Towards an objective measurement of emotional stress: Preliminary analysis based on heart rate variability.*

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Abstract—**This paper presents a study performed in 25 young healthy subjects measuring the evolution of heart rate variability (HRV) indices during emotional stress. Acute emotional stress was generated with a modified version of Trier Social Stress Test (TSST). The TSST comprises several tasks which include a memory test, anticipation of stress, public exposition, and an arithmetic task. Each task has different demanding conditions, carrying subjects' emotional stress to different states. An autogenic relaxation was done before TSST. Significant differences in HRV indices were observed in the arithmetic and memory task with respect to the relaxation stage. In particular during the arithmetic task, mean heart rate increased 22% (p-value <0.00001) the power in the very low frequency band increased 47% (p-value <0.00001 and normalized power in the low frequency (LF) band increased 19% (p-value <0.04). These results support a sympathetic activation during these tasks.**

I. Introduction

Stress is a set of physiological responses to external stimulus that prepare the body to environment changes, usually generating an alert state. Within description, stress can be considered a positive survival mechanism of adaptation. However repetitive stress states are associated with chronic diseases, facilitating or increasing its manifestation in the major body systems such as the digestive, nervous, endocrine, muscular, etc.

Emotional state affects, among other the autonomous nervous system (ANS) [1]. Since the ANS controls the heart, measuring cardiac activity seems to be a non-invasive way for evaluating the state of the ANS. Consequently, changes in heart rate, defined as heart rate variability (HRV), point to the heart's ability to respond to multiple physiological and environment stimulus. On the other hand, heart rate variability is associated with sympathetic nervous system (SNS) and parasympathetic nervous system (PNS) balance and therefore it has been proposed as an indicator of a person´s emotional state [2],[3], [4], [5].

It is known that HRV power in the frequency range between 0.04 and 0.15 Hz (low–frequency , LF) is related to both sympathetic and parasympathetic modulation, while power in the frequency range between 0.15 and 0.4 Hz (high–frequency, HF) is related to parasympathetic modulation and mainly due to respiratory sinus arrhythmia [6].

The presented work involves experimental measurements of electrophysiological, biochemical and psychometric variables in healthy young students from the Autonomous University of Barcelona. Acute emotional stress was generated by a modification of the Trier Social Stress Test (TSST), which is widely used on stress research [7],[8], [9]. An analysis of HRV changes during different stressful events of the TSST session with respect to a relaxing state is presented in the following sections.

II. Materials and Methods

A. Data Collection

The analysis was performed on 25 subjects (16 women and 9 men) with an average age of 21.36±2.97 years (range 30-18). All subjects have not been diagnosed with any chronic disease or psychopathology. They are non-regular consumer of psychotropic substances, alcohol or tobacco. It is a socio-demographic homogenous group with a body mass index lower than 30. The ethics committee of Autonomous University of Barcelona approved the study protocol.

A modification of the TSST was used to induce acute emotional stress after a guided autogenic relaxation stage. Experimental sessions were done in the mornings, at the same time of the day. Each session was around 30 minutes long, according to the following protocol:

- Relax Time (10 min): an autogenic relaxation guided by an audio record is performed, to obtain a similar emotional state for all subjects (***PR***).
- Memory test (5 min) has two parts: first three short stories are told to the subject (***ST***). During the second part he/she has to repeat aloud as many as details as possible of each story during 30 seconds (***MT)*** [10]. During this part they were video recorded.
- Stress Anticipation time (10 min): Subject is asked to go to an empty room while his/her video is evaluated. This will increase his/her anxiety state before the next part (***SA***).
- Video display (3 min): the subject goes back to the previous room, where there is a public of at least three people. In front of the public it is displayed the video where the subject is remembering the story, followed by a video where a same sex actor is remembering most of the details. (**VD**).

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- Arithmetic Task (5 min): During 5 minutes the subject is asked to count back from 1022 in steps of 13. If he/she makes an error then he/she has to start again from the beginning (***AT***).

B. Physiological Measurement

Three leads of Electrocardiography (ECG) were recorded and sampled at 1 kHz using Medicom system, ABP-10 module (Medicom MTD Ltd, Russia).

R-peak series are estimated from the ECG using an algorithm based on the discrete wavelet transform [11]. Ectopic beats, false and misdetections were detected and fixed before the computation of the RR series. Besides, an instantaneous HR signal is obtained from the beat occurrence times using an algorithm based on the integral pulse frequency modulation model, which accounts for the presence of ectopic beats[12].

For each subject and for each session task the following HRV indices are computed:

Time indices: mean heart rate (HR), standard deviation of all NN Intervals (SDNN), root mean square of successive differences (rMSSD), and percentage of pairs of adjacent NN intervals differing by more than 50ms (pNN50), were computed from the fixed RR series.

Frequency indices: LF power (P_{LF}) and HF power (P_{HF}) were computed from the power spectral density of the HRV signal, calculated using Fourier transform. The HRV signal is obtained subtracting from the instantaneous HR signal, a low pass filtered HR signal (cut-off frequency of 0.03Hz), which mainly accounts for changes in mean HR. The LF/HF ratio was as well computed. Power in the very low frequency (VLF) band, range from 0 to 0.03Hz, was computed from the power spectral density of the lowpass filtered HR signal as in [13]. P_{LFn} and P_{HFn} are LF power and HF power normalized by the sum of P_{LF} and P_{HF} respectively.

C. Statistical analysis

HRV indices median values were obtained in a 3- 5 minutes time range depending on the activity. In the case of ST, MT, VD, and AT it was taken the hall time interval. For PR and SA 5 minutes range was selected (PR: minute 3 to 8, SA: minute 2,5 to 7,5).

PR moment is considered as a basal state, therefore is the reference state for comparisons. Wilcoxon signed rank test is performed to find pairwise difference between each session task. Also Friedman Repeated Measures Analysis of Variance on Ranks, a non-parametric statistical test, is performed for each HRV indices to see if there are differences among the session stage/task. p-value < 0,05 is consider as statistically significant.

III. RESULTS

The Friedman test reveals that each task performed has a statistically significant effect on each HRV index (p-value < 0.0013), except on pNN50.

The median and median absolute deviation across subjects are reported (Table I) for every HRV index and session task (or stage): Relax Time, Story Telling, Memory Test, Stress Anticipation, Video display and Arithmetic Task. Differences with PR, basal stage, along the session for each HRV indices were computed and the statistically significant are highlighted in Table I.

Arithmetic Task is the highest stressing moment of the session because of the task itself and it is the end of 25 minutes stress test. It presents significant difference in almost all HRV indices with respect to PR. Some increments are very high such as 125% for P_{LF} (p-value=0.0045), 95% of P_{HF} (0.0025 p-value), and 22% for mean HR (0.00001 p-value). It is the only moment of the session that P_{LFn} shows significant difference with respect to pre-relax, increasing 19,6% (0.043 p-value).

MT, similar to AT, is a demanding task, so it has similar but lower significant difference with PR session 125 % of P_{LF} (0.03 p-value), 65.1 % of P_{HF} (0.02 p-value), Mean HR 15,8% (0.00001 p-value) and SDNN 44,4% (0.00001 p-value). Furthermore MT and AT don't have significant differences between their HRV indices, except an increase of 5% on Mean HR and 9% on P_{VLF}.

Neither SA nor VD state shows significant differences with PR state. However during VD, there is an increase in P_{HF} of 22,8 % with respect to PR values while P_{LF} increment is the lowest of all session moments . Additionally, both have significant differences with the most demanding tasks, MT and AT in each HRV indices.

Figure 1 display the distributions of HRV indices during the different tasks of the TSST. It can be appreciated how indices change from one task to another, and there are significant changes at MT and AT with respect to the other session tasks. Mean HR is significantly different among each session task (p-value<0.01), except between PR, SA and VD. Also P_{VLF} is significantly different except between PR - SA and ST-MT moments. P_{LFn} varies significantly between AT, and the less demanding tasks (PR, SA, VD), similarly MT with respect to SA and VD.

TABLE I. MEDIAN±MAD OF HR, SDNN, PPNN50, P_{VLF}, P_{LF}, P_{HF} AND P_{LFn} DURING THE DIFFERENT SESSION TASKS

HRV Index	Session Task					
	PR	***ST***	***MT***	***SA***	***VD***	***AT***
Mean HR (beat/min)	71,20 ±6,59	**78,62**** ±4,64	**82,44**** ±5,21	68,33 ±6,10	70,09 ±4,48	**86,86**** ±8,36
SDNN (s)	0,06 ±0,01	**0,08**** ±0,01	**0,09**** ±0,03	**0,08*** ±0,01	0,07 ±0,02	**0,10**** ±0,03
rMSSD (s)	0,85 ±0,08	**0,78**** ±9,64	**0,75**** ±8,76	0,89 ±5,99	0,86 ±9,31	**0,71**** ±9,83
pNN50 (%)	20,56 ±6,70	19,86 ±9,64	17,44 ±8,76	18,88 ±5,98	16,86 ±9,31	15,17 ±9,83
P_{VLF} (s^{-2})	1,80 ±0,32	**2,37**** ±0,31	**2,42**** ±0,32	1,68 ±0,31	**1,90**** ±0,33	**2,65**** ±0,50
P_{LF} (10^{-3} s^{-2})	0,96 ±0,25	1,43 ±0,45	**2,15*** ±0,61	1,2 ±0,51	1,05 ±0,31	**2,15**** ±0,96
P_{HF} (10^{-3} s^{-2})	1,29 ±0,52	1,49 ±0,67	**2,13*** ±0,84	1,26 ±0,53	1,58 ±0,48	**2,52**** ±0,86
P_{LFn} (%)	0,386 ±0,14	0,471 ±0,07	0,516 ±0,06	0,491 ±0,05	0,381 ±0,06	**0,461*** ±0,05
LF/HF	0,654 ±0,34	1,045 ±0,20	1,066 ±0,32	0,983 ±0,21	0,640 ±0,18	0,909 ±0,13

* HRV indices with significant values differences respect to Pre-relax state. Wilcoxon test
* p-value level <0.04 , ** p-value level <0.004

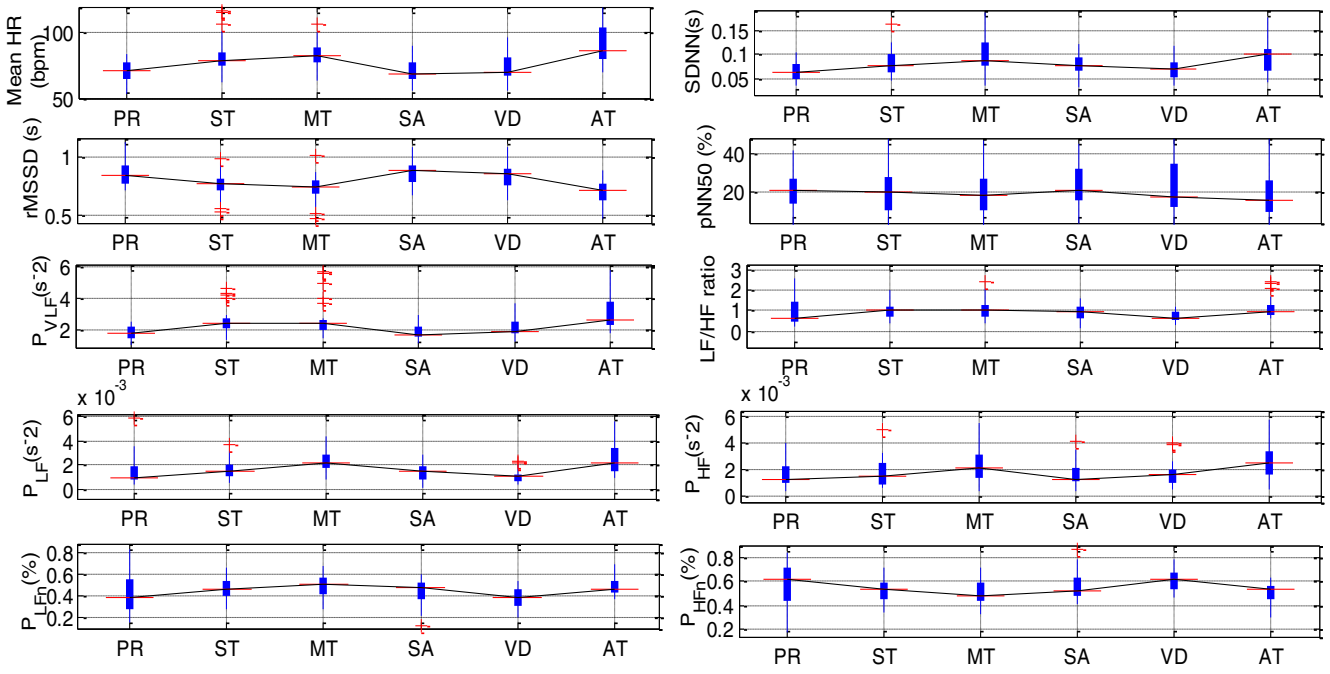

Figure 1. Median and 25th and 75th percentiles of HR, SDNN, rMSSD, pPNN50, P_{VLF}, LF7HF ratio,P_{LF} , P_{HF} , P_{LFn} and P_{HFn} during the different session tasks: PR (pre relax), ST (story telling) ,MT (memory test), SA (stress antcipation), VD(video) and AT (arithmetic task).

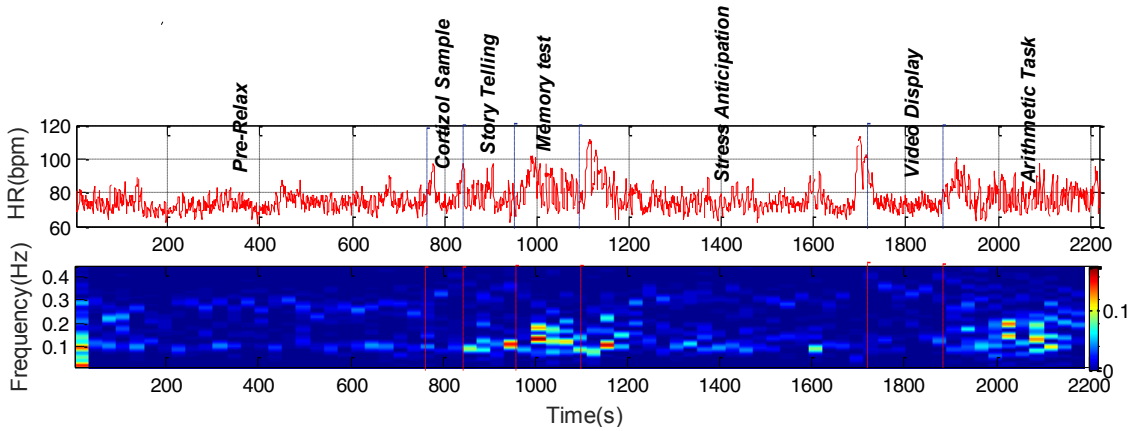

Figure 2. An example of HR signal during the TSST as well as a time-frequency spectrum obtained from the concatenation of the spectra computed from nonoverlapping 30-second windows.

Figure 2 displays the HR signal during the TSST as well as a time-frequency spectrum obtained from the concatenation of the spectra computed from nonoverlapping 30-second windows. There are higher variations at MT and AT moments.

IV. Discussion

Each session task has different demanding or elicited emotional condition so it is expected different emotional/arousal responses. HRV indices change during the session, with statistically significant differences among the different task, except pNN50, suggesting different emotional/arousal stage along the sessions.

There are significant changes at MT and AT with respect to PR and also SA and VD. Both MT and AT tasks are the most intellectually demanding and challenging of the session, so the most stressing. Mean HR increases in these both cognitive task, as in other studies in which the TSST is used [9] [7]. VLF band power reflects rapid changes in HR, then it is also related with stress response [1] . There is a significant increment of P_{VLF} in all session tasks with respect to relax state, being the highest at AT, except with SA.

Contrary to our results, not significant change in P_{HF} in arithmetic task with respect to a baseline level was reported in [7]. In this study respiration information was used to ensure that respiratory rate was within the HF range. In our study, which uses standard frequency bands for LF and HF, it may happen that during the PR respiratory frequency is within the LF band, so the HF band is not measuring respiratory sinus arrhythmia but just “noise”. During the

stress tasks, respiratory frequency increases and fall within the HF band, thus increasing the power in the HF band. However, this cannot be interpreted as an increase in parasympathetic activity.

LF/HF ratio does not show significant changes between PR and the other session tasks. LF/HF ratio is often associated with sympathetic and parasympathetic nervous system balance. However in [14] is illustrated that in some cases there is not a linear relationship between LF/HF ratio and sympathetic and parasympathetic activity, since there are other factors such as respiration rate, diseases or physiological challenges, which influences the LF/HF ratio.

LF normalized power increased 19% during AT with respect to PR, suggesting a sympathetic activation. Although the first part of the memory test, ST, also demands concentration, it is only listening. This may be the reason why there are significant differences only in mean HR and SDNN indices, but not in frequency indices.

HRV indices during SA are similar to PR, suggesting that this task did not increase the emotional stress as it was expected. It may be because it was an unreal situation, so subjects may find it more relaxing than the previous tasks.

In the case of VD, a stress response was expected due to being evaluated in front other people. However, we noticed that it elicited embarrassing feelings or shame rather than stress. So, because of the large range of personality characteristic among subjects the response to this stimulus was unequal. Since it is not a demanding task, LF power is as similar levels as during PR, and HRV indices show significant differences with respect to AT

V. Conclusion

In this study, HRV has been studied at different stressful tasks of a TSST session, with different demanding conditions, such as memory task, anticipation to stress, public exposition and an arithmetic task.

HRV indices displayed significant differences among the different task suggesting different emotional/arousal stage along the session. During the arithmetic and memory tasks most HRV indices (mean HR, SDNN, rMSSD, P_{VLF}, P_{LF}, P_{HF} and P_{LFn}) displayed significant differences with respect to the relaxing stage, supporting a sympathetic activation during these tasks. Story telling and video display show significant changes with respect to the relaxing stage only in mean HR

The arithmetic task as the stress session ended provoked significant differences in almost all HRV indices with respect to a relaxing phase and also with the rest of the moments of the session, so it is a higher stressful state with respect to the other session task.

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