RR interval analysis for the distinction between stress, physical activity and no activity using a portable ECG*

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Abstract— **Methods based exclusively on heart rate hardly allow to differentiate between physical activity, stress, relaxation, and rest, that is why an additional sensor like activity/movement sensor added for detection and classification. The response of the heart to physical activity, stress, relaxation, and no activity can be very similar. In this study, we can observe the influence of induced stress and analyze which metrics could be considered for its detection. The changes in the Root Mean Square of the Successive Differences provide us with information about physiological changes. A set of measurements collecting the RR intervals was taken. The intervals are used as a parameter to distinguish four different stages. Parameters like skin conductivity or skin temperature were not used because the main aim is to maintain a minimum number of sensors and devices and thereby to increase the wearability in the future.**

I. INTRODUCTION

In modern society, the awareness about health and the collecting of bio vital data are topics of great importance and interest, putting a focus on stress [1]. Currently, there are different approaches to how to measure stress. The approaches can be categorized in self-report questionnaires, measurements using biomarkers like adrenalin and cortisol [2], measurements using different behavior patterns [3], and measurement of stress using sensors for physiological parameters [4]. However, with a very reduced set of obtained parameters, it is difficult to distinguish between physical activities and negative factors like stress.

Currently, there is a variety of different consumer devices that can measure heart rate, for example, portable EGC and activity monitoring systems, which can be used for detecting stress. Nevertheless, the main difficulty remains the correct distinction between activity and stress.

It is well known that stress has long-term adverse effects on the cardiovascular system [5, 6, 7]; it reduces life quality, affects the immune response [8], and can trigger spontaneous panic attacks [9]. Among others, long-term effects of stress make it difficult to give an adequate response to physical and mental demands [10, 11, 12]. Extremely long exposure to stress can even modify brain structures [13]. Generally, stress can be considered as a negative influence that should be perceived and avoided. For the detection and measurement of stress, it is essential to make a distinction between different categories of stress and physical activity.

Furthermore, it is necessary to understand and to consider that stress is not the peak of a dramatic event, but stress is caused by events that require a fast response or elevated activity. Stress is a part of our daily life, and it helps us to estimate and respond faster to dangerous situations and to react more efficiently under critical circumstances, e.g., to decide whether to escape or to confront the danger. That means, in case of real danger, stress serves as a mechanism that allows us to react faster, more efficiently, and to prioritize body functions to achieve the maximal performance [14]. So, even stress should be evaluated in its context.

On the other hand, physical activities have long-term positive effects, like changes in body composition [15], as well as changes in the heart rate, blood pressure, or skin conductivity. The effects of physical activity can be divided into imminent and long-term. Relaxation also influences heart behavior and systolic pressure, as mentioned in [16, 17]. From this perspective, stress, physical activity, and relaxation influence the heart.

On an earlier attempt to measure stress and to differentiate between stress and physical activity with the help of ECG and RR intervals, we were confronted with misdetections caused by the similarity of the heart rate in case of stress and physical activity. The detected changes impacted heart rate, blood pressure, skin conductivity, or vision. [13, 18]. These difficulties are the reason why a relaxation phase was introduced in the experiment.

For the purpose of characterizing and examining the influence of stress on the behavior of the heart, an experiment was conducted in which the RR intervals were measured in four different situations: 'mental stress', 'physical activity', 'relaxation' and 'no activity'. A certain difference in the data is expected.

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During the experiment, we used a wearable wireless system that was designed to record electromyography (EMG), electrocardiography (ECG), and accelerometer data [19, 20] to collect data from the subjects. The wireless system is not invasive, and it consists of nodes that record and transmit motion-related body signals like activity and ECG data.

II. State of the Art

Currently, most methods to measure stress can be divided into four categories. The first category which is traditionally seen as the golden standard for stress studies is based on questionnaires and self-report, the second method uses biomarkers like adrenalin and cortisol, the third one uses physiological signals, and the last category employs behavior analysis.

Stress questionnaires or stress reports are the most widely used method of measurement. A version of stress reports is the 'Perceivers Stress Scale' that measures the perceived stress degree in different situations [3]. The main drawbacks of this method are the time required for completing the questionnaires and individual motivation and perception. This method has been questioned because it is subject to falsification of the results. After all, the results rely only on memory, and the perceptions of stress persist, although the stressor already disappeared. A standard fast questionnaire that is widely used is the (PSQ) Perceived Stress Questionnaire [21]. On the stress reports, the participants are asked about their feelings of happiness, anger, stress, frustration, etc. The second and third approaches use physiological methods. The second approach detects hormones like cortisol and adrenaline in blood or saliva [2]. The third approach uses vital data [22] like heart rate (HR), electrocardiogram (ECG), skin conductivity (electrodermal activity), electromyogram (EMG), heart rate variability (HRV) calculated from ECG. The advantage of this method is that it allows detecting meditation and relaxation because it also influences the heart activity [23]. The last method to detect stress is a 'behavior analysis'. The focus of this method is to observe the difference in behavior under stress. As an example, the way a person is typing while being stressed [24, 25] or driving under stress [26]. These methods are specially designed for specific use cases and have to be adapted for each new use case.

A popular method to detect and monitor physical activity includes smartwatches and wearable sensors that are placed on the body [4]. For example, it is possible to measure EMG, ECG, photoplethysmography (PPG), and temperature. Smartwatches and similar devices can be easily bought nowadays, but on the other hand, the significant disadvantage of wearables is that the signal quality depends on the right placement.

III. System Architecture

A. Experiment design

The approach used for this work consists of hardware and software parts: (i) The recording of the data is done with sensors placed on the skin, and (ii) the processing of the collected data is done in software. The experiment is split into four phases. In the (1) phase, called no activity, the subject avoids any activity and rests – quietly sitting on a chair and waiting while not doing anything. The (2) phase is called physical activity, i.e., the subject executes a set of predefined physical exercises. In the (3) phase, mental stress, the subject is exposed to mental stressors. The (4) phase is relaxation; here, the participant listens to relaxing music. While the experiment is running, the system collects the ECG, heart rate, and activity data of each subject.

The aim of the first phase, no activity, is to obtain the ECG values that will be used as a reference baseline. During this phase, the participant rests, sitting in a comfortable chair, doing nothing but waiting for 5 minutes.

During the second phase, physical activity, the ECG data is collected while the participant is doing physical exercises. The participant does the following activities: 11 biceps curls, 11 lateral raises, one isometric contraction (approx. 10 sec), 11 frontal raises, and 11 vertical rises. The physical activity phase has a duration of approx. 5 minutes.

During the third stage, mental stress, the person is exposed to stress tests like the Stroop test [27], the Trier test [28], and quick performing arithmetical operations. Currently, we prefer Trier tests due to reproducibility and because of the popularity of the test to induce stress. We modified the Trier test by removing the IV (Peripheral venous catheter) for blood sampling and removing the arithmetical operations segment. Also, the duration of the test is shortened from 20 to 15 minutes, but no additional modifications were made. The test is divided into three segments of 5 minutes. The participant is given 10 minutes to prepare a 10 minutes presentation on a given topic. After 5 minutes of preparation, the participant is asked to stop the preparation and to present the topic. Five minutes after the start of the presentation, the participant is asked to stop and told that the test is over, and he or she can relax and calm down.

B. Data acquisition & processing

ECG and accelerometer data are recorded during the experiment with a wireless sensor node [19]. Three mobile nodes are used in the experiment. Two mobile nodes capture EMG data for activity recognition, and the third node captures ECG data for mental stress, physical activity, and relaxation detection. The EMG data is currently not used for this approach, but in future developments, it could be integrated for activity classification and better classification of stress. The nodes are placed on one of the musculus pectoralis major for ECG data and on the biceps brachii, deltoideus medius, for EMG data. The duration of each session was limited to 5, followed by 2 minutes pause between the stages.

The collected data of the nodes are stored in separate files, one for each session. Each dataset contains a timestamp, ECG, accelerometer, and temperature data.

An RR interval is defined as the time between two consecutive R peaks from a QRS complex. The data is collected by the ECG node automatically. The algorithm for extracting RR intervals proceed as following: The RR Intervals have to fulfill the following criteria to be considered a valid RR value. First, the current R-value has to have a value higher than 250 mV. Values under this threshold are not considered as valid R peaks. If the maximum is detected, it is defined as the R peak. After successfully detecting an R peak, the algorithm waits for 100 ms until another possible R peak can be detected. Values below 100 ms are discarded. After several continuous R peaks are detected, the time difference between two R peaks is calculated by subtracting their timestamps. Also, the RR intervals with a value shorter than 250 ms or longer than 2000 ms are considered an artifact and discarded. Values higher than 2000 ms can occur if more than one R peak was not detected. The proposed algorithm for RR interval extraction still has to be validated, but previous tests have shown good usability.

After a correct detection of the RR intervals, two consecutive intervals are correlated as data tuple. This data tuple creates a correlation plot that visualizes the change and the tendency of the data, as shown in Fig.1. The variance is calculated afterward. This value is a good indicator of the amount of stress as a more significant variance indicates a bigger change in the RR interval and a more significant change in the behavior of the heart. A higher variance of the RR intervals means a lower stress level. As mentioned in [29], a healthy heart is not a metronome, its behavior is complex, and the system has to adapt fast to sudden (physical and physiological) changes of the environment. Stress influences this complex behavior lowering some nonlinear components. As an example, low High-Frequency is strongly associated with anxiety, worry, panic, and stress. The analysis of a RR interval can be used as in [30] for assessing cardiovascular arrhythmia and other events. We use this characteristic to find the tendency of stress.

TABLE I. TENDENCIES AND CHARACTERISTICS

	min	*max*	*mean*	*sdt*	*mode*	*RMSSD*
1	0,6363	1,5697	0,7702	0,1264	0,7150	77,3300
2	0,6414	1,6612	0,7946	0,1133	0,7557	79,5480
3	0,6414	1,7729	0,8491	0,1240	0,7557	85,0010
4	0,6125	1,4910	0,7086	0,0908	0,6485	78,5490
5	0,6375	1,3290	0,8561	0,0724	0,8780	85,2160
6	0,6745	1,5850	0,9213	0,0811	0,9275	91,5990

1. Presentation preparation, 2 presentations, 3 relaxation of presentation, 4 physical activity, 5 no activity, 6 relaxation.

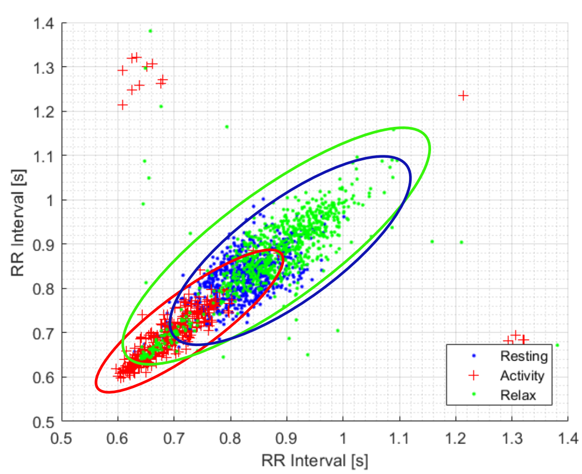

Figure 1. Data from the experiment comparing physical activity and relaxation. Resting means no activity.

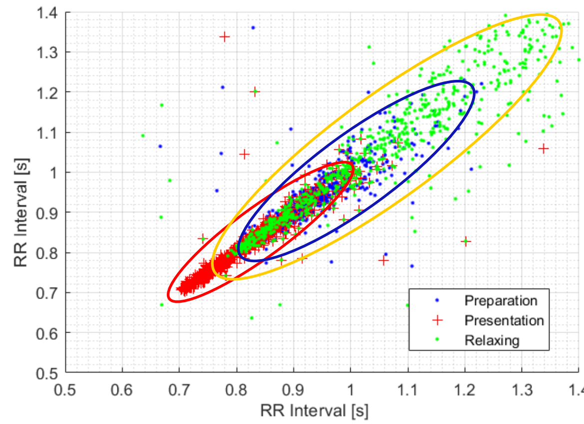

Figure 2. Data from the experiment comparing results from the Trier test.

IV. Discussion of Results

The objective of this experiment is to collect data and to observe the behavior of the heart in different situations. The experiment was realized with five subjects aged between 25 and 30. Each subject informed us that the Trier test was perceived as stressful. As we can see from Table 1, each kind of activity has a different Root Mean Square of the Successive Differences (RMSSD). Especially the phases that produce higher stress show a lower RMSSD. It is also visible in the graphics that the RR intervals are more spread in less stressful situations (incremented variance), and the RR intervals spread less in situations that are more stressful (decremented variance). Generally, phases like presentation and preparation of presentation are perceived as stressful and have lower variation. The relaxation phase shows higher variation and is also perceived as not stressful. Phases like no activity were not conclusive because the values spread from low to high RMSSD. The phase of physical activity also had a low RMSSD because the participants had to count the number of repetitions done, which was adding extra stress. As we observe in Fig.1 and Fig.2, the values of relaxing and no activity spread the most. In phases that were stressful for the participants like presentation preparation, we observe that the data is compacted.

The current algorithm that is implemented observes the variation of the progressing RMSSD. If the RMSSD shows a significant growth in the next 50 beats, it is interpreted as a relaxing situation. Otherwise, it can be interpreted as a sign that the subject is in a stressful situation.

To validate and improve the system, a more critical study will be carried out. Also, a physical stressor could be added to help to separate out more clearly the different phases. Also, a test in a real-world environment will be considered in a future study.

V. Conclusion and Future Work

Distinguishing stress from physical exercises has been one of the most important tasks when working with a very reduced set of parameters based on bio vital data monitoring for stress detection. A first study has been carried out to cluster the behavior of subjects into four different categories: 'no activity', 'physical activity', 'mental stress', and 'relaxation'. As we mentioned before, stress, physical activity, and relaxation have a strong influence on the behavior of the heart, although they also show similar characteristics in the RR data. In general, it is essential to distinguish stress and physical activity, and therefore, to reduce misdetection. The obtained data shows that there are changes in the behavior of the heart. We can observe that the RR intervals become shorter while activity and longer while resting. We could also observe that sometimes easy exercises and simple mental work can also induce stress. The data shows a change in the variance, as well. In the future, the setup will be used as one of the cases for an AAL implementation in Living Labs. The subjects are going to be instructed, and then they can execute the test on their own.

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