Heart Rate Variability as a Tool to Distinguish Periods of Physical and Mental Stress in a Laboratory Environment.

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Abstract— **Job stress is a huge problem in today's society. Therefore, being able to detect mental stress is very important. Here, ECG signals of 28 test persons under several conditions (rest, 45° shoulder abduction, IQ test, combination of postural and mental task) are examined by heart rate variability (HRV), a simple but powerful noninvasive methodology. This study showed clearly that HRV is a very useful and cheap tool to detect mental and physical stress. Not only a distinction with rest condition could be made, but even physical and mental load showed significantly different HRV characteristics, creating many possibilities in job stress detection in daily life circumstances.**

Keywords—**Heart rate variability (HRV), mental load, physical load, stress**

I. Introduction

Since the nineties, markers of stress and other psychosocial factors are associated with coronary disease [1, 2]. Compared to other lifestyle risk factors, stress is different because no consensus exists with respect to either definition or measurement. Inevitably, stress is subjective and it can encompass several aspects, from external stressors such as adverse life events, financial problems or job stress to potential reactions such as depression, vital exhaustion, sleeping difficulties or anxiety. In this study, we focus on job stress, being a huge problem in today's society since about half of work-related illnesses are directly or indirectly related to stress, costing billions of euros each year in EU as reported by the European Commission [3]. Several studies have shown a link between the level of work stress and disease [4-6].

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Stress, here defined as a mismatch between perceived demands and perceived capacities to meet those demands, changes the physiological balance of the autonomic nervous system (ANS), which is divided into a sympathetic and parasympathetic or vagal branch. Both components operate simultaneously and balance each other dynamically in normal conditions. When a person is exposed to a stressor, the sympathetic system becomes more activated, resulting in the secretion of the hormones epinephrine and norepinephrine into the blood. This hormonal secretion causes a change in some physiological signals, e.g. an increased heart rate and breathing rate. When the stressor disappears, the vagal system takes over to decrease among others sweating, heart rhythm and breathing rate.

Heart rate variability (HRV) refers to the beat-to-beat alternations in heart beat intervals and provides quantitative markers of autonomic regulation [7-9], capable of distinguishing between different autonomic profiles as related to diabetic neuropathy [8], posture [10] or hypertension [11]. Therefore, HRV can also be applied to detect stress [12]. Moreover, it is a simple and powerful noninvasive methodology having enormous practical advantages with a minimum of technical constraints, which makes it useful everywhere. While most papers about HRV and stress focus on the relation between the stress level, assessed by simple questionnaires, and some HRV parameters, the goal of this study is to investigate whether HRV can be used to detect mental and physical stress as created by a simple stressor as in every day life. More specific, the discrimination between mental workload and physical activity, in literature known to be methodologically difficult [13], is studied.

II. Methods

A. Data acquisition

28 participants were monitored, 15 men and 13 women with mean age of 22 (±1.96) years and an average body mass index of 22.2 (±0.43) kg/m^2. The study population consisted of students and young people working at the Katholieke Universiteit Leuven. In a laboratory environment, the subjects went through a protocol with four different conditions, of which 3 active conditions, each followed by a rest condition. The complete protocol was made in collaboration with psychologists. During the rest condition (R), relaxing pictures were shown to put them at ease. The three active conditions consist of a postural task

(PT), namely a 45° shoulder abduction, a mental task (MT), more specifically an IQ-test, and a combination of postural and mental load (MPT). The sequence of the active conditions was fully randomized amongst the participants. While the PT condition had a fixed duration of 6 minutes, MT and MPT were of variable length depending on the speed the subjects solved the IQ questions with a maximum of 10 minutes.

Electrodes (Ag-AgCl, 10 mm diameter, Nikomed, Denmark) were placed on the body to measure the ECG. The data were registered with EMG preamplifiers from Mega Electronics Ltd (Finland). These analog signals were amplified and low pass filtered (450Hz). The Daqbook 2005 (IoTech, Ohio, USA) was used to digitize the signals at a frequency of 1000 Hz with 16-bit resolution.

B. Heart Rate Variability analysis

After detection of the R peaks in the ECG signal by the Pan-Tompkins algorithm, the RR interval time series was preprocessed to correct for missing and ectopic beats.

Linear HRV parameters were obtained in agreement with the standards of measurement, proposed by the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [8]. Mean and standard deviation (SD) of the tachogram, the square root of the mean of the sum of the squares of differences between consecutive RR intervals (rMSSD) and the percentage of intervals that vary more than 50 ms from the previous interval (pNN50) were calculated in the time domain.

After resampling the tachogram at 2 Hz, the power spectral density (PSD) was computed by using fast Fourier transformation. In the frequency domain, low frequency power (LF: 0.04 – 0.15 Hz), high frequency power (HF: 0.16 – 0.40 Hz) and total power (0.01 – 1.00 Hz), as well as the ratio of low over high frequency power (LF/HF), were calculated. In addition, the power can be expressed in absolute values (ms^2) or in normalized units (NU).

Statistical analysis was done by the nonparametric Wilcoxon Signed Rank test to compare, for each HRV parameter, the values pairwise between the different conditions. $P < 0.05$ was considered statistically significant.

III. Results

A typical tachogram with indication of the different conditions is illustrated in Fig. 1. Note the clear transition between the conditions, meaning a good visual distinction between rest and active conditions at first sight.

As some HRV parameters, such as SDNN, depend on the recording length, a comparison between conditions can only be done by calculating each HRV parameter on segments of 2 minutes, which is the duration of the shortest condition in the dataset. Not only the first 2 minutes of each

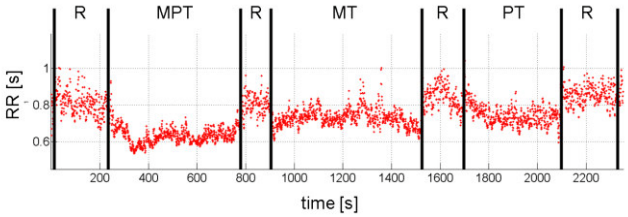

Fig. 1. A typical tachogram of a subject with indication of the different conditions.

condition are considered, but also the last 2 minutes, making it possible to examine an eventual evolution in time. All rest periods are averaged and considered as 1 condition.

Mean RR (Fig. 2) is significantly higher in R than in MT, PT or MPT ($p<0.0005$) as could be expected from Fig. 1. In the beginning, heart rate is maximal during MPT ($p=6.1$ E-5 vs. PT and $p=4.5$ E-4 vs. MT) followed by MT ($p=0.24$ vs. PT) and PT, while PT became the condition with the highest heart rate when looking to the condition ends.

SDNN, giving information about the total variability of heart control, was higher during rest, although this difference was only significant ($p=0.01$) compared to the mental task during the last 2 minutes as shown in Fig. 3.

Fig. 4 presents the results for rMSSD, which reflects vagal modulation of ANS as pNN50 and HF do according to literature. These three parameters showed the same evolutions as expected. The differences are quasi identical to mean RR, namely significantly higher in R compared to PT, MT and MPT. In addition, those parameters were significantly lower in MPT than MT, both in the beginning ($p<0.03$) and at the end ($p<0.02$) of the period. Even here, the results for PT changed over time, being the highest of all active conditions the first minutes and becoming the lowest at the end.

LF/HF and LF (NU), both characterizing the sympathovagal balance and depicted in Fig. 5, had a big increase during MPT, in the beginning only significant ($p=0.04$) to PT, but at the end to MT ($p=0.02$) and R ($p=0.014$). Again, the parameters changed completely within the PT condition, from the lowest one to the highest one.

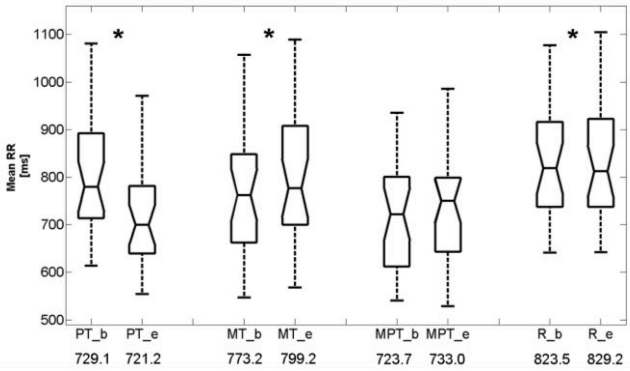

Fig. 2. Boxplots of the mean RR intervals for the different conditions, where *b* indicates the first 2 minutes and *e* the last 2 minutes of the specific condition. Statistical differences ($p < 0.05$) between both time periods are shown by *. Below the figure, the mean values are given.

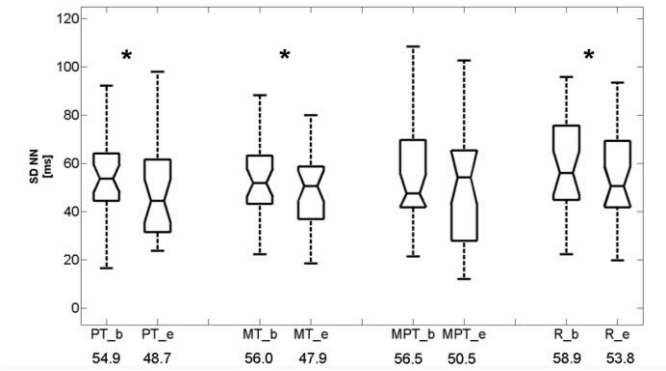

Fig. 3. Boxplots of SDNN for the different conditions, where *b* indicates the first 2 minutes and *e* the last 2 minutes of the specific condition. Statistical differences ($p < 0.05$) between both time periods are shown by *. Below the figure, the mean values are given.

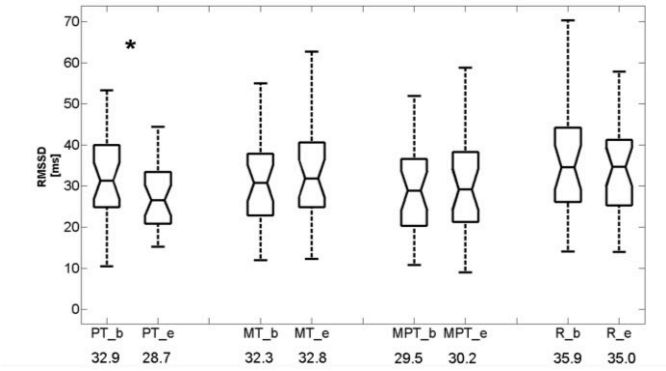

Fig. 4. Boxplots of rMSSD for the different conditions, where *b* indicates the first 2 minutes and *e* the last 2 minutes of the specific condition. Statistical differences ($p < 0.05$) between both time periods are shown by *. Below the figure, the mean values are given.

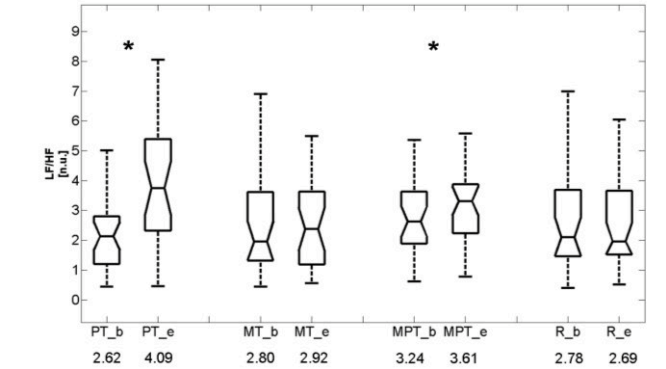

Fig. 5. Boxplots of the LF/HF for the different conditions, where *b* indicates the first 2 minutes and *e* the last 2 minutes of the specific condition. Statistical differences ($p < 0.05$) between both time periods are shown by *. Below the figure, the mean values are given.

IV. Discussion

Standard HRV parameters were calculated in several conditions: rest, physical task, mental task and combination of both. For almost all described measures, the active conditions can be distinguished from the rest condition. As expected, MPT was heavier than MT, resulting in a significantly higher heart rate and a significantly lower vagal modulation (rMSSD, pNN50, HF). These changes can be explained by means of an additional effect when combining tasks compared to a single load. Exactly the same could be found for the sympathovagal balance (LF/HF, LF (NU)), however only at the end of the periods, showing the increased dominance of sympathetic to parasympathetic branch due to the combination of both tasks.

Mental stress decreased high frequency components, but increased low frequency components of heartbeat interval time series as already noted in [14]. Another recent study [15] found that HRV patterns showed significantly decreased variances in high stress subjects, indicating somewhat disturbed ANS rhythms under the influence of chronic stress. Consequently, sympathetic predominance, vagal withdrawal and baroreflex impairment might represent the autonomic counterpart of the complex psycho-physiological changes underlying the increase in cardiovascular risk associated with chronic stress [16, 17].

The results for PT vary in time with values between those of R and MT in the beginning, but exceeding those of MPT in the last 2 minutes. Evolutions in time were also observed within other conditions. Mean RR interval increased significantly in R ($p=0.02$) and MT ($p=0.01$), respectively because people are recuperating after a mental or physical load and because they become more familiar with the mental task. In both cases, we hypothesize that this increase was caused by the relaxation process. In MPT, the opposite effect of the mental and physical task concerning mean RR counteracts, leading to a small increase. This observation gives rise to the hypothesis that the familiarization has a bigger impact on heart rate control than the exhaustion by the physical task. With respect to the sympathovagal balance, there is a small decrease during rest, but an increase during MT and MPT ($p=0.05$) showing that the vagal pathways of ANS became relatively a bit more active in rest while the sympathetic modulation gained importance in case of mental stress.

Two limitations of the study have to be noticed. First, not all conditions are equal in length causing problems in calculating one value for each HRV parameter in each condition. Second, 45° shoulder abduction is not representative as physical load in an office environment as we focus on job stress detection. Therefore, new measurements are being recorded solving these remarks. In the new study, breathing information is monitored additionally while time-frequency analysis will be applied to deal with quickly changing heart rates and their inherent influence on other HRV parameters.

V. Conclusion

This study showed clearly that heart rate variability (HRV) is a very useful and cheap tool to detect mental and physical stress. Not only a distinction with rest condition could be made, but even physical and mental load showed significantly different HRV characteristics, creating many possibilities in stress detection in every day life circumstances.

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