Heart Rate Variability Indicating Stress Visualized by Correlations Plots

Wilhelm Daniel Scherz[1], Juan Antonio Ortega[2],
Natividad Martínez Madrid[3], and Ralf Seepold[1]

[1]HTWG Konstanz, Brauneggerstr. 55, 78462 Konstanz, Germany
{wscherz,ralf.seepold}@htwg-konstanz.de
http://uc-lab.in.htwg-konstanz.de
[2] Universidad de Sevilla, Avda. Reina Mercedes s/n, 41012 Sevilla, Spain
jortega@us.es
http://www.us.es
[3]University Reutlingen, Alteburgstraße 150, 72762 Reutlingen, Germany
natividad.martinez@reutlingen-university.de
http://iotlab.reutlingen-university.de

Abstract. Stress is recognized as a factor of predominant disease and in the future the costs for treatment will increase. The presented approach tries to detect stress in a very basic and easy to implement way, so that the cost for the device and effort to wear it remain low. The user should benefit from the fact that the system offers an easy interface reporting the status of his body in real time. In parallel, the system provides interfaces to pass the obtained data forward for further processing and (professional) analyses, in case the user agrees. The system is designed to be used in every day's activities and it is not restricted to laboratory use or environments. The implementation of the enhanced prototype shows that the detection of stress and the reporting can be managed using correlation plots and automatic pattern recognition even on a very light-weighted microcontroller platform.

1 Introduction

For humans stress is regarded as a negative sensation and organisations like the World Health Organisation (WHO) recognise stress as a predominant disease [1] because of its continuous presence in modern life. Among well-known consequences of high and perdurable stress is failure to respond adequate to fiscal, mental and emotional demands [2, 3, 4]

As a result of high level of stress in modern society the amount of people who face long term limitations like burnouts or cardiac infarcts is increasing. This leads to the growth of the treating and healing costs for people suffering from stress illnesses. Assuming that many societies have an aging population, stress and the negative consequences of stress will influence the age and healthiness of people.

Stress appeared as a natural response that allowed people to react fast and effec-tively in dangerous situations. Stress triggers biological mechanisms that reorganise the priorities and works of the organism in order to reach the maximum performance when facing threat. This is also called the ‘fight or flight response’ [5].

Nowadays stress is the result of the exposure to high demands and pressure in daily life that can be both mental and physical [6], e. g. constant desertions demand or constant time pressure. Stress became permanent and due to this it causes variety of disorders. Among the symptoms of overabundance of stress are fatigue, sleep problems, etc. [7].

Stress can be self-induced or induced in a laboratory by using special exercises like the Trier test [8] or the Strop test. **Fig. 1** shows some of the symptoms of stress. The reaction to stress has not changed over the time although lifestyle, technologies and everyday habits changed a lot.

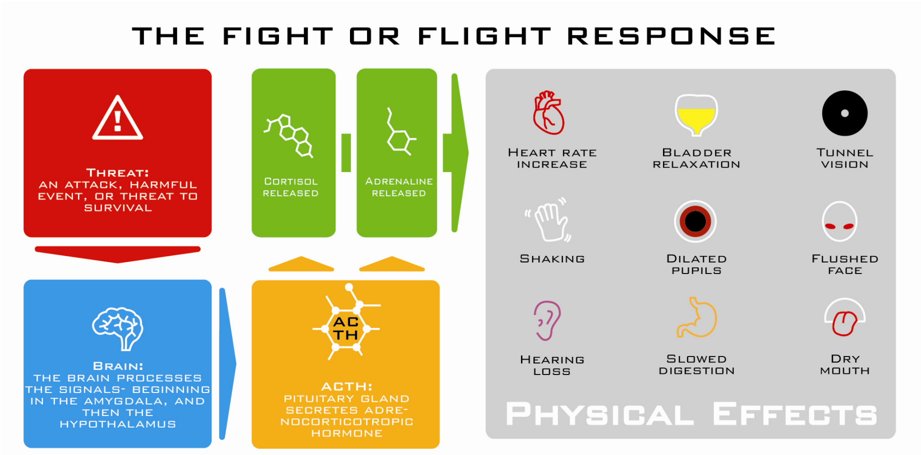

Fig. 1. Symptoms and physical response of stress

As shown in **Fig. 1** in case of a threat, the body activates several processes that prepare it for a fight against the threat or for fleeing from it. The brain is supporting this process, when releasing cortisol and adrenaline hormones, reducing the functionality of systems that are not necessity for imminent surviving like genitourinary system, digestion, hearing, peripheral view, etc. Furthermore, it is increasing the functionally of mechanisms supporting successful flee or fight strategies like an increased heart rate or dilated pupils.

One of the main reasons why stress is underestimated and at the same time one of the factors that complicate its detection is the subjective perception of stress: Some people demonstrate immediately symptoms of stress while others do not notice when passing the threshold of just ‘being busy’ to an objective high stress level [9]. This is why it is important to find an objective way to determine stress, or if possible, to determine the moment before a person passes the threshold.

The approach used in this work is based on the electrical characteristics of the heart (ECG). The system consists of hardware and software platform capable of hosting various algorithm and sensors for biological parameter measurement. The platform provides basic connectivity to a body area network and telemetric support for professional online analysis. The user is continuously informed about the current status.

2 State of the Art

The monitoring of indicators detecting stress has a long history but often it is used only to capture physical parameters like the heart rate without correlating the parameters directly. In only few cases the person will receive direct feedback but it is wearing a black-box. The results are analysed offline and diagnosis are reported later. However, due to miniaturization we notice a shift from purely professional and certified systems into a grey zone of recommendation and reporting devices not directly involved in professional medical systems. Independent from the area of expertise and from cost factor, the availability and relevant type of devices for our approach can be divided into three categories:

- Approaches that do not use additional sensors
- Approaches that require a well-controlled laboratory environment
- Approaches that require external sensors

The first group covers approaches that do not require sensors use and they analyse little differences in behaviour between not being stressed and being stressed. Examples are [10, 11] where examining and monitoring the way of typing while being stressed. The disadvantage of this approach is complexity and difficulty of adapting it to multiple environments and to calibrate to an individual. These approaches are most often context based and not human centred.

The second group are approaches requiring laboratory environments. Most often, they provide accurate and precise stress detection. The hormones cortisol, adrenaline and other stress hormones that are released in saliva and blood are measured for determining stress [12]. The limitation of these methods is that they lack mobility together with real time detection. Besides that these approaches are invasive and expensive due to the necessary equipment and precision.

The third group are characterized by approaches that use external psychological sensors like in [13]. For example, stress measurement while driving. The driver is monitored with an electrocardiogram (ECG) and an electromyogram that records the electrical activity of muscles (EMG), skin conductivity (SC), breath sensor and video camera that observes the driver. The main disadvantage is the limitation in the degree of movement and in this case the missing online analysis of all the data after it was collected. So, the driver is not receiving immediate feedback.

The approach that we develop uses an own developed low cost ECG which is compact, wearable, non-invasive and real time capable what allows different and usage in different contexts. The analyses results can be reported directly to the user via different very simple (or more detailed) user-interfaces, while the raw data is buffered or passed online for further processing by professionals. The buffer capability is relevant since mobile solutions do not offer connectivity in every place (e.g.

metro ride). This paper is also based on our previous studies and models for stress measurement [2, 4].

3 System Architecture

According to the previous studies mentioned above, we took the decision to develop a light weighted and low-cost system independent from smartphone sensor capabilities. In this approach, we concentrate on the ECG signals first because we would like to evaluate how accurate is the stress detection when capturing only one biological parameter. Of course, the system is open to capture more parameters and to cooperate with other external sensors (like smartphone sensors). For this enhanced prototype, we used the smartphone as the communication platform providing connectivity. The principle architecture is shown in **Fig. 2**. The system is composed of three parts: ECG sensors with the capability of continuous recording/extracting biological data, microprocessor for processing the signal and visualization device to give feedback to the user. A smartphone (or similar) to provide connectivity.

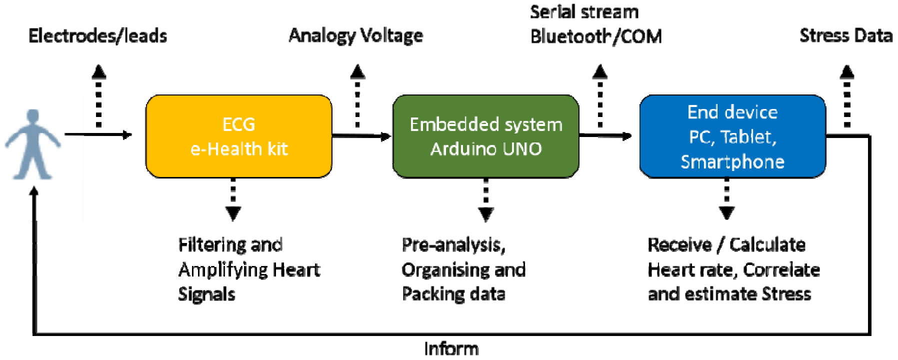

Fig. 2. System architecture for collecting, pre-processing and visualizing of biological data

The ECG board computes the signal obtained from the electrodes. Like in traditional ECG devices, three electrodes are used. The ECG unit composes the signal and send it as an analogue output to the microcontroller. In the moment, the microcontroller digitalizes the analogue signal and performs some pre-processing and filtering. Using the digitalized data we calculate the heart rate (HR) and the RR interval that is defined as the interval between two R peaks as shown in **Fig. 3**. The RR interval and the heart rate are later used for determining stress. With the help of the prototyping

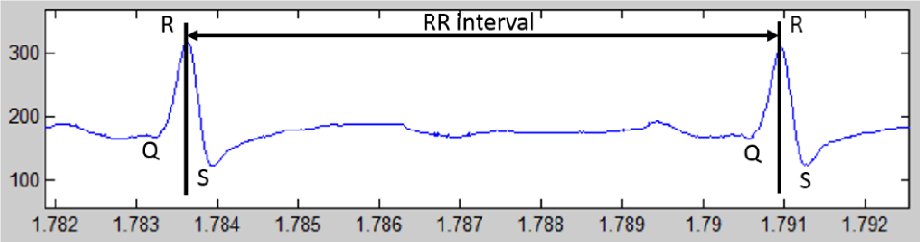

Fig. 3. Definition of an RR interval in a QRS segment

board or the connected smartphone, the user can be informed about his current status. As used in previous prototypes, a traffic light interface is suited to display easy to catch information. The interface display may be part of the board or the smartphone device implementing a small app. The more precise data is passed to the backend as stress data.

4 Stress Detection Method

Our method to detect stress is based on the ECG signal. As mentioned there are several possibilities to capture biological parameters, however, the ECG signal is easy to capture and the way to capture it is quite resistant against movements and thus guaranteeing an always-available signal. Based on the system architecture, the prototype supports direct access and processing of sensor data in real time. The ECG signal describes the electrical characteristic of the heart and is usually used for diagnostic proposes [14]. At the same time ECG data is unique enough to be used for identification of persons[15].

As shown in **Fig. 3**, we use the RR interval (the RR interval represents the duration between two consecutive heartbeats (1)) or the heart rate to calculate the heart rate variability (HRV). Later, the HRV is used for determining stress.

$$RR_{interval} = R_i - R_{i-1}, \tag{1}$$

HRV is calculated by examining the relations between two heart beats. Usually HRV correlates strongly with the respiration sinus. In [16] the influence of the breathing sinus on the heart rate is described. We can assume that HRV stays almost constant when a person is not stressed and the variation stops behaving regularly when the person is stressed.

Fig. 3 is normalised in the y-axis over a range between 0 to 350 mV (2) and the x-axis shows the time in ms (3).

$$0 \leq Y \geq 350, \tag{2}$$

$$x \geq 0, \tag{3}$$

To optimise and reduce the resources needed, for the detection of the R peaks and for the calculation of the RR interval (1) we define a threshold value of 250 mV

$$R_j > 250_{mv}, \tag{4}$$

And so that the current R value is a peak, it has to be a maxima (5), $R_i$is the list of RR maxima

$$(R_{j-1} < R_j) \wedge (R_j > R_{j+1}) \xrightarrow{Then} R_i = R_j, \tag{5}$$

Only if both conditions (4, 5) are fulfilled, we have successfully detected R-peak (5). When we have detected two R peaks we can calculate the RR interval (1) by measuring the time difference between two peaks.

Next step is to correlate the RR and the HRV computed. If we visualise the obtained data in a two dimensional space, we obtain a correlation plot, e.g. **Fig. 4**.

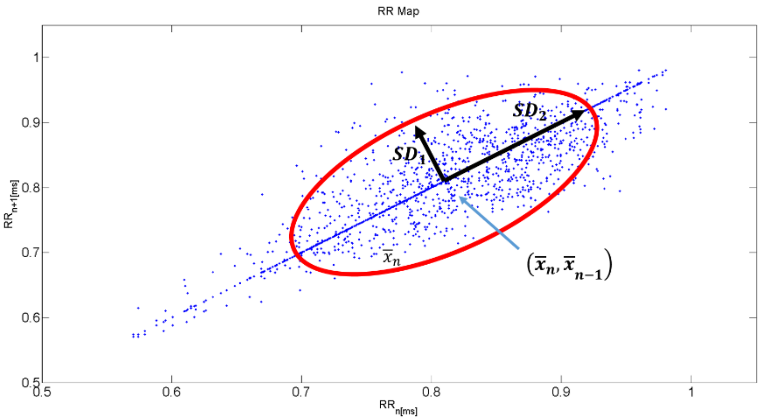

Fig. 4. Correlation plot of RR intervals that visualizes the HRV and their self-similarity

The x-axis and y-axis of the plot are defined as (6, 7).

$$X = \{RR_i, RR_{i+1}, \dots RR_n\}, \tag{6}$$

$$Y = \{RR_{i+1}, RR_{i+2}, \dots RR_{n+1}\}, \tag{7}$$

In the plot **Fig. 4** high concentration of values is notable in the centre of the plot. This concentration of the points indicates lower stress level. If the values would spared ao lot, it would indicate that the person is under stress.

The total variability can be expressed as the product of SD_1 and SD_2.

$$SD_1 = \sqrt{var(x_1)} \rightarrow x_1 = \frac{x_n - x_{n+1}}{\sqrt{2}}, \tag{8}$$

$$SD_2 = \sqrt{var(x_2)} \rightarrow x_2 = \frac{x_n + x_{n+1}}{\sqrt{2}}, \tag{9}$$

The current variance of the RR interval is calculated using the standard derivation like in (11) and (10).

$$\sigma = \left(\frac{1}{n-1} \sum_{i=0}^{n} (x_i - \overline{x})^2 \right)^{\frac{1}{2}}, \qquad (10)$$

$$\sigma = \left(\frac{1}{n} \sum_{i=0}^{n} (x_i - \overline{x})^2 \right)^{\frac{1}{2}}, \qquad (11)$$

5 Application of System and Results Obtained

The system has been implement on top of an Arduino Uno R3 prototyping board with the self-made ECG component stacked on top of the board. The ECG electrodes have been connected to the board and besides that a third board has been stacked in top of this providing a slot for a small SD memory card. The memory card may be integrated in the future directly to the ECG board as part of a future redesign. All candidates have been volunteer students aged between 23 and 28, none of them were smokers or alcoholics. The methods used in this work assume that none of the candidates suffered from cardiac problems or mental anomalies nor used a pacemaker.

As a method for inducing stress on the volunteers, we used the Trier Social Stress Test [8] because this method can be easily established in our laboratory environment and a driving simulator that has been used for the tests as well.

The Trier Social Stress Test was realised in three phases (anticipation period, presentation period and cool down period), the duration of each was 5 minutes. During the test, the volunteer has to prepare and make a small presentation on a random topic.

The driving simulator that we used in the experiment requires two mechanism to induce stress. A points system is introduced to reward the volunteer for fast and complex driving manoeuvres. The level of difficulty increases over time. As consequence, the fastest driver usually makes more complicated manoeuvres to increase the reward points but at the same time such driving manner increases the probability to lose all the points in case of mistake (accident).

The data that was obtained during the experiment has been processed and visualised using our approach. In the following, results from two volunteers are shown. The first person has a lower heart rate but is being under constant stress. The second person has a higher heart rate but is not under stress. Both datasets have the same length.

Fig. 5 and **Fig. 6** show the correlations plots of the RR intervals and **Fig. 7** and **Fig. 8** show the HRV.

Fig. 5 clearly shows that the values are more wide spread than in **Fig. 6**. This spreading of the values is caused by the stress and the conditions that were mentioned above (**Fig. 1**). Stress influences the heart rate and as the result the variation between two heart beats becomes bigger. Most of the values in **Fig. 5** belong to the interval between 0.7 and 0.9 sec for the RR interval (heart rate interval is between 66.7 bpm and 85.7 bpm).

Fig. 6 shows that the values of the second volunteer (relaxed and breathing calm and regularly) without stress does not spread as much as the values in **Fig. 5** although the heart rate is higher (the RR interval is shorter). Most of the values are between 0.45 sec and 0.6 sec (130 bpm and 85 bpm)

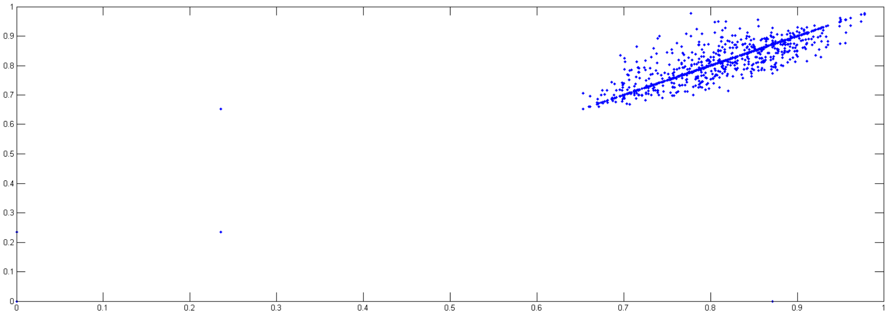

Fig. 5. Candidate under stress and with low HR

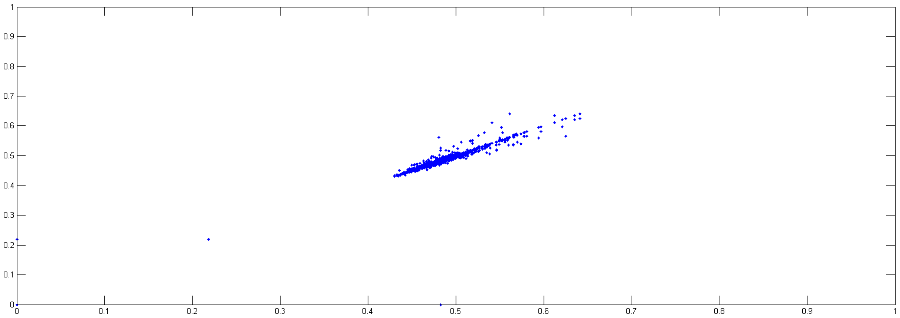

Fig. 6. Candidate no stress and with high HR

Comparing of the **Fig. 7** and **Fig. 8** shows that the values in **Fig. 8** vary less and more regularly than the values of **Fig. 7**.

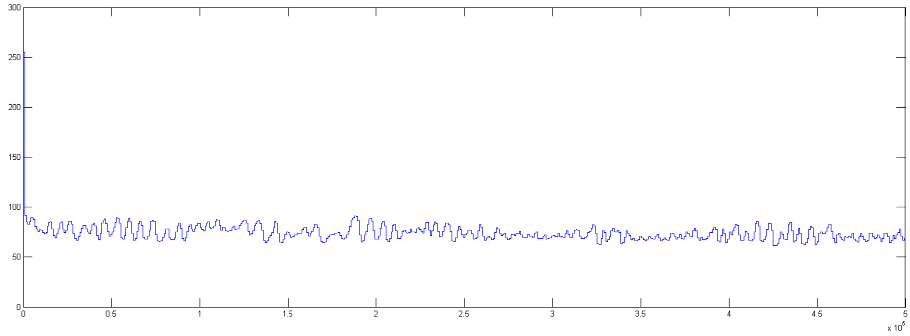

Fig. 7. Continuous HRV visualization of not uniform signal of a stressed candidate

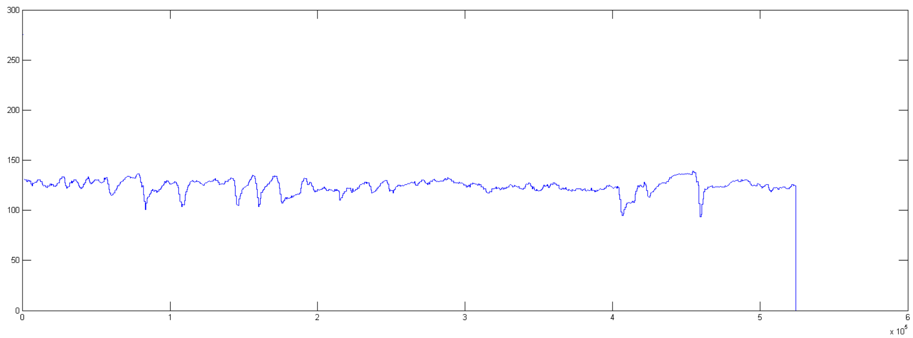

Fig. 8. Continuous HRV visualization of not stressed candidates

6 Conclusions and Future Work

This work presents a system architecture and an algorithm for calculating stress based on the HRV. The system is designed to be light-weighted, to integrate in mobile, cheap and easy to use devices like smartphone or even without the smartphone. The prototype can be currently connected to a different system like PC and smartphones. The algorithm for stress detection has been implemented with a small footprint and can be deployed in small prototyping board. For the experiment we used an Arduino Uno R3 development board.

The results of experiments has shown that stress can be detected even in cases when people have naturally low or high heart rate.

A future challenge of the system is the sensibility to abrupt and very strong movements, for example in some sporting activities. The movement of the electrodes during these measurements may cause strong interferences and artefacts in the signal. A solution to this problem could be a software reconstruction and filtering of the signal or using the same approach with a sensor that does not generate interferences. In the next step, it is planned to use a more powerful microcontroller boards in order to shift the processing functionality to the place where the data is captured, apply more sophisticated filters and overcome lacks in sensor signals during some sport activities. A third step will be the redesign of the ECG boards to tune it for low power and being more compact to be mobile.

References

[1] WHO, Cross-national comparisons of the prevalences and correlates of mental disorders. Bulletin of the World Health Organization, pp. 413–426 (2000)

[2] Fernández, J.M., Augusto, J.C., Seepold, R., Madrid, N.M.: A Sensor Technology Survey for a Stress Aware Trading Process. IEEE Trans. on Systems, Man and Cybernetics Part C: Applications and Reviews 42(6), 809–824 (2012)

[3] Fernández, J.M., Augusto, J.C., Seepold, R., Madrid, N.M.: Why Traders Need Ambient Intelligence. In: Augusto, J.C., Corchado, J.M., Novais, P., Analide, C. (eds.) ISAmI 2010. AISC, vol. 72, pp. 229–236. Springer, Heidelberg (2010)

[4] Fernández, J.M., Augusto, J.C., Trombino, G., Seepold, R., Madrid, N.M.: Self-Aware Trader: A New Approach to Safer Trading. Journal of Universal Computer Science (2013)

[5] Jansen, A.S.P., Van Nguyen, X., Karpitskiy, V., Thomas, C.: Central command neurons of the sympathetic nervous system: basis of the fight-or-flight response. Science 270, 644–646 (1995)

[6] Kidd, T., Carvalho, L.A., Steptoe, A.: The relationship between cortisol responses to laboratory stress andcortisol profiles in daily life. Biological Psychology, 34–40 (2014)

[7] Torbjörn, Å., John, A., Mats, L., Nicola, O., öran, K.G.: Do sleep, stress, and illness explain daily variations in fatigue?. Journal of Psychosomatic Research, 280–285 (2014)

[8] Kirschbaum, C., Pirke, K.-M., Hellhammer, D.H.: The 'Trier Social Stress Test'- A Tool for Investigating Pyschobiological Stress Responses in a Laboratory Settings. Neuropychobiologie, 78–81 (1993)

[9] Madrid, N.M., Fernandes, J.M., Seepold, R., Augusto, J.C.: Ambient assisted living (AAL) and smart homes. Springer Series on Chemical Sensors and Biosensors, vol. 13, pp. 39–71 (2013)

[10] Gunawardhane, S.D., De Silva, P.M., Kulathunga, D.S., Arunatileka, S.M.: Non Invasive Human Stress Detection Using Key Stroke Dynamics and Pattern Variations. In: International Conference on Advances in ICT for Emerging Regions (ICTer), Colombo (2013)

[11] Vizer, L., Zhou, L., Sears, A.: Automated stress detection using keystroke and linguistic features: an exploratory study. Int. J. of Human-Computer Studies 67(10), 870–886 (2009)

[12] Juliane, H., Melanie, S.: The physiological response to Trier Social Stress Test relates to subjective measures of stress during but not before or after the test. Psychoneuroendocrinology 37(1) (2012)

[13] Healey, J.A., Picard, R.W.: Detecting Stress During Real-World Driving Tasks Using Physiological Sensors. IEEE Transactions on Intelligent Transportation Systems 6(2) (2005)

[14] Dubin, D.: Rapid Interpretation of EKG's, Tampa. COVER Publishing Co., Florida (2000)

[15] Israel, S.A., Irvineb, J.M., Chengb, A., Wiederholdc, M.D.D., Wiederholdd, B.K.: ECG to identify individuals. Pattern Recognition, 133–142 (2004)

[16] Hirsch, J.A., Bishop, B.: Respiratory sinus arrhythmia in humans: how breathing pattern modulates heart rate. American Journal of Physiology - Heart and Circulatory Physiology (1981)