Design and development of experiments with emotional stimulation techniques by means of image and sound to improve the individual's resilience against stress.

Lara Cuevas Blanco and Albert Puiggròs Figueras
Polytechnic University of Catalonia, Catalonia, Department of Electronics
Jordi Girona Road, 1, 08034 Barcelona
e-mail address: lara.cuevas@estudiantat.upc.edu, albert.puiggros@estudiantat.upc.edu

ABSTRACT

The World Health Organization has defined stress as the "Health Epidemic of the 21st Century". Chronic stress is found to be one of the main causes of growing numbers of physical chronic diseases. Even though there are some challenges, there is a lot of evidence to support the use of sound, images and resonant breathing to combat stress. However, music and image therapy are not easily integrated in our daily lives as it is largely based on personal preferences that may also be linked to cultural sensitivity.

The search for reliable stress biomarkers has established heart rate variability (HRV) as a suitable, cost-effective, non-invasive index for stress and stress vulnerability in mammals. The focus of this project will be to study how rhythmic sonic emotional stimulation techniques, rhythmic visual emotional stimulation and resonant breathing can be used to control the HRV performance with the intention of reducing and controlling stress.

I. INTRODUCTION

In the 21st century, stress has emerged as a pervasive health epidemic. Among several circumstances, studies have revealed a notable correlation between stress levels and urban environments, found to contribute not only to stress but anxiety and depression. Moreover, stress has also been identified as a significant catalyst for various physical disorders such as hypertension arthritis, type II diabetes, obesity and heart diseases[1].

A growing body of research has shown that sound and music can effectively counteract stress and its effects. Specifically, music therapy, brain entrainment therapies and, primarily, binaural beats that have exhibited their potential in reducing stress-related symptoms[2]. However, such implementations present several scalability issues. On the one hand, music therapy, which traditionally focused on relaxation and pleasure, relies heavily on individual taste and emotional response to specific music content. This results in a challenging implementation when considering a therapy on a larger scale or collective interventions. In contrast, techniques such as binaural beats offer a more universally applicable approach by taking into account the physiological similarities between human beings. In fact, they have shown promising results for reducing the effects of chronic stress. Nevertheless, the invasive nature and high cost of brain monitoring devices makes their application limited. Thus, in order to overcome these limitations and explore new ways to manage stress far from traditional implementations, an alternative approach is required, covering the rhythmic nature of sound and its potential impact on stress reduction.

The search for stress biomarkers has been challenging through the years due to the lack of consensus on stress definition and costly analytical methods. As a direct result, researchers have turned to the autonomic nervous system (ANS) and its link to stress. Through the measurement of the cardiac vagal tone, which affects heart rate (HR) and heart rate variability (HRV), the balance between the parasympathetic and sympathetic branches of the ANS can be observed. As a suitable index of stress in mammals, vagal tone monitoring and understanding will be one of the main purposes of this work.

To increase resilience to stress, the main goal is to implement reverse engineering HRV by stimulating the arterial baroreflex to regulate blood pressure. Resonant stimulation of the arterial baroreflex can be achieved by means of techniques such as resonant breathing. On top of that, these processes aim to maximize HRV and improve stress resilience. Yet, while methods like resonant breathing have been broadly studied, the use of acoustic signals for rhythmic emotional stimulation (RES) is less investigated. Acoustic RES offers benefits such as passive participation, non-invasiveness, subjectivity, scalability and cost-effectiveness. Hence, it provides the potential to be implemented in several circumstances and may be useful as a method for stress reduction.

II. STATE OF THE ART

CARDIAC VAGAL TONE AND HRV

As stated previously, stress is defined as a response to certain stimuli which disrupts the balance and stability of the body. The stress response involves physiological and behavior changes to maintain **homeostasis** -the regulation of the blood circulation to meet the demands of the different organ and tissue systems- in the presence of stressors. Moreover, the response is triggered into the brain, more concretely in the amygdala. The stress response is regulated mainly by two endocrine pathways: the Sympathetic Adrenal Medullary (SAM) axis and the Hypothalamic Pituitary Adrenal (HPA) axis, which provide an efficient link with the ANS. Deeply coordinated, both pathways are involved in the release of hormones which prepare the body to help cope stress once activated by the ANS. Without going into further detail, the interplay, the response and the coordination of these endocrine pathways can lead to useful stress biomarkers. In the same way, the balance between ANS and SNS brings useful stress biomarkers which relate with the endocrine system just mentioned.

The interplay between the sympathetic and parasympathetic branches of the ANS highly influence the activity of the cardiac vagal tone. Remark the fact that the parasympathetic nervous system relates to restoration of body calm and composed states. Conversely, the sympathetic nervous system is associated to prepare the body for the known fight to fight response.

Cardiac vagal tone refers to the activity of the vagus nerve on the heart. It is a major component of the parasympathetic nervous system: it can slow down heart rate, promote relaxation and support cardiovascular activity. As it can considerably be affected by the SAM axis and HPA axis, cardiac vagal tone is an important indicator of the activity of the parasympathetic nervous system and its influence on the heart rate and HRV. Higher cardiac vagal tone is related with better physiological regulation and increased HRV. Lower cardiac vagal tone -monotonous heartbeat-, is related with reduced parasympathetic influence and lower HRV, resulting in possible stress, anxiety and depression. However, cardiac vagal tone is highly complicated to measure. Because of its effect on the heart rate, it can be better observed by examining its correlation with HR and HRV.

Overall, cardiac vagal tone and HRV are well acknowledged as valid biomarkers to detect stress physiological symptoms, which, in summary, result from the interplay of parasympathetic and sympathetic activity.

Chest-based Strap and Adhesive single-lead ecg

In order to study the time intervals between consecutive heartbeats, the standard technique would be using an Electrocardiogram (ECG) sensor, as it provides the most accurate data, capturing the heart's electrical function by providing a graph of voltage over time. The display represents the PQRST complex that can be further divided into three distinct components: the P wave, the QRS complex and the T wave. The P wave represents the depolarization of the atrial myocardium, while the QRS complex reflects the depolarization of the ventricular myocardium. Lastly, the T wave signifies the repolarization of the ventricular myocardium. This relationship between the voltage levels of the action potential and the voltage levels captured on the skin's surface during the PQRST complex is visually depicted in *Figure 1*.

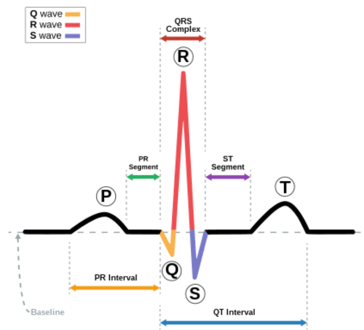

Figure 1. ECG of a human heart in normal sinus rhythm[3]

Our main focus will be studying the RR intervals, meaning the time elapsed between two successive R waves of the QRS signal on the electrocardiogram.

In the case of the respiratory cycle and RSA (Respiratory Sinus Arrhythmia) studies have shown they are a direct measurement of the cardiac vagal tone -an index of stress and stress vulnerability-. Briefly summarized, when we inhale, the diaphragm contracts and moves downward, while the chest cavity expands, leading to a decrease in intrathoracic pressure and a corresponding decrease in atrial pressure. As a result, blood flow to the heart increases, reducing the firing response of the baroreceptors and subsequently diminishing vagal tone. Consequently, there is an increase in heart rate. As we exhale, the diaphragm relaxes and moves upward, reducing the size of the chest cavity, increasing the intrathoracic pressure. The elevated pressure limits the venous return to the heart, which leads to reduced atrial expansion. Additionally, the increased intrathoracic pressure activates baroreceptors to a greater extent. Consequently, the inhibition of vagal tone is relieved, resulting in a decrease in heart rate.

In order to obtain successful results and allow RSA to be used as an index of stress, the breathing must be paced (resonant breathing at 0.1Hz)[4] in order to undergo respiratory variations. When doing so, the body enters in a state that maximizes HRV, generating HR stable oscillations of higher amplitude associated with better resilience to stress and improved emotional well-being.

III. METHODOLOGIES

The main goal of this project is to observe HRV fluctuations due to external stimuli and, primarily, due to acoustic stimuli. Moreover, we aim to identify certain variabilities related to the nature of each stimuli -either positive, negative or neutral-.

A series of experiments will be set in order to test the hypothesis that acoustic RES can reduce and improve the resilience to stress in comparison to image RES and resonant breathing. In order to prove that using rhythmic acoustic RES you can induce high-amplitude HRV oscillations, a controlled environment -dark and quiet space- will be needed in order for the experiments to take place.

Using the software of PsychoPy and the Biopac M36 for the data acquisition, participants will be presented with visual and auditory stimuli[5] and their ECG and respiratory parameters will be captured - a methodology employed by Drs. Evgeny Vaschillo and Bronya Vaschillo in their studies for HRV maximization via resonant stimulation-[6][7][8].

The resonant stimulation of the arterial baroreflexes will be studied by comparing different methods like Image RES, Acoustic RES and Resonant Breathing. However, some baseline measurements will be performed before each experiment in order to get CVS (Cardiovascular) reference readings and to guarantee the recovery after each experiment before starting the following one[9].

The Vanilla Baseline Reading consists of looking at a screen during five minutes where squares change color every ten seconds and the participants are asked to count the number of blue squares.

The image stimuli will consist of projecting pictures from the International Affective Picture System, dividing them into 3 blocks of 15 images each with a 1-minute rest period in between blocks. Each block represents pictures of negative, positive or neutral emotional valence that will be presented in random order. The frequency of presentation of images corresponds to 5 seconds in order to target the resonant frequency of the arterial baroreflexes of 0.1Hz.

The Sound RES experiments will consist of playing sounds from the International Affective Digital Sounds, with closed-back headphones on, in order to evaluate the acoustic stimuli. This experiment will follow the same pattern as the image RES, meaning it will be divided into three blocks (presented in random order) with 15 sounds each, presenting negative, positive and neutral emotional valence sounds, with a duration of 5 seconds per sound, in order to target resonant frequency of the arterial baroreflexes of 0.1Hz.

Lastly, the Resonant Breathing experiment will consist of guided deep breathing exercises that will also be divided into 3 blocks. Each one will last for 150 seconds with a resting period of 1-minute in between them.

The procedure in order to obtain adequate results was quite simple. Each participant had to fill out a questionnaire where we asked basic questions (history of cardiovascular problems, mental health issues, coffee and alcohol intake in the previous 12 hours, etc) and a written consent form to get some basic global information prior to analyzing their ECG. Having filled the form, they will be placed in a comfortable chair at a distance of 1.5m from a screen and connected to the equipment used to capture the biosignals. The Biopac M36 was employed to capture both ECG and respiration parameters via the SS29L electrodes and SS5LB respiratory effort transducer in response to the experiments run by PsychoPy. A keyboard was placed in front of the participants in order to press the enter key to initialize each experiment and also to start recording the data -we used an Arduino in order to synchronize the start of each experiment with the recording of the data-.

IV. RESULTS

As we already stated, our main focus will be to estimate the amount of variability of the time period between two successive heartbeats (RR interval). In order to do this, we must analyze the MDRR and (Average of RR intervals) and SDRR (Standard deviation of RR intervals), a measure of the beat-to-beat variability in the HR. A higher standard deviation indicates greater variability in heart rate, reflecting the fluctuation in the intervals between consecutive heartbeats while a lower SDRR suggests more regularity in the heart. However, it must be taken into account that a higher SDRR typically indicates better HRV, associated with a healthier cardiovascular system[10].

The RMSD (root mean square of successive sinus-initiated interbeat intervals in milliseconds) captures the fluctuations from one heartbeat to another, demonstrating a stronger correlation with the high-frequency (HF) variations in heart rate variability (HRV). Therefore, it serves as the primary time-domain metric for assessing changes in HRV influenced by the vagus nerve. A higher RMSD value indicates greater variability in RR intervals, while a lower value suggests more regularity in the HR.

As far as the analysis and interpretation of the data, we will be studying the results for the sound and image stimuli, and the respiratory data will not be considered -all the data has been recorded over a period of approximately 50 minutes (duration of the whole experiment) and several graphs will be briefly discussed-. Once the HR is measured, we performed an RR graph for each patient as shown in *Figure 2*. Afterwards, we proceeded with the following statistical analysis in which we identify MSRR, SDRR and RMSD.

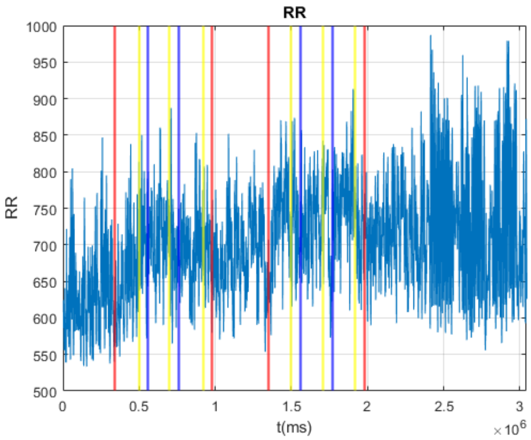

Figure 2. Graphical representation of the RR intervals

On the one hand, we can clearly observe that both image and sound stimuli considerably alter the normal HRV level as, for each of the sets in which stimuli interact with the patient, we can identify a change in heart rate functionality. It can be observed how Image RES results in higher stimulation as the results (*Figure 4*) show a clear distinction in between each gate -either positive, negative or neutral-. As it can be seen in *Figure 4*, there is either an increase or decrease of the SDRR that can be observed, corresponding each to a set of images. Particularly, it can be noticeable how for positive images there is an increase with respect to the rest of the data and, for the negative images, a decrease. However, the impact of the stimuli on the subject is considerable, indicating a positive response to positive stimuli -increased HRV- and negative response to negative stimuli -decreased HRV-. Moreover, when comparing the results with the baseline established during the Vanilla testing we can observe a considerable increase in MDRR. As shown in *Figure 3*, the MDRR increases with respect to the Vanilla recordings once either the image or acoustic stimuli are presented. Then, we will take this data as reference.

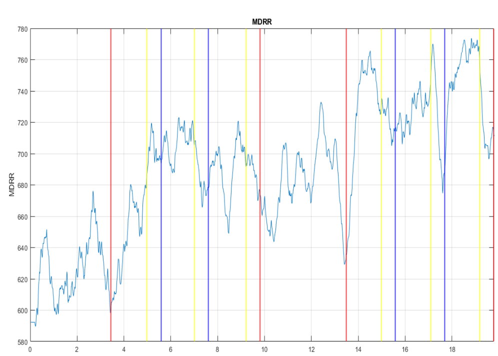

Figure 3. MDRR graph measuring the response during the first four parts. Each set can be identified as follows: Image RES(first red-red interval), Sound RES (second red-red interval) and in between the Vanilla Test.

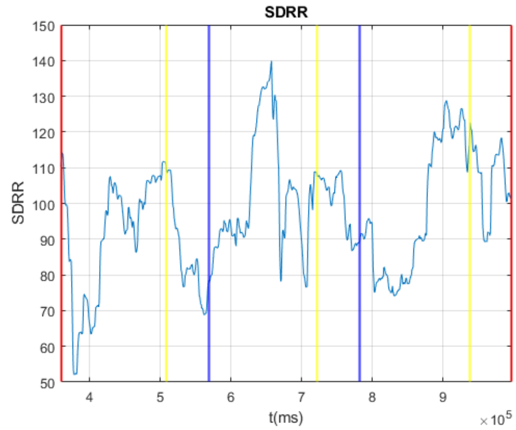

Figure 4. SDRR graph measuring response to Image RES with respectively Negative (First interval enclosed between red and yellow lines), Positive (Third interval enclosed between blue and yellow lines) and Neutral (Fifth interval enclosed between blue and yellow lines) set of images. The shorter intervals represent a time space of transition between sets in which there is no image.

On the other hand, the results for sound RES do not show a clear response to the stimuli. Nevertheless, some appreciations can be made. Considering *Figure 5*, we can clearly see that MDRR increases considerably during the positive sound exposure. In contrast, it decreases when the subject is exposed to negative acoustics. Therefore, the results adjust to those expected. However, other results regarding one of the patients did not turn out as anticipated.

Even though the results shown in *Figure 5* illustrate a significant change in front of each of the stimuli, the variability does not match notably that expected. Once the positive acoustic stimuli is presented a relatively high increase of the RMSD occurs, indicating greater HRV variability. Then, inside the same positive set of sounds, an abrupt decrease appears. As for the other two sets -negative and neutral- the RMSD graph shows a notable increase at first followed by a clearly decreasing tendency. For the negative stimuli, this indicates that the stimuli affects and triggers the ANS when exposed and, afterwards, results in a decrease of the HRV as we would expect, as if the impact of the stimuli took longer than expected. Still, these particular results do not quite fit the anticipated.

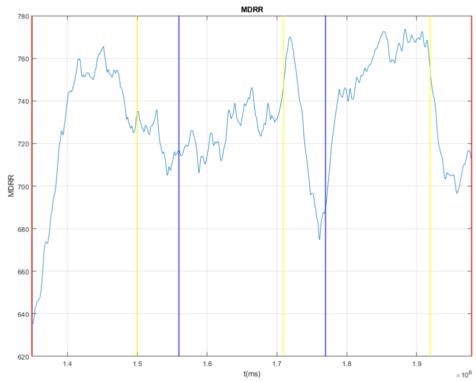

Figure 5. MDRR graph measuring the response to sound RES with respectively Neutral (First interval enclosed between red and yellow lines), Negative (Third interval enclosed between blue and yellow lines) and Positive (Fifth interval enclosed between blue and yellow lines) set of sounds. The shorter intervals represent a time space of transition between sets in which there is no image.

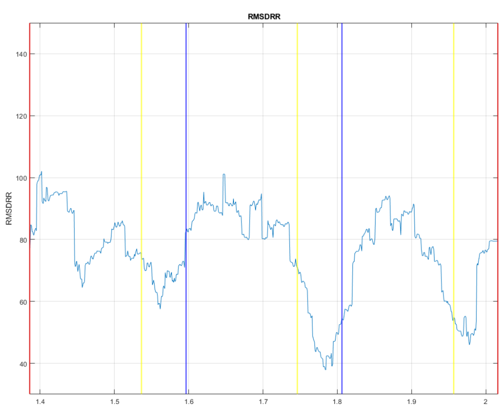

Figure 6. RMSD graph measuring the response to sound RES with respectively Positive (First interval enclosed between red and yellow lines), Negative (Third interval enclosed between blue and yellow lines) and Neutral (Fifth interval enclosed between blue and yellow lines). The shorter intervals represent a time space of transition between sets in which there is no image.

Overall, taking into account all the data collected, we must conclude that acoustic stimuli effectively triggers a response from de ANS in the form of HRV variations. However, the kind of response and the posterior application in stress resilience requires further investigation and more experimentation as it must be taken into consideration the different results depending on each individual. Moreover, we could allow more time between sets of stimuli in order to let participants recover and potentially observe more significant variations of the HRV .Even though we found several difficulties when analyzing and interpreting the results due to lack of experience and short time, the results are promising and the experimental set has appeared to be successful.

V. CONCLUSIONS

On balance, based on the data collected, it can be concluded that acoustic stimuli effectively elicits a response from the autonomic nervous system (ANS) in the form of heart rate variability (HRV) variation. However, further investigation and experimentation are needed to understand the nature of this response and its potential application in stress resilience. In the same way, further data analysis is required in order to explore precisely the response. It's also important to consider the influence of individual emotional response to the presented stimuli, such as cultural sensitivity and apprehensiveness, as these factors affect the results.

Remark the fact that this work provides a preliminary overview of the subject and more research and experimentation is needed. This project aims to explore possible implementations of sound stimuli in daily life to reduce stress and, while the results demonstrate an actual response to the stimuli, further experimental data is required to establish a stronger correlation between acoustic stimuli and HRV.

VI. REFERENCES

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