Continuous noninvasive Pulse Transit Time Measurement for Psycho-physiological Stress Monitoring

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***Abstract*—Stress is one of the most common reasons for a number of serious diseases. For the prevention and treatment of stress, a psycho-physiological monitoring system for stress measurement is needed. Because of the multifarious influences of stress on the physiological response of the body, a stress measurement system has to take into account as many parameters as possible. The pulse transit time (PTT), which is determined by measuring the ECG and the pulse wave at for example a finger, gives comprehensive information about the cardiovascular system. In a study we investigate the correlation between the PTT and the stress induced by a psychological experiment. We found out that there is a strong correlation and that PTT is an appropriate parameter for stress measurement.**

Keywords: stress; pulse transit time; psycho-physiological monitoring; cognitive performance

I. INTRODUCTION

Stressful lifestyle and lack of physical activity have a negative impact on one's health and could lead to heart and blood circulation diseases, as well as several psychosomatic illnesses. These mentioned Diseases belong to the most frequent causes of death in Germany according to the German statistical federal office (www.gbe-bund.de).

„The term 'stress' is generally defined in biological systems as any condition that seriously perturbs the physiological/psychological homeostasis of an organism" [1].

"Stress is a biologically significant factor that, by altering brain cell properties, can disturb cognitive processes such as learning and memorizing, and consequently limit the quality of human life" [1].

Excessive stress releases reactions on different levels. One observes reactions on the cognitive level, on the emotional level and on the vegetative-hormonal level as well as on the muscular level. Predominantly the reactions on the vegetative-hormonal level of the body can be measured.

These reactions are caused by an activation of the sympathetic nervous system and by the release of hormones (adrenalin, noradrenalin, testosterone and cortisol). Consequences arising out of this are an increase of the respiration rate and the heart rate, a constriction of the blood vessels as well as an increase of the blood pressure and a reaction of the electrodermal activity and energetic metabolism.

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. 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.

In order to help people adapt to their stressful everyday life in an easier way and to investigate the different possibilities of balancing one's physical and mental resources and thus achieving one's best cognitive performance, several workgroups are trying to make the psycho physiological load on people measurable. In fact they try to find indicators, which could show and quantify one's stress and activity level and thus give an idea about one's physical and mental state.

In this context hiper.campus project (see Figure 1) was initiated at Karlsruhe Institute of Technology (KIT). The aim of the project is to investigate correlations of emotional activation (mainly stress), physical activity and cognitive abilities. In several studies we try to identify parameters considered as relevant for the advancement of well-being and cognitive ability. These parameters will deliver the basis for the development of individual support-systems which can be used by students and co-workers of the university. Several methods of ambulatory monitoring, which provide the registration of subjective and physiological aspects as well as options for feedback, should be applied. These aims will be realized by contributions and close cooperations of scientists from different fields of research like information technology, sports science, education science and psychology.

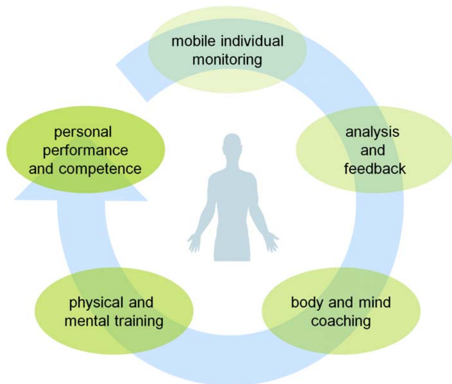

Figure 1. hiper.campus: coaching concept towards an improved cognitive performance with technical support of the Body & Mind Monitoring System

II. Methods

A. *Pulse Transit Time*

The pulse transit time or PTT represents the time needed by a pulse wave to exit the heart and reach the PPG (PhotoPlethysmoGramm) measurement site. In addition one should know that the bigger the distance between that site and the heart is, the less impact mistaken measurement values (in time domain) has on the PTT determination. For this reason the pulse wave is detected at the finger tip [2].

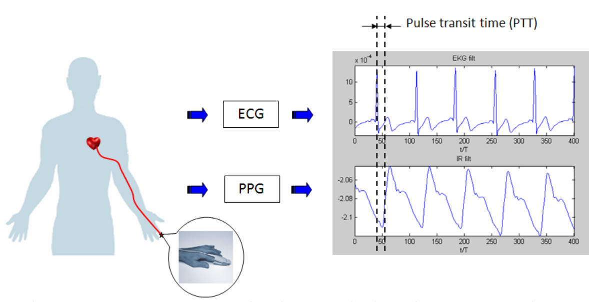

Figure 2. Measurement of pulse transit time from ECG and PPG

As shown in Figure 2, the PTT can be determined by calculating the time difference between the r-wave or QRS-complex of the ECG signal and the characteristic p-base point or 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 (see Figure 3). The main advantage of using the p-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 artefact robustness.

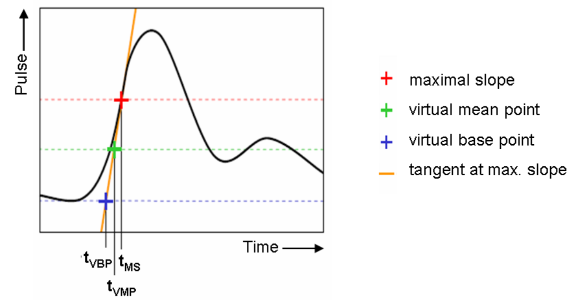

Figure 3. Determination of the virtual base point or p-base point in a pulse wave

Furthermore and because of physiological and anatomical limitations such us minimal/maximal pulse wave velocity or length of the blood vessel segment, the pulse transit time is constrained to be in a defined interval. This could be used to discard no valid PTT values due to measurement artifacts. If we consider a minimal/maximal pulse wave velocity respectively of 4m/s and 20m/s, a minimal/maximal length of the measurement segment respectively of 0.2m and 1.5m and a maximal pre ejection period (PEP), which is comprised in the calculated PTT, of 0.1s, then we get a validity range of PTT from 0.11s to 0.475s [3].

B. *System for Measurement of pulse transit time*

In this section the implemented Body & Mind Monitoring System, which has been used in the conducted study to determine the PTT changes of the test person, will be described.

This system comprises a modular hardware set-up, which has a variety of sensors (see Figure 4). These sensors allow a long-time non-invasive monitoring of some physiological parameters such as ECG, PPG, GSR and respiration. These could be relevant for the determination of the stress level of the test person. Furthermore a 3D acceleration sensor-node is used to simultaneously collect information about the activity of that person. The measured signals are then collected and saved either by a notebook or PC through a signal acquisition card in case of stationary test scenarios or by an integrated data logger equipped with a memory card and a Bluetooth interface in case of ambulatory test scenarios. Subsequently an offline post processing of the collected physiological data can be applied. Another additional feature of the LabVIEW application, which is meant for online visualizing the measured biosignals and saving them locally, is to give the observer, during the stress test, the possibility of setting markers. In this way the different data sets corresponding to the different phases of the stress test can be identified during the offline post processing.

Figure 4. Body & Mind Monitoring System

In the following sections, the different plug-in sensor modules, which are used to determine the pulse transit time, will be described in more details.

ECG-Sensor

To detect ECG-Signal, we are using the two-lead method. For instance, we measure the skin potential in the left arm, in the right arm and in a reference position on the body surface by means of gel electrodes.

Photoplethysmograph

A finger clip transmission photoplethysmograph is used to register the PPG. In fact, a current source delivers around 18 mA to the IR-Led of the sensor and a very simple voltage divider circuit allows detecting the signal of the photodiode. This latter correlates with the amount of blood in the finger and thus reflects the pulse wave in the blood vessels.

C. Method to stimulate stress situation

The „Trier Social Stress Test" (TSST) is a method for induction of moderate psycho-biological stress responses. 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 prepare their talks. After finishing the interview one member of the committee describes a second task. The test person has to serially subtract the number 13 from 1687. On every mistake restarting at 1687 is demanded. During the test period subjects are filmed by a video camera [6].

A meta-analysis conducted by Dickerson and Kemeny [7] and reviewing 208 laboratory studies of acute psychological stressors demonstrated that the TSST is a reliable instrument eliciting robust physiological stress reactions.

D. Subjects

The subjects were 20 high school students. 8 datasets were discarded due to artifacts or bad signals. In fact the major problem was with the PPG signal, which showed an important susceptibility to any sudden movement of the hand, at which the photoplethysmograph is placed. The remaining exploitable datasets were taken from 6 males and 6 females. Their age was ranging between 16-19 years.

In order to consolidate the current results and to be able to draw more reliable conclusions, a further study with 20 students is still in analysis phase, the first results confirm the results of this study.

E. Study procedure

The system for measurement of pulse transit time was applied to the subjects and the recording was started. Then they were in rest for 5 minutes (baseline phase). In the next 20 minutes the anticipation period and the test period of the TSST (see 2.3) took place. Following the TSST procedure subjects stayed in rest again for recovery from the stress reaction (3 min).

F. Biosignal processing

The analogue signals have been digitalized at 100Hz. The following digital signal processing has been done with MATLAB. 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 detection feature of the r-wave in the ECG signal has been done with the OSEA method [8]. Heart rate has been then calculated using the adjusted data. Besides, an automatic artifact inspection process didn't take in account the r-waves, whose corresponding heart rate differs more than 30% from a moving average, as described in [9]. The p-base point in the PPG signal has been detected as described in section 2.1. 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 has been calculated over the defined phases. Figure 5 shows the typical run of the registered heart rate and pulse transit time curves during one stress test.

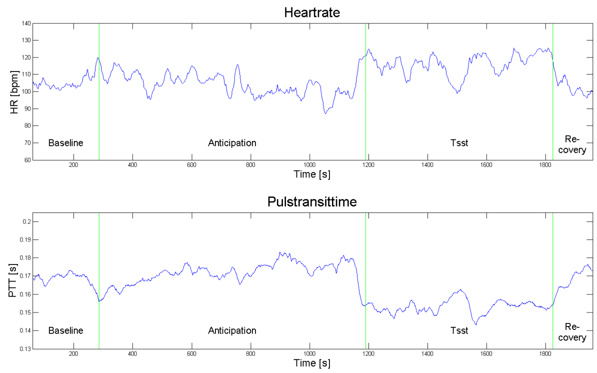

Figure 5. Heart rate and pulse transit time plotted over time for a test person

III. Results

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 corresponding changes in PTT curve. The calculated mean and standard deviation are shown in table 1. Paired samples t-test yields significant difference between baseline and stress phase (t=8.77, p=.001).

TABLE 1. Calculated mean and standard deviation

	Phase	Mean	SD
Heart rate [bpm]	Baseline	92,54	14,35
	Anticipation	99,89	11,43
	TSST	106,73	12,79
	Recovery	92,48	13,69
Pulse transit time [ms]	Baseline	201,2	19,81
	Anticipation	191,3	19,02
	TSST	178,3	20,06
	Recovery	200,0	20,68

IV. Discussion

The measurement of pulse transit time for detection of stress seems to be a very significant method. 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 the stress level of a person. A main drawback about that method is the necessity of the measurement of the pulse wave at an extremity (in our case at a finger tip), which is prone to big signal distortions in case of any sudden movement of the hand. To compensate this, an alternative fixation technique for the photoplethysmograph and/or methods for detection and compensation of artifacts in the PPG signal must be investigated.

Further experiments, which involves a larger number of test persons, have to been done to endorse the proposed theorie and prove its reproducibility.

V. Acknowledgment

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