Psycho-physiological Stress Monitoring using Mobile and Continous Pulse Transit Time Measurement

Stefan Hey
House of Competence, hiper.campus
Karlsruhe Institute of Technology
Karlsruhe, Germany
Stefan.hey@kit.edu

Hatem Sghir
House of Competence, hiper.campus
Karlsruhe Institute of Technology
Karlsruhe, Germany
Hatem.sghir@kit.edu

Abstract—**In the last years stress has become one of the most serious health problems in industrialized western countries. It is one of the most common reasons for a number of serious diseases and an important factor for increasing cost in health systems. Beside this, over the last years there has been an increasing interest in finding new methods for capturing psychological, behavioral and physiological data in real-time using infield data acquisition systems. Within our research group a system for ambulatory assessment of psycho-physiological signals for real-time data capture was developed. Because of the multivarious influences of stress on the physiological response of the body, a stress measurement system has to take into account as many parameters as possible. Pulse transit time (PTT) gives comprehensive information about the cardiovascular system. It is determined by measuring the ECG and the pulse wave; the latter is noninvasively measured either on a finger or on an earlobe. In a further study we discovered a strong correlation between stress and PTT and that PTT is an appropriate parameter for stress measurement. The paper describes the use of a mobile PTT-measurement system for monitoring stress in everyday life.**

Keywords-component; stress; mobile; PTT;ECG

I. Introduction

Excessive stress releases reactions on different levels in the human body. One can observe reactions on the cognitive level [1], the emotional state of a person, the vegetative-hormonal system, as well as on the muscular level.

Predominantly the reactions on the vegetative-hormonal level of the body can be measured by different methods. For the measurement of stress, one can distinguish between invasive and non-invasive methods, or between stationary (laboratory) equipment and mobile measurement systems.

The physiological reactions are caused by an activation of the sympathetic nervous system and by the release of hormones (adrenalin, noradrenalin, testosterone and cortisol). These hormones are released as a consequence of the activation of the hypothalamic-pituitary-adrenal axis (HPA or HTPA axis), the neuroendocrine system that controls reactions to stress and regulates many body processes, i.e., mood and emotions, the immune system, as well as many others.

Consequences arising out of this are: an increase of the respiration and heart rate, a constriction of the blood vessels, an increase of the blood pressure, a reaction of the electrodermal activity and energetic metabolism [4].

The goal of a reliable measurement of stress is to obtain a comprehensive overview of the entire reaction chain within the body by a simple monitoring system. The monitoring system has to be non-invasive, mobile and unobtrusive in order to be accepted by a user as part of their everyday life.

Under these circumstances the use of the pulse transit time seems to be an ideal parameter for stress measurement. Almost all of the cardiovascular parameters (heart rate, blood pressure, artery resistance) can be linked with one another. The PTT could be measured non-invasively by a system that simultaneously records ECG and photoplethysmogramm.

Several workgroups are trying to make the psycho-physiological load on people measurable, in order to help people adapt to their stressful everyday life in a simpler fashion. In other words, to investigate the different possibilities of balancing one's physical and mental resources thereby achieving one's best cognitive performance.

In fact, they are attempting to find indicators which could show and quantify one's stress and activity level and thusly give an idea about one's physical and mental state.

This paper is organized as follows: in Section II, a description of the methods used to extract stress indicators and to validate PTT as an appropriate indicator for the acute stress level is given. Following this, the research results on the topic will be presented in Section III. Lastly, a discussion on future research plans and concluding remarks are presented.

II. Methods

A. *Pulse Transit Time*

The pulse transit time or PTT represents the time needed by a blood pulse wave to exit the heart and reach the PPG (PhotoPlethysmoGramm) measurement site. To increase the accuracy of the measurement, the distance between that site and the heart should be as long as possible. In this case, the impact of measurement errors in time domain is smaller compared to the measurement result. Beside this, the measurement site must to be accessible for the sensor device and robust enough against artifacts, e.g. caused by

 ISBN: 978-1-61208-119-9

movements. For this reason the pulse wave is detected at the finger tip [2].

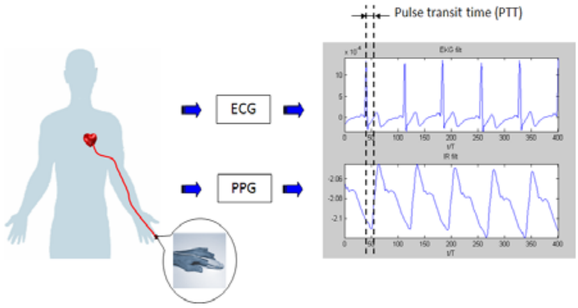

Figure 1. Measurement of pulse transit time from ECG and PPG.

As shown in Figure 1, the PTT can be determined by calculating the time difference between the r-wave of the ECG signal and the virtual base point of the PPG signal. This latter corresponds to the intersection point between the tangent to the pulse wave at the point with the maximal slope during the systolic rise phase and the horizontal line going through the point having the absolute minimum. The main advantage of using the base point to calculate the PTT is that the p-base point, which is determined out of two characteristic points in the pulse wave, guarantees a better noise and artifact robustness compared to other possible points of the photoplethysmogramm like the maximum of the p-wave.

B. Mobile Measurement System

This section describes the mobile measurement system used in this study. For the assessment of the biosignal, the SOMNOscreen plus system from somnomedics (Randersacker, Germany) was used. With this system we measured ECG-signal, photoplethysmograph signal, the electrodermal activity and the respiration signal.

These signals could be relevant for the determination of the stress level of the test person. Furthermore, a 3D acceleration sensor-node [3], [9] is used to simultaneously collect information about the activity of the user. The measurement of physical activity is important to interpret the cardio-respiratory physiological signals in field studies.

1) ECG-Sensor: We are using the two-lead method to detect ECG-Signal with a sample rate of 1024 Hz. By means of gel electrodes we measure the skin potential on the chest of one person. To eliminate motion artifacts, the cables of the electrodes are fixed to the surface of the body.

2) Photoplethysmograph: A finger clip transmission photoplethysmograph is used to register the PPG. The signal of the photodiode correlates with the amount of blood in the finger and thus reflects the pulse wave in the blood vessels. The PPG signal is also acquired with a sample rate of 1024 Hz.

C. Simulation of stress in laboratory environment

The „Trier Social Stress Test" (TSST) [5] is used in laboratory environment for induction of moderate psycho-biological stress responses. A meta-analysis conducted by Dickerson and Kemeny [6], reviewing 208 laboratory studies of acute psychological stressors, demonstrated that the TSST is a reliable instrument eliciting robust physiological stress reactions.

The TSST consists of an anticipation period (10 min) and a test period (10 min).

In the anticipation period three persons are introduced as a selection committee. The subjects are told that after a preparation time a job interview will take place, in which they have to deliver a free speech introducing themselves and answer questions asked by the committee (5 min).

Following these instructions the subjects were instructed to prepare their talks, in which they had 10 minutes. After this they made their short presentation to the committee and responded to the panel's questions. Following this interview, one member of the committee presented a second task the participant must partake in. The test person has to subtract the number 13 from 1687, backwards in sequence. Each mistake restarts the subtraction from the beginning at 1687. During the whole test period subjects are filmed by a video camera [5], and they are informed, that these film are used for further analysis of the test.

D. Measurement of baseline during night

Normally, baseline values of physiological data in „Trier Social Stress Test" (TSST) experiments are measured at the beginning of the test. After connecting the sensors to the test persons, baseline values are captured just before the anticipation phase starts. But a number of people show increased vital parameters when coming to the laboratory for a test, even if they don't know exactly what happens during the experiment.

To obtain a reliable baseline value of physiological data, monitoring during the night after the laboratory test is necessary. To measure the physiological signal during the night an unobtrusive measurement system is needed, so that it does not disturb the sleeping pattern of the user to maintain the influences of the measurement signals as small as possible.

E. Subjects

28 students (14 female, 14 male) from the Karlsruhe Institute of Technology were selected to participate in the study. They were misleadingly informed beforehand that the goal of the study was to test a new medical device; they were not told that the actual intentions of the study were to measure stress. This procedure was necessary in case of a stress study to avoid influences on the measurement result.

F. Study procedure

We designed a detailed and complex procedure for this study (see figure 2).

After the reception of the participant, an informed and written agreement is given by each individual. Some common information about the person is collected from questionnaire. After this, the system for measurement of pulse transit time was applied to the subject and the recording was started. Immediately they were instructed to a take a 5 minute pause. After this phase, a first saliva cortisol measurement and a subjective assessment of the mental state (MDBF) were collected. This was followed by a second phase, where the subjects had to lie down (baseline phase). In the next 20 minutes the anticipation period and the test period of the TSST took place. At the beginning and the end of each phase, saliva cortisol levels, as well as MDBF, were assessed.

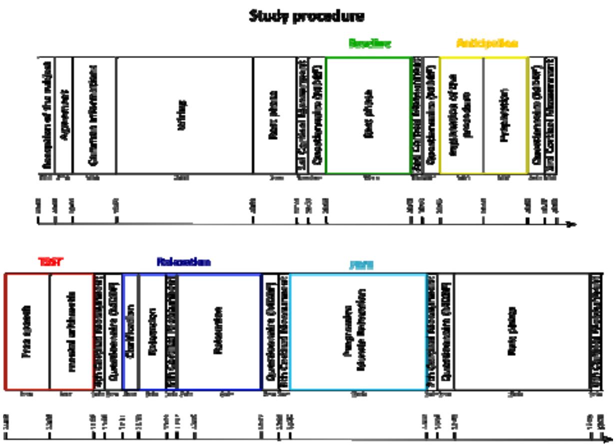

Figure 2. Study procedure in laboratory environment.

Following the TSST procedure consisting of the job interview and the arithmetic problem, subjects stayed in rest again for recovery from the stress reaction (10 min), a cortisol and MDBF measurement followed. Then a special relaxation technique, the so called progressive muscle relaxation (PMR), was performed during a period of time of 20 minutes. With this procedure we can get valid data for relaxed state as a reference that could be compared to the phases during the stress test. This phase also ended with saliva cortisol an MDBF measurement. The last phase of the laboratory period was a normal passive phase with no action for again 20 minutes. After the laboratory phase, the study procedure included a monitoring phase of the daily activities of the individual, including the night after the experiment. The measurement devices were removed from the individuals that following morning.

G. Biosignal processing

The digital signal processing has been done in MATLAB with an integrated analysis environment for psycho-physiological signals. ECG and PPG biosignals have been filtered in respect to the nature of the signal in order to suppress noise (e.g. power line interference). The feature detection of the r-wave in the ECG signal has been done with the OSEA algorithm [7]. Heart rate has then been calculated using the adjusted data. Furthermore, an automatic artifact inspection process did not take in account the r-waves, whose corresponding heart rate differs more than 30% from a moving average [8].

The p-base point in the PPG signal has been detected as described in section II.A. As a result, the pulse transit time could be obtained as the time difference between both of the identified features namely the r-wave and the p-base point. Subsequently a validation operation assured that the PTT is within a reasonable interval. Finally, the arithmetic mean value has been calculated over the defined phases.

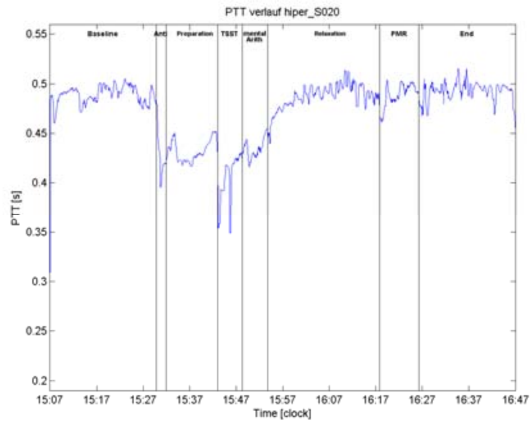

Figure 3. Pulse transit time plotted over time for a test person.

Figure 3 shows the typical signal sequence of the registered pulse transit time curves during one stress test in the laboratory environment using mobile PTT-sensor. In this figure, at the beginning of the measurement one can see the baseline phase with a relatively high value of PTT, followed by a sudden decrease at the beginning of the anticipation phase. At the beginning of the TSST, one could see another decrease in PTT. During the Relaxation a PMR, the PTT rises up to the level at the beginning of the test.

In comparison to this, the signal sequence of the heart-rate for the same individual is shown in Figure 4. One can see an inverted course of the graph. There is also a difference in the reaction time of the parameter at the beginning of a stressful phase.

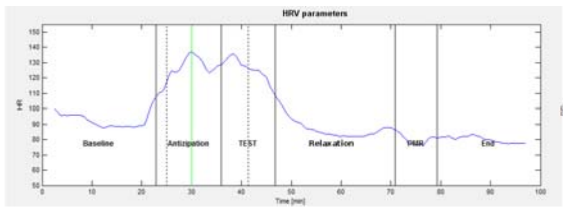

Figure 4. Heart rate plotted over time for a test person.

To control the evidence of the physiolocal signals during the different phases of the study, we calculated a Poincare-plot of the R-R-intervals in the baseline phase, the anticipation phase and in PMR-phase. As we can see in figure 5, there is a significant difference in HRV in phases with stress (anticipation) and phases of relaxation (PMR).

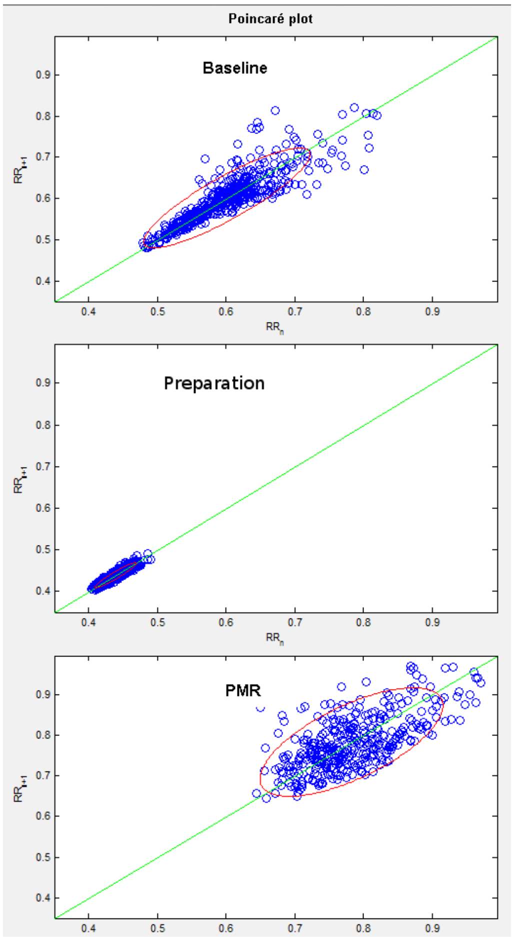

Figure 5. Poincarre plot for a test person.

III. Results and Discussion

The study shows that a mobile acquisition of pulse transit time (PTT) is possible.

The expected behavior of the PTT according to the defined phases could be registered. In fact, one could identify the stressful moments during the TSST test by the corresponding changes in PTT curve. Further analyses needs to show the benefit of a measurement of PTT during night. The analysis of this data is still in progress and will be presented in a later paper.

In Addition to other methods of psycho-physiological monitoring, the mobile measurement of pulse transit time for stress detection appears to be a very significant method as described in this paper.

Due to the fact that pulse transit time comprises much more information than heart rate and heart rate variability, this parameter provides more precise estimation of a person's stress level. This was shown in a previous work [8].

IV. Future Work and Conclusion

A more detailed analysis of the whole data acquired in this study is necessary in order to consolidate the preliminary results shown in this paper and to be able to draw a more reliable conclusion.

A further psycho-physiological analysis that compares the cortisol level to a subjective behavior state needs to be done in order to endorse the proposed method. In the next studies, an integrated sensor platform combined with a PDA-based e-diary method using myExperience software [10] will be used.

Acknowledgment

The Research Group hiper.campus received financial support by the "Concept for the future" of Karlsruhe Institute of Technology within the framework of the German Excellence Initiative.

References

[1] J.J.Kim and D.M. Diamond, "*The stressed hippocampus, synaptic plasticity and lost memory*," Nature Reviews, vol. 3, 2002, pp. 453-462.

[2] P. Vollmer, P. Boll, W. Stork, N. Lutter, A. Wagner, U. Großmann and J. Ottenbacher, "*Entwicklung eines mobilen, kontinuierlichen und nicht-invasiven Blutdruckmessgerätes mit Bluetooth Daten-übertragung*," Illmenau: BMT, 2004.

[3] L. Jatobá, U. Großmann, J. Ottenbacher, S. Härtel, B. von Haaren, W. Stork, K.D. Müller-Glaser and K. Bös, "*Obtaining Energy Expenditure and Physical Activity from Acceleration Signals for Context-aware Evaluation of Cardiovascular Parameter*," Venezuela, CLAIB, 2007.

[4] R. L-C. Pan, B. Chen and J. K-J. Li, "*noninvasive monitoring of autonomic cardiovascular control during stress*," Bioengineering Conference, Proceedings of the 1993 IEEE Nineteenth Annual Northeast, March 1993, pp. 187 – 188.

[5] C. Kirschbaum, K.-M. Pirke and D. H. Hellhammer, "*The „Trier Social Stress Test" - a tool for investigating psychobiological stress responses in a laboratory setting*," Neuropsychobiology, vol. 28, 1993, pp. 28, 76-81.

[6] S. S. Dickerson and M. E. Kemeny, "*Acute stressors and cortisol responses: a theoretical integration and synthesis of laboratory research*," Psychological Bulletin, vol. 130 (3), 2004, pp. 355-391.

[7] P. S. Hamilton, "*Open Source ECG Analysis Software (OSEA)*," www.eplimited.com.

[8] S. Hey, A. Gharbi, B. von Haaren, K. Walter, N. König and S. Löffler, "*Continuous non-invasive Pulse Transit Time Measurement for Psycho-physiological Stress Monitoring*," Proceeding of the International Conference on eHealth, Telemedicine, and Social Medicine eTELEMED 2009, Cancun, Feb. 2009, IEEE Computer Society Conference Proceedings, pp. 113 – 116.

[9] S. Härtel, J.-P. Gnam, S. Löffler, K. Bös, "*Estimation of Energy Expenditure using Accelerometers and activity-based Energy-models – Validation of a new device*". European Review of Aging and Physical Activity, Springer 2010

[10] J. Stumpp, P. Anastasopoulou, S. Hey, "*Platform for ambulatory assessment of psycho-physiological signals and online data capture*". 7th International Conference on Methods and Techniques in Behavioral Research "Measuring Behavior 2010", Eindhoven 2010