Advanced Wireless Sensors Used to Monitor the Impact of Environment Design on Human Physiology

Erik VAVRINSKY[1,3,5], *Veronika KOTRADYOVA*[2], *Helena SVOBODOVA*[3,4], *Martin KOPANI*[3], *Martin DONOVAL*[1,5], *Samuel SEDLAK*[1], *Jan SUBJAK*[1,5], *Tomas ZAVODNIK*[1]

[1]Institute of Electronics and Photonics, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology, Ilkovicova 3, 812 19 Bratislava, Slovak Republic
[2]Institute of Interior and Exhibition Design/ BCDlab, Faculty of Architecture, Slovak University of Technology, Nam. Slobody 19, 812 45 Bratislava, Slovak Republic
[3]Institute of Medical Physics, Biophysics, Informatics and Telemedicine, Faculty of Medicine, Comenius University, Sasinkova 2, 813 72 Bratislava, Slovak Republic
[4]Department of Simulation and Virtual Medical Education, Faculty of Medicine, Comenius University, Sasinkova 4, 812 72 Bratislava, Slovak Republic
[5]NanoDesign ltd., Drotarska 19A, 811 04 Bratislava, Slovak Republic

erik.vavrinsky@stuba.sk, veronika.kotradyova@stuba.sk, svobodovahs@gmail.com, martin.kopani@fmed.uniba.sk, martin.donoval@stuba.sk, samuellsedlak@gmail.com, subjak.jan@gmail.com, tomyzav@gmail.com

DOI: 10.15598/aeee.v17i3.3310

Abstract. *This article describes modern wireless sensor devices and their application in the measurements of the human physiology. We used our own advanced ECG Holter device and EEG helmet to record the heart and brain activity impacted by different environments, materials, colors or body positions during work. In this paper, we want to show the interactions between humans and architecture design, which modify human work performance and well-being. This paper is a conclusion of the 3 different pilot studies, where different scopes of human-space interaction were explored. In the experiments, we aimed mostly at wood materials and their beneficial effects on the nervous system. The research in its actual state is primarily focused on optimizing the methods of the ECG data analysis from our Holter device and the EEG data from helmet. Based on these data, we will improve the methodology of the experiments for the next enhanced research with aspiration to automate data analysis.*

Keywords

ECG holter, EEG, environment design, human physiology, wireless sensors, wooden materials.

1. Introduction

Wireless devices used to monitor the human physiological parameters are very important for easy recording of individuals in many environments, where is not possible usage of wired laboratory devices. We realized various experiments, where the physiological parameters of the humans were explored.

The shape and choice of materials and colors influence human health, activity, psychic state, work efficiency and human well-being [1] and [2]. In general, it is possible to declare that the more natural materials in their authentic form and more nature-evoking solutions are present in the immediate surrounding environment of a human being during his long-term daily assets. The explanation comes from evolutionary biology and psychology. Natural materials are beneficial to the nervous system, which responds to something well known to him, which he does not need to constantly "scan". A nervous system, that is directly linked to our unconscious and genetic memory responds to natural materials, is gently stimulated and can be easily recovered. Natural materials are a part of our archetypes in the traditional material culture. Their use significantly contributes to the creation of a supportive environment and environment for well-being. Its positive properties for the comfort and health of the human, for the internal environment and its microclimates can be formulated as follows. It aggravates and softens the overall atmosphere of the space supporting coziness. It is aesthetically attractive - its shape and surface properties - the color of the wood is warm to earthy, its color, texture, structure, invoice can also soften and "warm" otherwise cold lighting in space. It has excellent haptic properties - contact comfort, especially by softwoods. Wood-based materials are well formable and adaptable to the shape of the human body. Thanks to the comfort features, they allow good control over the body positions and the possibilities of their variation. They also have antibacterial properties, especially pine, larch and oak. The wood regulates air humidity and emissions. It is a part of our culture, collective unconscious, and it is in genetic memory. However, in order to have an ecological meaning, it is necessary to apply natural materials from renewable raw materials from sustainable forestry or agriculture. Most of these strengths of wood are effective when the wood is free from any surface treatment. Application of the wood significantly supports regenerative effect of built- environment for the human nervous system and it can contribute to recovery in the health care facilities. Research in this area provides an evidence base of positive health impacts of wood used in the built environment [3]. However, the measurement of perception of aesthetical quality of materials is challenging [4]. Several methods for verification of user preferences might be implemented including surveys and hedonistic/preferences tests. They might provide quantitative and/or qualitative feedback. Selection of materials, as well as target groups of respondents, should be carefully planned in order to obtain reliable results. Assessment can be performed by using only visual stimuli or it can include other senses (in both cases, use of real or virtual samples can be implemented). Using the real samples and employing more senses than only vision (hearing, taste, smell and/or touch) during the assessment is a superior approach. Human perception tests might be supported by the measuring of physiological responses in order to provide a complete picture of human emotions [5].

Till now, we have prepared series of many experiments for optimization of the ECG Holter [6] and [7]. Below, we describe three already finalized experiments. In the 1st experiment, we monitored physiological parameters of the humans in various body positions, in the area with limits in space and diminished move which influence work efficiency and creativity during routine work. There was an aim to show the direct impact in different body postures by work, to show that not only standard right angle sitting, but also active sitting, perching, standing and relaxed posture are suitable for work, being effective or creative by working task. Thus, interior elements allowing these alternative postures can be included in the standard working environment and they can be a part of working culture. The 2nd experiment aimed to response of the humans to the different environmental settings. We developed an application to simulate various living spaces by virtual reality and measured response of the neural system. The application BCDapp was developed in 2014–2015 with the aim to found out the instrument to simulate the different environmental settings, namely by choice of materials and their surfaces and to see the impact of human well-being. The app also has its own evaluation mechanism that tells respondents the impact of their choice. In our continuing experiment, we also measured the physiological parameters of volunteers interacting with different materials - oak wood, chipboard and white laminate. Individuals were sitting in front of the selected material with closed eyes, then they touch it and finally, they were looking on these materials.

2. Material and Methods

In all experiments, we specifically measured heart rate and respiration activity using our own designed ECG Holter and brain activity by commercial EEG helmet Emotiv EPOC. All devices used for these experiments are wireless, therefore, they do not physically limit our volunteers. The experiments were done in BCD laboratory at Faculty of Architecture, STU.

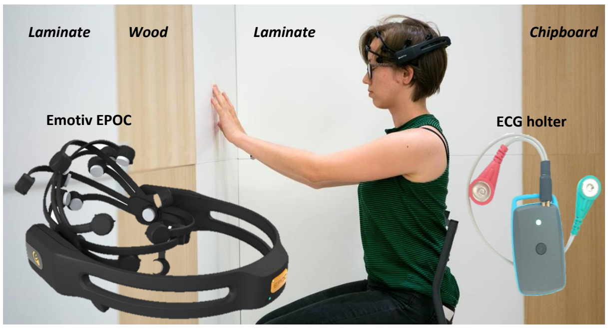

Fig. 1: Volunteer with wireless ECG holter on chest and EEG helmet Emotiv Epoc on head.

Designed Holter monitor (Fig. 1, Fig. 2 and Tab. 1) uses the latest advances available in the microelectronics today. The device was primarily designed for 24-hour daily monitoring of ECG and it can be useful in many clinical applications including diagnosis of arrhythmias, ischemia, or heart failure. The core of the Holter device are analog font-end Texas Instruments ADS1292R and microcontroller ATxmega 128A3. The ADS1292R is 2-channel, 24-bit, $\Delta - \Sigma$ AD converter with a built-in programmable gain amplifier, internal reference, and an on-board oscillator.

The ADS1292R incorporates all features commonly required in portable, low-power medical electrocardiogram with sports and fitness applications. Power consumption of one channel is only 335 µW. Used version also includes impedance measurement function where 32/64 kHz modulating square wave signal is driving the human body impedance trough known impedances. After demodulation and low pass (2–4 Hz) filtering, we can obtain the respiration. The ATxmega 128A3 is low power, high-performance 16-bit µcontroller featuring 128 KB flash program memory, 8 KB SRAM, 2048 Byte EEPROM, and up to 32 MIPS throughput at 32 MHz. The device is capable of achieving extremely low power consumption, which is required by both portable electronics and other battery-powered applications. The ECG Holter is extended by the gyroscope STMicroelectronics L3GD20, accelerometer with magnetometer STMicroelectronics LSM303D and barometer with temperature sensor Bosh BMP180. Total power consumption of the device is 3 mA (on 250 SPS). By using standard 120 mAh Li-Pol cell, system allows operating time over 40 hours. Ideal working time (25 hours) can be achieved on 500 SPS. Thanks to microcontroller implemented HRV (Heart Rate Variability) detection algorithms, ECG Holter can be switched in HRV mode (only HRV peaks are detected) for extended operation time of few days. Data are stored in CSV format to built-in 4 GB SD card, with possibility of conversion to +EDF format. The Holter is fixed to the human body using pre-gelled disposable Ag/AgCl electrodes. Optical signalization and trigger button are installed on the top of the Holter. Acoustic signalization and micro USB connector for recharging, data transfer and parameter set are located on the reverse side. Holter is equipped with real-time clock for time-log management. The real-time is after connecting of Holter to PC automatically set and corrected. Thanks to all these features, following the latest trends, we can use our device in wide range of experiments and monitoring in several scientific areas. In these experiments, the ECG Holter measures heart and respiration signals at sampling rate 500 Hz and acceleration on 100 SPS.

From these signals, we calculated Heart Rate (HR), Respiration Rate (RR), Respiration Volume (RV) and we did detailed HRV analysis [8] and [9]. The accelerometer was used only as a supplement to simplify evaluation and artifact suppression. The HR is reflecting activity of the autonomic nervous system, and the changes of this activity provide a suitable indicator of the human state and mood. HRV is often a first glance, where we can recognize good health - if HRV is higher, heart beats are more variable and person is readier for action, on the other hand, a low HRV is associated with increased arousal or ill health (it is a significant predictor of mortality from several diseases). The usage of HRV analysis is wide, not only for medical use, but also for measuring of the emotions, thoughts, behavior or feelings. From psychology studies, we know that HRV is associated with many factors, for example an increase in HRV is related to increased self-control abilities, greater social skills, and better abilities to cope with stress. In our HRV analysis, we used frequency-domain methods, data related to the amount of Low Frequency - LF (0.04–0.15 Hz), which represents a measurement of sympathetic nervous system activity. Sympathetic activity affects the body performance and is active in an attack, escape behavior or exceptional straining. Measurements of High Frequency - HF (0.15–0.4 Hz) correlate to parasympathetic activity which can be an expression of regeneration and the formation of body reserves. It takes care of relax and the rest. In addition, a ratio of LF and HF (LF/HF) can determine the information regarding the amount of sympathetic/parasympathetic nervous system activity. Low values represent relax, rest and energy saving, vice versa, high values mean increased performance and body strain [9], [10] and [11]. Very common visualization of HRV is a Poincare plot. The Poincare plot shows how well each RR interval predicts the next. A greater spread of values means an increased HRV, conversely, the closer bunching of the values together means less HRV. The typical Poincare scatter plots of the healthy controls exhibit a greater dispersion. There is significant correlation between LF and SD2, HF and SD1, and LF/HF and SD2/SD.

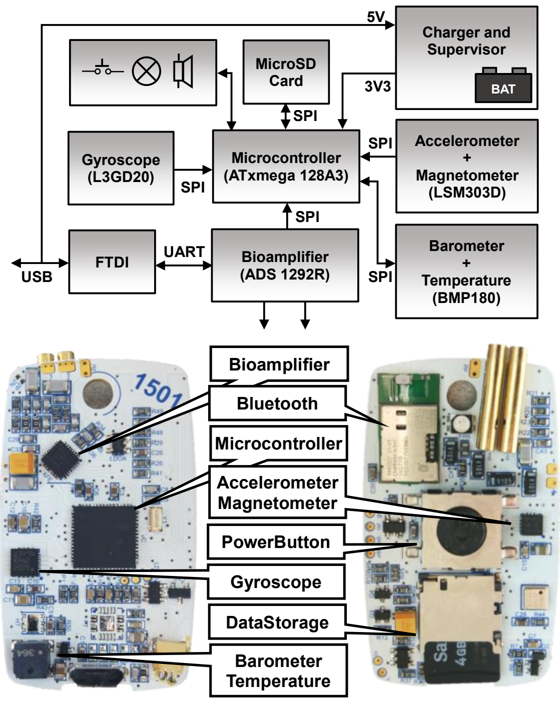

Fig. 2: ECG holter: Block diagram and PCB layout.

Next device used for measuring of the physiological parameters, concretely the brain waves, was an EEG

Tab. 1: Technical parameters of ECG holter.

Bioamplifier	**TI ADS 1292R**
Number of channels	2 Low-Noise PGAs
Programmable gains	1, 2, 3, 4, 6, 8 or 12
Resolution	24-bit, no data missing
Sampling rates	125–8000 SPS
Power	335 mW/channel
Input-referred noise	8 μV_{PP} (150 Hz BW, $G = 6$)
Input bias current	200 pA
CMRR	−105 dB
Built-in	Respiration impedance, measurement, oscillator and reference, RLD, lead-off, detection, test signals
Additional functions	Flexible power-down, standby
Microcontroller	**ATxmega 128A3**
Performance / speed	16-bit AVR / 32 MHz
Program memory SRAM	128 kB 8 KB
Acceleration sensor	**STMicroelectronics LSM303D**
Ranges	±2 g/±4 g/±8 g/±16 g (3D)
Resolution Sampling rate	16-bit 3–1600 SPS
Magnetometer	**STMicroelectronics LSM303D**
Ranges	2, 4, 8, 12 G (3D)
Resolution Sampling rate	16-bit 3–100 SPS
Gyroscope	**STMicroelectronics L3GD20**
Ranges	250, 500, 2000 dps (3D)
Resolution Sampling rate	16-bit 95–750 SPS
Barometer	**Bosh BMP180**
Ranges	300–1100 hPa
Resolution Sampling rate	16-bit 2–50 SPS
Temperature	**Bosh BMP180**
Range / accuracy	0–65 °C / ±1 °C
Data storage	Integrated 4 GB SD card
Output data format	CSV, EDF+
Supply voltage	Li-Pol 120 mAh cell
Battery life	up to 40 h (on 250 SPS), 20 min charging
Connectivity	Micro USB
Optional	2.4 GHz Bluetooth® - 10 m range
Operating temperature	−40–85 °C
Electrodes	Disposable Ag/AgCl
Dimensions	37×25×15 mm
Power consumption	3 mA (on 250 SPS)
Next features	RGB LED and acoustic signalization, trigger button, real-time clock

Emotiv Epoc (Fig. 1 and Tab. 2). The Emotiv Epoc is 14-channel; 14-bit helmet, which uses saline-based wet sensors. Its sampling frequency is constant 128 Hz.

Tab. 2: Technical parameters of EEG helmet Emotiv Epoc.

Number of Channels	14 AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, C6, F4, F8, AF4
References	In the CMS/DRL noise cancellation configuration P3/P4 locations
Sampling method	Sequential sampling. Single ADC
Sampling rate	128 SPS (2048 Hz internal)
Resolution	14-bits 1 $LSB = 0.51$ μV
Bandwidth	0.2–43 Hz, digital notch filters
Filtering	8 Digital 5th order sinc filter
Dynamic range	8.4 mV_{pp}
Coupling mode	AC coupled
Built-In	2-axis gyroscope
Connectivity	2.4 GHz Bluetooth® Smart
Output format	EDF
Supply voltage	Li-Pol 640 mAh cell
Battery life	up to 6 hours using Bluetooth Smart
Electrodes	Saline based wet sensors

The EEG analysis includes the evaluation of the alpha waves EEG (α) (8–12 Hz), appearing during relaxation and when person has closed eyes, beta waves EEG (β) (12–30 Hz), which relate with raised concentration and thinking [11], [12], [13] and [14]. We also aimed at SensoriMotor Rhythm EEG (SMR), which is closer part of beta waves (12–15 Hz) interpreted as so-called „relaxed attention“. That means executive efficiency when people are concentrated and attentive without any extra effort for a longer time period [15] and [16]. The environmental setting supporting this state should be very suitable for a standard executive working task. The EEG (α) was measured in frontal cortex, responsible for executive functions, planning, motivation, organization and solving problems, in the temporal lobe, responsible for language understanding, behavior and memory and parietal lobe, which is specialized for processing of body information. The EEG (β) was evaluated in occipital lobe responsible for vision and imagination and again in parietal lobe. The EEG (SMR) was sensed only in central area, which is responsible for sensing and feeling.

All obtained data were first evaluated in LabChart program (ADInstruments). Additional statistical analysis was done in Microsoft Excel, Origin Lab and GraphPad.

2.1. Impact of Office Environment Design - Body Positions

The experiment was aimed to analyze the impact of design work surrounding. We measured the physiological parameters of a group of 6 volunteers (25–30 years old). The experiment was done in 5 various working positions in office environment - standard sitting (Fig. 3(a)), where abdomen of our volunteers was pressed, perching (Fig. 3(c)), where people had supported buttock, dynamic sitting, when volunteers were forced to get balance and adapt (Fig. 3(b)), standing, when the abdomen is released but you need focus on balance and relaxed semi-laying position. Total time of experiment was about 40 minutes. We evaluated HR, RR, RV, LF/HF ratio and did psychological tests to concentration and working efficiency of our volunteers.

(a) (b) (c)

Fig. 3: Standard (a), dynamic (b) and perch sitting(c).

2.2. Simulation of Environments - Choice of Materials and Colors

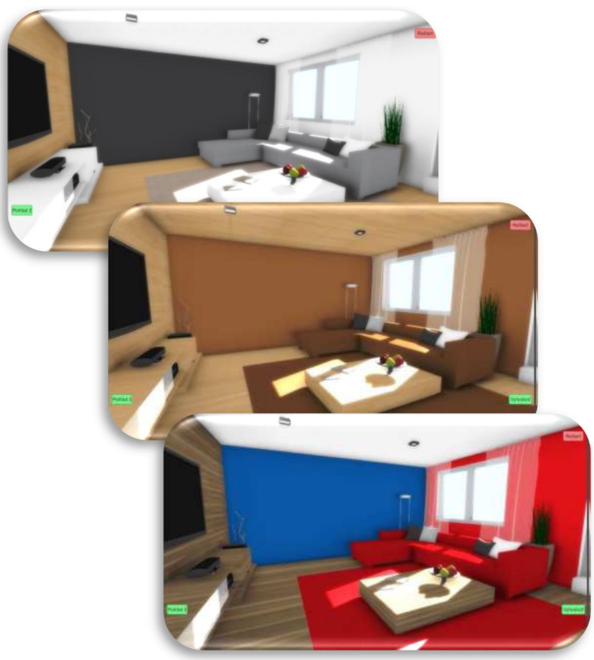

Fig. 4: Natural, wood and synthetic environment simulation.

The 2nd experiment implied usage of the application BCDapp. This application allows editing and simulating different environments and works within a web interface or virtual reality. We simulated different choice of materials and colors in the one room. In our experiment, we used 3 different settings (Fig. 4). Our volunteers saw 3 rooms, the 1st with warm and neutral, dark and light colors and with natural materials-textiles, the 2nd room was in brownish colors with wooden materials and the 3rd room, the most stimulating, in strong colors and with artificial imitation wood and synthetic textiles. These artificial materials have considered to evoking physiological reaction related to stress. The aim of this pilot test was to verify the methodology of the evaluation system of the BCDapp - if our evaluation based on research is compatible with the physiological responses of the control sample of respondents. We measured EEG (SMR) and monitored HR, RR, LF/HF of our volunteers sitting 80 cm from the computer.

2.3. Interaction with Wood Materials

In this experiment (Fig. 1), we measured physiological parameters of the 11 volunteers (3 women and 8 men) interacting with different materials - oak wood, chipboard and white laminate as reference material. The individuals were sitting in distance of 1 meter in front of the selected material (1×2 m boards) with closed eyes (1 minute), then they were touching this material (30 seconds),and finally, they were looking on this material (1 minute). All phases were repeated in 5 consecutive environments. The complete test lasted roughly 13 minutes for each person. During the test, physiological activity (HR, RR, RV, LF/HF and complete EEG) was monitored.

3. Results

3.1. Impact of Office Environment Design - Body Positions

Typical signals measured during the 1stexperiment are shown in Fig. 5 and detailed overall analysis follows in Tab. 3. We observed increased physical activity during dynamic sitting by highest LF/HF ratio (+52 %), in comparison with average values, which showed increased activity of the body, because volunteers were forced to balance in sitting position. These values are proper for training and they improve mental condition. The lowest RV (−27 %) and relative low HR (−3.2 %) at the same time represent saving of the heart muscle. However, longer sitting in this position could degrade amounts of blood oxygen causing by faster exhaustion and that can degrade the brain activity. Very similar nervous activity was observed during staying, where we expected similarly high values of LF/HF (+30 %). The values were little lower in compare to dynamic sitting, which may be related to the fact that balancing in standing position is for people more natural position. On the opposite, we got here the highest HR (7.8 %) and the highest RV (+38 %) thanks to released abdomen, which can be favorable for people with allergy or asthma but it is not very proper for people with heart problems. The lowest LF/HF ratio of course was observed in semi-lying position when human body mostly rest and relax and it is not suitable for work, you will fall easy to sleep. This position also showed the slowest and calmest breathing RR (−5.8 %), lowest LF/HF (−71 %) and lowest HR (−8.1 %), which causes visibly parasympathetic dominance. Standard sitting and perch sitting appeared suitable for office work, because physical activity does not disturb psychical activity, the values of LF/HF ratio are not so high (−18 % and +6 %), therefore, person can be more concentrated and easily focused. To support this claim, we began to include EEG (SMR) evaluation in further experiments.

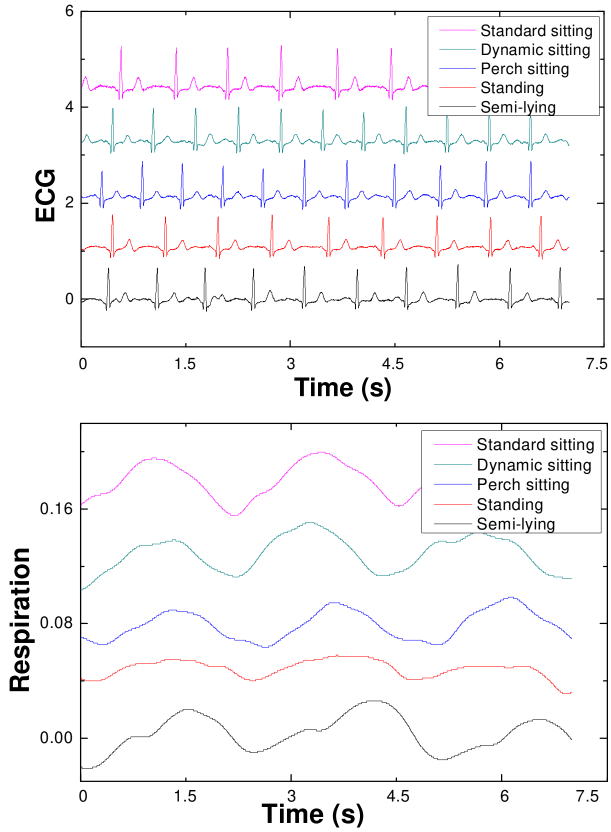

Fig. 5: Workplaces comparison - ECG and respiration signal.

Tab. 3: Average physiological values impacted by different office sitting positions.

	HR	**RR**	**RV**	**LF**	**HF**	**LF /HF**
	BPM	BPM	-	ms^2	ms^2	-
Standard sitting	79.3	21.8	0.031	1087	805	1.35
Dynamic sitting	76.7	24.2	0.026	1255	502	2.50
Perch siting	81.9	23.1	0.035	964	554	1.74
Standing	85.3	22.6	0.049	947	443	2.14
Semi-lying	72.7	21.3	0.036	813	1692	0.48

3.2. Simulation of Environments - Choice of Materials and Colors

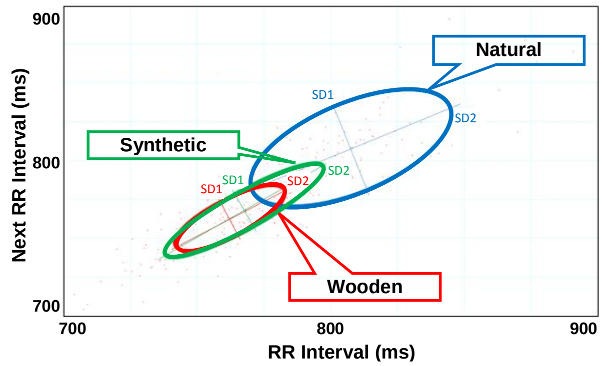

Fig. 6: Typical Poincare plot affected by environment simulation.

Tab. 4: Average percentage changes of the physiological values due to used materials and colors.

	HR	**RR**	**SMR**	**LF /HF**
Natural /neutral	−1.5 %	7.2 %	18.8 %	−18.9 %
Wooden /brownish colors	0.0 %	−6.1 %	7.0 %	−28.0%
Synthetic /strong colors	1.5 %	−1.0 %	−25.8 %	47.0 %

In the 2nd experiment (Tab. 4), we observed that environment with natural materials, neutral colors and balanced settings of the space is the best for office work because it increases creativity, understanding, thinking and resolving of problems, which is underpinned by increased level of SMR waves (+18.8 %) compared to the average values in all environments. This environment also reduced HR (−1.5 %) and increased RR (+7.2 %). Wooden materials with brownish colors are

Tab. 5: Average percentage change compared to white laminate. *(Bold numbers represent statistic relevant values).*

		HR	RR	RV	LF/HF	EEG (Θ) f7	f3	t7	p7	p8	t8	f4	f8
Wood	Sitting	1	**−7**	25	**40**	**−5**	−2	4	18	10	2	4	**−9**
	Touching	0	**15**	36	6	−8	4	−6	9	−3	−7	3	**−20**
	Watching	**2**	−1	81	28	**30**	9	8	**−13**	1	−1	5	−5
Chipboard	Sitting	1	6	2	**61**	5	−1	**−9**	**−11**	9	6	16	**13**
	Touching	2	1	9	**91**	−2	5	−1	**−11**	−1	14	14	**−12**
	Watching	1	8	22	−2	−1	**−6**	0	2	−6	6	0	16

		EEG (α)				EEG (β)								SMR	
		p7	o1	o2	p8	af3	f7	f3	p7	p8	f4	f8	af4	fc5	fc6
Wood	Sitting	11	2	8	8	11	10	10	8	14	10	−1	11	9	13
	Touching	**1**	**−2**	**8**	**0**	−1	**−16**	−9	−11	−7	−2	−2	4	**−9**	10
	Watching	**−11**	**−5**	**−9**	**−7**	18	5	14	8	−2	7	1	**14**	14	10
Chipboard	Sitting	8	−2	4	0	6	7	13	2	4	7	38	3	7	0
	Touching	8	9	8	−2	8	16	6	2	5	7	−5	2	0	**11**
	Watching	−7	−6	−6	−2	−6	−14	0	3	−3	3	18	−4	−1	1

ideal for relaxation, because LF/HF (−28 %) and RR (−6.1 %) were at the lowest levels. Misbalanced environment with synthetic materials and strong colors is for humans' very stressful, which is documented by very low SMR waves (−25.8 %) and very high LF/HF ratio (+47 %), which means that people are distracted. In this experiment, we also used Poincare plots (Fig. 6) for HRV analysis. The resultant SD2/SD1 correlates to LF/HF analysis as was expected, so it is not necessary to evaluate in next experimental setting. We can say that it is only different representation of LF, HF and LF/HF results.

3.3. Interaction with Wood Materials

The next experiment (Fig. 7) was focused on different materials (wood, laminate and chipboard) and effect of these materials on our volunteers (Tab. 5). We measured decreased RR and increased RV when people were sitting in front of the wood and what was interesting, when volunteers were touching wood, we detected increased SMR and EEG (α) waves on the right hemisphere, appeared during emotions and creativity. Viceversa, the waves were decreased in the frontal cortex of the left hemisphere responsible for logic and analytical thinking. This is done in the frontal part of the brain, which is responsible for executive functions, planning. The chipboard affected the most positively EEG (β) waves. Concretely, the sitting in front of the wood decreased RR −7±4 % (chipboard 6±16 %) and increased RV +25 % (+2 % chipboard). Total brain activity was also visibly increased (about 9 %). Higher level of the LF/HF ratio (+40 ± 117 %) showed higher activity and supported these results. Important result is that the SMR waves increased +11 ± 29 % and chipboard only +3.5 %. During touching wood, the RR increased (+15 ± 10 %), the RV increased (+36 ± 48 %) and also EEG (α) waves increased +4.2 %, the SMR waves increased +9.8 % on the right hemisphere and dropped on left hemisphere area (F7: EEG (β) −16 ± 16 %). This trend is not visible during touching chipboard (increased RR only +1±24 % and RV +9±74 %). But, the LF/HF ratio especially increased during touching chipboard +91 % and increased only +6 % during touching wood. The differences in pulse values were during interaction with wood +2 ± 2 % (chipboard +1 ± 7 %) showing activation of the body. However, these data might be related to the various structure of the wood. The body activity is also shown by evidence of a decline of the EEG (α) waves (−8.2±29 %) in comparison with chipboard (−5.1 ± 21 %) and by increasing of the EEG (β) waves (+8 ± 28 %) in comparison with chipboard

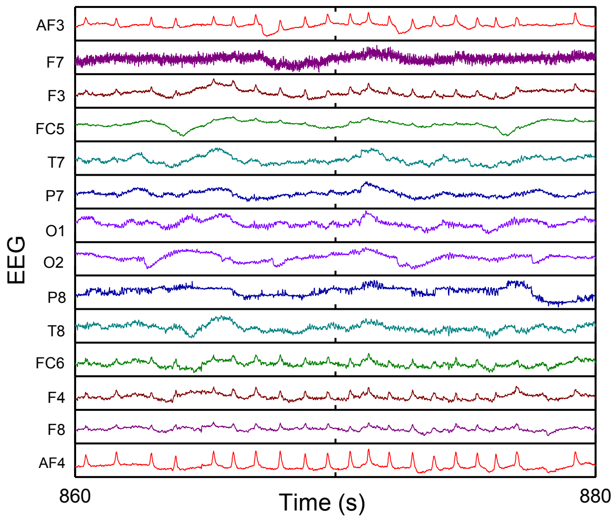

Fig. 7: Example of obtained EEG signal - watching on oak wood.

(-0.4 ± 15.4 %). The EEG (β) waves were higher in the left hemisphere compared to the right (11.1 % vs. 5 %). Wood also positively increased performance, and showed also increased SMR waves $+11.9 \pm 31$ % (chipboard -0.1 ± 11 %). These outputs signify higher cerebral blood flow and good antimicrobial effect (tested on the Institute of Microbiology, STU) of the wood to respiration. Increased LF/HF ratio shows higher brain activity and it reveals to be ideal for the office rooms and bedrooms.

4. Conclusion

The main aim of our experiments is the optimization and improvement of the measurement and the methodology of the evaluation of physiological parameters acquired by our ECG Holter and EEG Epoc device. It was confirmed that human physiology is strongly influenced by environment around us. Therefore, appropriate work surrounding designed from natural materials or fabrics with balanced colors can improve performance of the individuals. Increase activity, logic thinking and creativity, which lead to better work satisfaction is also stimulated by suitable positions. We presented three experiments where we showed human physiological parameters influenced by environments and working positions. It was our first clue to the physiological experiments on humans impacted by environment design. Analysis of this 1st experiment "Impact of office environment design - body positions" led to supporting our approaches on measurements of human well-being and it promoted our upgrade to use EEG helmet, which we added in 2nd experiment. In this experiment, we also used BCDapp application in virtual reality with different environmental settings for recording experimental data. Virtual reality allows easy changing of the environment parameters, which influence people without big changes of real surrounding or without disturbance in one room. This approach is perspective tool for measurement of human responses to various environmental stimuli. Added the EEG data analysis helped better understand human physiological status. The brain waves data showed, which part of the brain is active and what this activity means. We aimed at the SMR waves, which are suitable indicator of the increased brain activity without stress and of the well-being of the individuals. All these parameters were measured in the 3rd experiment, where volunteers interacted with wood, laminate and chipboard. This experiment is pointed to relevance of the materials around us, in our homes or offices. Natural materials and fabrics showed positive impact on work efficiency, creativity and they also have good impact on stress or depression of the humans. For more accurate results, we require higher number of the volunteers in our experiments. Also, we want to prolong time of the impact of selected material on volunteers or locate persons to environment without knowledge about materials. Interesting appear experiments with full environment, where all senses are absorbed surrounding; for example, sense of smell can be important in wood environment. Our next work is continuing with experiments in the real hospital environment, concretely in waiting room at National Oncological Institute, which was designed especially to maximize the benefits of using natural materials. We hypothesize good influence of wood on patients and its antimicrobial ability maximizes benefits of this design.

Acknowledgment

This contribution was created on the basis of the project "Establishment, Development and Scientific Management of a Research Center for the Analysis and Protection of Data" (ITMS project code: 26240120037), supported by Operational Programme Research and Development funded by the European Regional Development Fund and supported by the Slovak Research and Development Agency under contract APVV 16-0567 - Identity SK.

References

[1] KOMPIER M. and C. COOPER. Preventing Stress, Improving Productivity: European Case Studies in the Workplace. *Stress Medicine*. 1999, vol. 15, iss. 4, pp. 261–262. ISSN 1532-2998. DOI: 10.1002/(SICI)1099-1700(199910)15:4<261::AID-SMI843>3.0.CO;2-H.

[2] DE CROON, E., J. SLUITER, P. P. KUIJER and M. FRINGS-DRESEN. The effect of office concepts on worker health and performance: a systematic review of the literature. *Ergonomics*. 2005, vol. 48, iss. 2, pp. 119–134. ISSN 0014-0139. DOI: 10.1080/00140130512331319409.

[3] BURNARD, M. D. and A. KUTNAR. Wood and human stress in the built indoor environment: a review. *Wood Science and Technology*. 2015, vol. 49, iss. 5, pp. 969–986. ISSN 0043-7719. DOI: 10.1007/s00226-015-0747-3.

[4] EEKHOUT, M. *Methodology for Product Development in Architecture*. 1st ed. Delft: Delft University Press/IOS Press, 2008. ISBN: 158-60-3965-2.

[5] SANDAK, A., M., M. J. SANDAK, A. LANDOWSKA and V. KOTRADYOVA. Human interaction with wood - what to measure, how to measure? In: *Living with modified wood.*

Belgrade: University of Belgrade, 2018, pp. 20–21. ISBN 978-86-7299-280-9.

[6] KOTRADYOVA, V., I. SALCER and E. VAVRINSKY. Environmental Simulations and their Role in the Research of Human Responses to Environmental Stimuli. *Applied Mechanics and Materials*. 2016, vol. 861, iss. 1, pp. 618–624. ISSN 1662-7482. DOI: 10.4028/www.scientific.net/AMM.861.618.

[7] KOTRADYOVA, V. and E. VAVRINSKY. Reduction of Environmental Stress through Spatial Arrangements and Different Choices of Body Positions in Indoor Environment. *Applied Mechanics and Materials*. 2016, vol. 824, iss. 1, pp. 259–266. ISSN 1662-7482. DOI: 10.4028/www.scientific.net/AMM.824.259.

[8] NGUYEN, A., S. ANSARI, M. HOOSHMAND, K. LIN, H. GHANBARI, J. GRYAK and K. NAJARIAN. Comparative Study on Heart Rate Variability Analysis for Atrial Fibrillation Detection in Short Single-Lead ECG Recordings. In: *40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. Honolulu: IEEE, 2018, pp. 526–529. ISBN 978-1-5386-3646-6. DOI: 10.1109/EMBC.2018.8512345.

[9] VON ROSENBERG, W., T. CHANWIMALUEANG, T. ADJEI, U. JAFFER, V. GOVERDOVSKY and D. P. MANDIC. Resolving Ambiguities in the LF/HF Ratio: LF-HF Scatter Plots for the Categorization of Mental and Physical Stress from HRV. *Frontiers in Physiology*. 2017, vol. 8, iss. 1, pp. 1–12. ISSN 1664-042X. DOI: 10.3389/fphys.2017.00360.

[10] MILLIS, R. M., V. BOND, B. H. CURRY, K. KUMAR, S. PEMMINATI, V. R. GORANTLA and K. KADUR. Nonlinear Conte-Zbilut-Federici (CZF) Method of Computing LF/HF Ratio: A More Reliable Index of Changes in Heart Rate Variability. *Journal of Pharmacopuncture*. 2016, vol. 19, iss. 3, pp. 207–212. ISSN 2093-6966. DOI: 10.3831/KPI.2016.19.021.

[11] BRENNAN, M., M. PALANISWAMI and P. KAMEN. Poincare plot interpretation using a physiological model of HRV based on a network of oscillators. *American Journal of Physiology-Heart and Circulatory Physiology*. 2002, vol. 283, iss. 5, pp. 1873–1886. ISSN 0363-6135. DOI: 10.1152/ajpheart.00405.2000.

[12] KUMAR, J. S. and P. BHUVANESWARI. Analysis of Electroencephalography (EEG) Signals and Its Categorization - A Study. *Procedia Engineering*. 2012, vol. 38, iss. 1, pp. 2525–2536. ISSN 1877-7058. DOI: 10.1016/j.proeng.2012.06.298.

[13] KANDA, P. A. M., E. F. OLIVEIRA and F. J. FRAGA. EEG epochs with less alpha rhythm improve discrimination of mild Alzheimer's. *Computer Methods and Programs in Biomedicine*. 2017, vol. 138, iss. 1, pp. 13–22. ISSN 0169-2607. DOI: 10.1016/j.cmpb.2016.09.023.

[14] BABILONI, C., C. DEL PERCIO and R. LIZIO. Abnormalities of cortical neural synchronization mechanisms in patients with dementia due to Alzheimer's and Lewy body diseases: an EEG study. *Neurobiology of Aging*. 2017, vol. 55, iss. 1, pp. 143–158. ISSN 0197-4580. DOI: 10.1016/j.neurobiolaging.2017.03.030.

[15] BOTREL, L., L. ACQUALAGNA, B. BLANKERTZ and A. KUBLER. Short progressive muscle relaxation or motor coordination training does not increase performance in a brain-computer interface based on sensorimotor rhythms (SMR). *International Journal of Psychophysiology*. 2017, vol. 121, iss. 1, pp. 29–37. ISSN 0167-8760. DOI: 10.1016/j.ijpsycho.2017.08.007.

[16] CALOMENI, M. R., V. FURTADO DA SILVA, B. B. VELASQUES, O. G. FEIJO, J. M. BITTENCOURT and A. P. RIBEIRO DE SOUZA. Modulatory Effect of Association of Brain Stimulation by Light and Binaural Beats in Specific Brain Waves. *Clinical Practice & Epidemiology in Mental Health*. 2017, vol. 13, iss. 1, pp. 134–144. ISSN 1745-0179. DOI: 10.2174/1745017901713010134.

About Authors

Erik VAVRINSKY received his Masters and Ph.D. degree from the Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in years 2002 and 2005, respectively. He has carried out postgraduate studies in area of thin-film microsensors and electrochemical biosensors. In present, he participates at the University education process as a lecturer. His current research interests include design, characterization and testing of sensor systems and biomonitoring devices. Dominant part of his multidisciplinary research is focused on human physiology.

Veronika KOTRADYOVA is lecturer, researcher and project manager at the Faculty of Architecture STU Bratislava, Institute of Interior and Exhibition Design, Slovak Republic since 2002. She is a graduate of Wood Science and Technology Faculty of TU Zvolen, specialization furniture and interior design. Beginning with eco-design, her research specialization is body conscious design /human centered design, which she began in 2006 as a visiting Fulbright scholar at UC Berkeley, USA. Since 2011 she is dealing with topic of Interaction of Wood and Human, whereas she was leading research, including experimental study "Wood in health care facilities".

Helena SVOBODOVA obtained her Master's degree in the field of molecular biology at Faculty of Natural Science, Comenius University, in 2014. In present, she is a Ph.D. student at the department of biophysics, Faculty of Medicine. Her research interests include metabolism of iron, neurodegenerative diseases, EEG, EMG, ECG, sensor systems and bio-monitoring devices. In 2017, she worked at University of Eastern Finland on models of Alzheimer disease.

Martin KOPANI is head of Institute of Medical Physics, Biophysics, Informatics and Telemedicine. His research activities focus on application of various physical methods in study of cells and tissues, mainly in terms of the presence, localization, distribution, and structure of some chemical elements.

Martin DONOVAL received his Master's and Ph.D. degrees in Electronics from Slovak University of Technology in Bratislava. He has carried out postgraduate studies in area of IC design. He participated in the establishment of the Department of electronic systems with focus on reliability testing, design of smart electronic systems and off-chip innovative solutions. Currently, he is responsible for projects particularly in a field of bio-electronics. As a member of the team he is involved in development of new prototypes and dedicated integrable electronics and reliability testing.

Samuel SEDLAK has obtained Master's degrees in Electronics from Slovak University of Technology in Bratislava. In his diploma thesis he dealt with the design of lamp which could affect the circular rhythms of man. The dissertation deals with recording and evaluation of biosignals as well as with electrical and optical monitoring of trisodium citrate in hemodialysis.

Jan SUBJAK received his Master's degree in field of Electronics and Photonics from Slovak University of Technology in Bratislava. He participated in the projects with main focus on bioelectronics, wearable devices and smart electronic systems in the field of Internet of things. Currently he is student of doctoral studies and is working closely with International Laser Centre. As a member of team he is involved in device reliability testing and development of new IoT devices.

Tomas ZAVODNIK finished her Master's degree in field of Electronics and Photonics from Slovak University of Technology in Bratislava. Currently he is responsible for software development on new IoT devices focusing mainly on bioelectronics and smart electronics. As a member of team he is involved and responsible for software engineering needed with every new prototype.