of virtual reality. It adds new information in the form of text and images. Mixed reality is a combination of virtual and augmented reality (Pancheva, 2012).

Characteristics of Virtual Reality HeadSet

VR helmets can be classified as low, medium, and high-class headsets. This classification is related to their technical indicators, for e.g., low class headsets are phone-dependent, middleclass headsets are autonomous depending on the Play Station 3, while high-end headsets are computer-dependent. All three types of helmets could be used in medicine, like for HRV assessment. A high-end virtual reality helmet, HMD Odyssey + , is used in the present study. It uses computer hardware, and at the same time, the helmet enhances the capabilities of Windows 10, and Mixed Reality as its operating system. The portal for this platform is a part of Windows 10. The device is suitable for simulation and training processes. For creating 3D serious games, the main feature of the helmet is "Head Tracking" - 6Dof. Another critical feature is Eye Tracking, which tracks eye movement. Thanks to this feature, the game describing the results in this article is launched. The limitation of this hardware is that it must be connected to a computer via a cable to work, which creates discomfort by restricting free movement. Visualizations settings depend on the position and orientation of the eyes. If the observer changes the position of his/her head, the view/camera must change accordingly. The Java programming language to create serious games. Java 3D offers the following features for Head Tracking: View, Sensor, Physical Body, and Physical Environment. 6Dof - six degrees of freedom is a device that provides 3D location and orientation information.

Virtual Reality Application

The VR in medicine –can be used in rehabilitation and for treating phobias. The patients can use it from their homes and do not have to go for the consultation, this is a great advantage, especially for people with reduced mobility. VR technology that allows the user to observe and interact simultaneously with the simulated environment like reality. When the user moves his head, the camera/view begins to rotate around the x, y, and z axes of space. Interaction with the 3D environment should be done through buttons, joystick, or 6Dof device. Research confirms that computer games have a great potential to improve educational processes.

Serious games

Serious games are used for scientific purposes not fun (Paunova). Such games can be of any genre, use any technology, should be developed for any platform and are simulation based. This computer simulation simulates a real-world situation and it is considered a kind of game. The player can explore a 3D version in a severe virtual world, like an avatar. The use of 3D simulation of the virtual world for educational purposes has increased significantly. Serious games simulate an actual situation with fictional characters and different scenarios. Here the player is immersed in a virtual world similar to the real one. Serious games for stress simulations should not be too extreme for the study, for a more extended period by recording RR (PP) interval series using an electrocardiographic, photoplethysmographic or Holter device (Gospodinov, 2019). The generated signals are analysed mathematically (Cheshmedziev, 2018).

Poincare method for HRV analysis

Mathematically HRV analysis can be done with linear and nonlinear methods (Ackharya et al., 2007; Ernst, 2014; Khandoker, 2013; Mirchev, 1998). Linear methods are standardised and used in clinical practice, while nonlinear methods are active research (Gospodinova, 2019). The characteristic of these mathematical methods is that they are universal and are used for data analysis in other scientific fields. This paper uses the nonlinear Poincaré – method (Khandoker, 2013; Smith, 2009). Poincaré's method is a new technique used for analysing HRV. It is a nonlinear graphical method, and its graph is placed on the two-dimensional coordinate axis. In it, each RR interval is plotted on the two-dimensional coordinate system. Each interval (previous and next) has coordinates (x, y). The line of identity is a graph on which the values of the abscissa and the ordinate are equal. The graph shifts are relative to this line. Parameter SD2 lies on the identity line, and parameter SD1 is perpendicular to the identity line. Poincaré's graph can be analysed by placing an ellipse on the graph formed by Poincaré's points. Two adjacent RR intervals represent one point on the graph. The first value is on the x-axis, and the second is on the y-axis. SD1 (standard deviation 1) and SD2 (standard deviation 2), as well as the area of the ellipse, are mainly used to estimate HRV. The considered two perimeters carry information about the width and length of the ellipse. The recommended recording period is between 5 and 20 minutes. The lowest value is for a healthy subject. Value ratios are related to a specific disease. The QRS complex is an element of the Electrocardiogram (ECG), which may sometimes be wider. A QRS complex varies between 0.05 and 0.09 seconds. A normal value is 0.10 seconds; if the value is greater than 0.10 seconds, the QRS complex becomes pathological. Var (d_1) is the variance of the variable d, and at the same time, var (d_2) is the variance of the variable d. The value of α is 45 degrees, followed by rotation relative to the two-dimensional coordinate axis because the graph is placed on the two-dimensional coordinate axis. They are setting the abscissa and ordinate values for x and y, respectively. In this case, the use of vectors and matrices is convenient. The vector $\overrightarrow{RR_i}$ sets the values for x, and the values for y through the vector $\overrightarrow{RR_{i+1}}$. The following conditions apply (Mazhar, 2015):

$$SD1 = \sqrt{var(d_1)} \quad (1)$$

$$SD2 = \sqrt{var(d_2)} \quad (2)$$

$$d_1 = \frac{\overrightarrow{RR_i}}{\sqrt{2}} - \frac{\overrightarrow{RR_{i+1}}}{\sqrt{2}} \quad (3)$$

$$d_2 = \frac{\overrightarrow{RR_i}}{\sqrt{2}} + \frac{\overrightarrow{RR_{i+1}}}{\sqrt{2}} \quad (4)$$

$$\overrightarrow{RR_i} = (RR_1, RR_2, RR_3, \dots\dots\dots\dots\dots\dots\dots\dots RR_{N-1}) \quad (5)$$

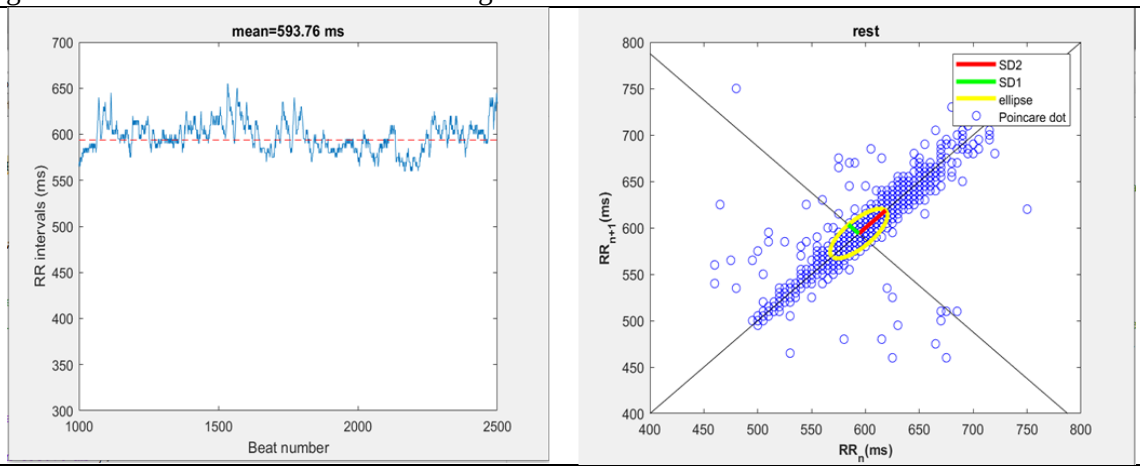
$$\overrightarrow{RR_{i+1}} = (RR_2, RR_3, RR_4, \dots\dots\dots\dots\dots\dots\dots\dots RR_N) \quad (6)$$

$$\begin{vmatrix} d_1 \\ d_2 \end{vmatrix} = \begin{bmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{bmatrix} \cdot \begin{vmatrix} RR_i \\ RR_{i+1} \end{vmatrix} \quad (7)$$

Results

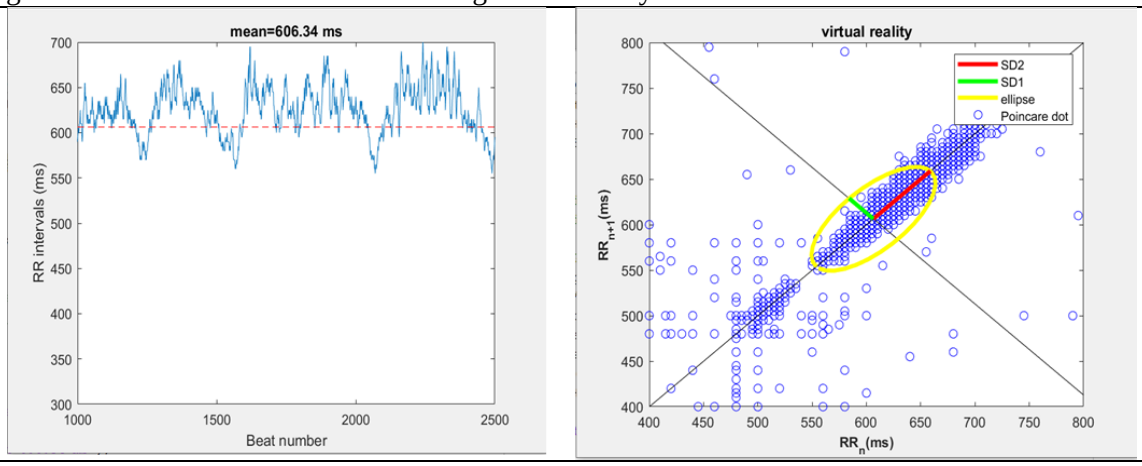
Three one-hour records are used to describe the results in this article: at rest, virtual reality, and running. The first five minutes cause a stressful situation followed by rest. A power runner-sprinter is being studied, mainly for 400 meters run. During the athlete's recovery period, when the parasympathetic tone is activated, an assessment of the impact of specific physical activity on HRV should be made. In this way, the athlete can be monitored, and the most appropriate training program can be compiled. This will essentially be able to protect the athlete from overload, fatigue, and unwanted injury and improve athletic performance and achievement. In athletics, specifically running disciplines, the Negroid race dominates. The coach must know how the athlete reacts to a stressful situation. The body of the three types of runners reacts differently to a specific physical activity, which requires compiling a different training program depending on the group to which the athlete belongs. After observing how the athlete reacts to the loads for about a month, it will be possible to determine by ECG what type of runner he/she is. Whether the runner should practice strength or endurance training. The results in this article are based on registered RR time interval series at rest and in stressful situations. Three, one-hour recordings were made using a Holter device to determine the parasympathetic tone, and the first 5 minutes were to assess sympathetic activity. The stressful situation was simulated using the 3D game Roller Coaster Apocalypse VR, using a virtual helmet HMD Oddysey +. The first recording started with 5 minutes of Virtual Reality and lasted with 55 minutes of rest (Fig.2). The second recording was made during a five-minute run and a 55-minute break (Fig.3). A 36-year-old strength athlete, 1.76 centimeters tall and weighing 76 kilograms was examined. The third recording is one hour at rest (Fig.1). The average value of the RR intervals at rest was 593.7621 ms (Fig. 3), and during a stressful situation through virtual reality, it increased to 606.3439 ms. During the run, the average value was 497.27. The Poincaré method was used to analyse the HRV. The ellipse in this method is characterised by length and width parameters. The length of the ellipse reflects the participation of non-respiratory components in the formation of total HRV. It is determined by parameter SD2. The ellipse's width considers long-term variations and demonstrates the contribution of respiratory arrhythmias to full HRV and is determined by the parameter SD1. At rest, it is observed that the Poincaré graph resembles an ellipse, where the parameter SD2 shows long-term variability, and it is almost equal to SD1, which determines the short-term value of HRV. On the other hand, during the stress caused by virtual reality, it is observed that the graph is also an ellipse of both parameters (SD2> SD1, ie 74.33> 31.68). Under running-induced stress, the chart is again elliptical, but the SD2 parameter is significantly larger than SD1, ie 56.61> 8.91. The resting state is 0.8199. The formula determines the face of the ellipses in the three cases: S = (SD1 * SD2 * pi) / 4. During running and recovery, the schedule of RR intervals is similar to that of a cardiac arrhythmia patient. It is also noticeable that the intervals decrease during running. During virtual reality, the intervals increase; this is clearly seen in their averages. The number of QRS complexes during running and then recovery significantly increased, which is due to the first 5 minutes of recording, i.e., during running; in this case, they are 7244 in number. During rest and virtual reality, about 1000 QRS complexes were compared to RR interval recordings. The number of QRS complexes is 40 more in the recording for HRV assessment during virtual reality than in the recording at 1 hour of rest. The game used for HRV analysis is too extreme and therefore does not allow long recordings longer than 5 minutes. As the feelings of nausea and discomfort started, the game must be stopped. It should also be noted that each person may react differently while recording and analyzing HRV through sports or virtual reality. The results in this article are based on the responses of a strength athlete. The other two types of running athletes will be studied in future studies. It is also assumed that the graphs of the three types of runners, i.e., power, endurance, and middle-distance runners, will be similar depending on the category in which they fall.

Figure 1: RR intervals and Poincaré' during rest



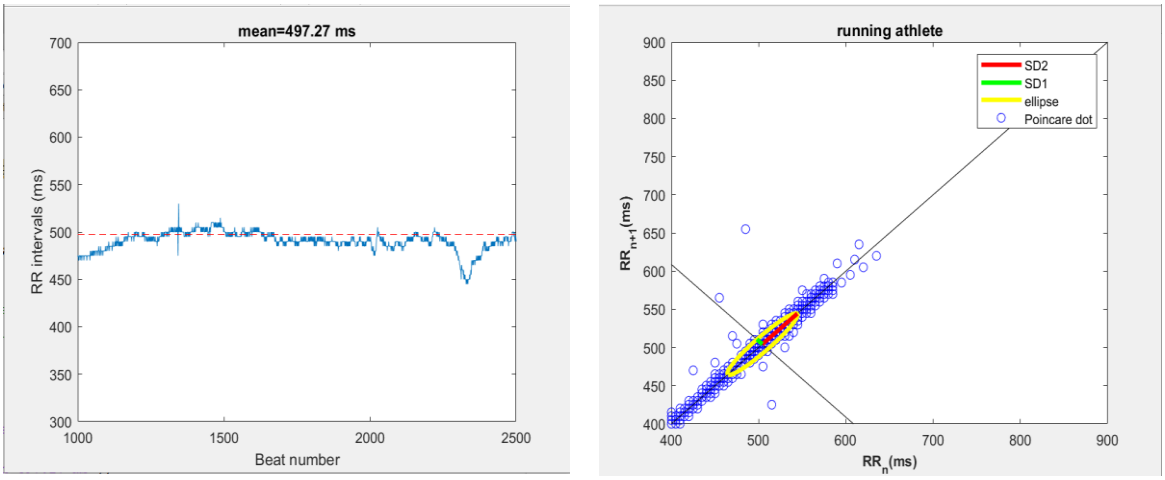
Source: Author

Figure 2: RR intervals and Poincare during virtual reality



Source: Author

Figure 3: RR intervals and Poincare during running



Source: Author

Conclusion

By applying the Poincaré method, a visual analysis of the HRV is performed, and the constructed graphic can be quantified by placing an ellipse on the graphic form. The ellipse is characterised by its length and width. The size of the ellipse reflects the participation of non-respiratory components in the formation

of total HRV. It is determined by the parameter SD2. The ellipse's width considers long-term variations and is determined by parameter SD1. It demonstrates the contribution of respiratory arrhythmias to full HRV. The results of the study are based on the three records of RR time intervals on a strength athlete. The first five minutes of the recordings assessed sympathetic activity, followed by a 55-minute assessment of parasympathetic activity. The QRS complexes during running and rest are 1000 more than in other records. The RR intervals during the study are similar to that of a arrhythmia patient. Poincaré's graphics in all three instances resemble an ellipse, being the most pronounced and larger in virtual reality. Future work will continue with a study of HRV among athletes. One approach of applying a stressful situation when assessing HRV is through 3D stereo film or a 3D serious game. In the future, work for simulating stressful situations, 3D serious games will be created based on 3D systems with immersion and/or without immersion. Also, the approaches proposed in this article to assess HRV will be applied to more patients and athletes. In this way, the behavior of each of the respective categories will be determined.

References

Ackharya, U., Suri, J., Spaan, J., Krishan, S. (2007). *Advances in Cardiac Signal Processing.* 121-165, Springer. doi:10.1007/978-3-540-36675-1

Aubert, S., Seps, B., Beckers, F. (2003). Heart Rate Variability in Athlets. *Sport medicine, 33*(12), 889-919. doi:10.2165/00007256-200333120-00003

Bogdanova, G. N. (2019). Digitization and Preservation of Digital Resources and Their Accessibility for Blind People, 184-206. IGI Global:Hershey. doi:10.4018/978-1-52225-7879-6.ch008

Bogdanova, G. T. (2013). Digitization and 3D scanning of historical artifacts. (pp. 133-138). Digital Presentation and Preservation of Cultural and Scientific Heritage.

Cheshmedziev, K. G. (2018). Obtaining the physiological data using the photoplethysmographic method. *CBU International Conference Proceedings*, 6, 870-874). doi:10.12955/cbup.v6.1265

Ernst, G. (2014). *Heart Rate Variabiliyu.* London: Springer-Verlag.

Georgieva, T. (2019). Investigation of Heart Rate Variability by Statistical Methods and Detrended Fluctuation Analysis. *CBU International Conference Proceedings*, 729-734. doi:10.12955/cbup.v7.1446

Gospodinov, M. C. (2019). Three Sensor Portable Information System for Physiological Data Registration. *Proceedings of CompSysTech 19 Proceedings of the 20th International Conference on Computer System and Technologies*, (pp. 36-41). New York. doi:10.1145/3345252.3345281

Gospodinova, E. (2019). Graphical Methods for Non-linear Analysis of Electrocardiographic Data. *CBU International Conference proceedings*, (pp. 864-869). doi:10.12955/cbup.v7.1497

Jinwu, K. X. (2014). Application of 3D stereoscopic visualization technology in casting aspect. *Chinese Casting, 11*(4), 308-313.

Khandoker, A. K. (2013). Poincare Plot Methods for Heart Rate Variability Analysis.

LaValle, M. (2016). Virtual Reality. 66-92. Retrieved from http://vr.cs.uiuc.edu/

Malinska, M. (2015). Heart Rate Variability (HRV) during virtual reality immersion. *International Journal of occupational saftey and ergonomics, 21*(1), 47-54. doi:10.1080/10803548.2015.1017964

Mazhar, B. E. (2015). Poincare Plot for Heart Rate Variability. *Engineering and Technology International Journal of Biomedical and Biological Engineering Vol:9, No:9*.

Minkovska, A. (2013). Virtualna realnost - edin nov nov pogled kam savremennoto obuchenie. 64-71.

Mirchev, S. (1998). Variabilnost na sardechnata chestota I standarti za izmervane na Sardechnosadovi zaboliavania. 28-35.

Mirza, M. L. (2012). A Comparative Study of Heart Rate Variability in Diabetic Subjects and Normal Subjects. *International Journal of Biomedical and Advance Research*, 640-644. doi:10.7439/ijbar.v3i8.542

Morgan, S., Mora, J. (2017). Effect off Heart Rate Variability Biofeedback on sport Performance, a systematic Review. *Springer*. doi:10.1007/S10484-017-9364-2

Pancheva, A. M. (2012). Dobavena realnost (Augmented Reality). Sashtnost I prilozenie. *V nazionalna konferenzia "Obrazovanieto v informazionnoto obshtestvo"*, (pp. 90-99).

Pantelidis, V. (2009). Reason to use Virtual Reality in Education and Training Courses and Model to Determine When to use Virtual Reality., (pp. 59-77).

Paunova, E. (n.d.). Inforrmazionnite tehnologii v pomosht na izgrazdaneto na znania.

Petkov, E. (2010). Educational Virtual Reality through a Multiview Autostereoscopic 3D Display, 505-508. Springer. doi:10.1007/978-90-481-9112-386

Piovesan, D. P. (2012). Virtual reality as a tool in Education, 295-298. Greece: IADIS Intrnational Conference and Cognition and Exploratory Learning in Digital age.

Smith, R. W. (2009). Dove Analyzing Heart Rate Variability in infants Using Non - Linear Poincare Techniques, 673-876.