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Using an Ambulatory Stress Monitoring Device to Identify Relaxation Due to Untrained Deep Breathing *

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Abstract— **The objective of this paper is to assess the efficacy of deep breathing as a relaxation activity using a wearable stress monitor. For this purpose, we developed a protocol with different mentally stressful activities interleaved with regular sessions of deep breathing. We used three physiological sensors: a heart rate monitor, a respiration sensor, and an electrodermal activity sensor, to extract parameters that are consistent with the dominance of the sympathetic nervous system. Our results indicate that a large number of subjects were not able to perform the paced deep breathing exercise properly, which caused their stress levels to increase rather than to decrease. The study also showed that our wearable stress monitor can be used to monitor breathing technique and assess its effectiveness in relaxing individuals.**

I. INTRODUCTION

The human body, undergoes several physiological and psychological changes when exposed to acute stressors. In today's contemporary lifestyle psychological stressors may remain pervasive and persistent for long periods. Prolonged stress can be detrimental to health, and can cause non-cardiac chest pain, hypertension, emotional disorders and cardiovascular diseases. It can also lead to abnormal or dysfunctional breathing [1], [2]. The literature indicates that balanced breathing significantly contributes to stress management and good health [3]. Improvements in sympathetic/parasympathetic homeostatic mechanisms, lung oxygenation and blood pH level can be achieved through deep breathing exercises [4]. There are many devices that are commercially available for respiratory training and stress management [6], [7]. However by using these tools, neither physiologists not psychologists can monitor breathing efficiency and stress levels continuously because of their immobility and accessibility. Nor does the user know whether the breathing exercises they are performing are actually relaxing them.

In this context, we have developed a wearable sensor monitoring device that captures a number of physiological variables known to be indicators of stress and arousal [8]. The device was designed to be non-invasive, comfortable and inconspicuous, in this way minimizing its interference with the user's daily life.

The aim of our study was to identify the effectiveness of deep breathing exercises as a relaxation technique. For this purpose, we asked the subjects to perform several deep breathing exercises interleaved with different stress-inducing activities. We hypothesized that deep breathing would be effective in relaxing the subjects. In this paper we analyze the physiological data collected during these metronome breathing sessions. The following section contains a brief review of the autonomic nervous system, autonomic imbalance and the influence of breathing on the autonomic nervous system. The experimental protocol and hardware has been described in section III. Analysis and results are presented in section IV, which is followed by a discussion and conclusions of our results in section V.

II. RELATIONSHIP BETWEEN AUTONOMIC NERVOUS SYSTEM & BREATHING

A. *Autonomic Nervous System & Autonomic Imbalance*

The Autonomic Nervous System (ANS) is a vital component of the neural system. The ANS is further divided into two branches: Sympathetic Nervous System (SNS) and Parasympathetic Nervous System (PNS). The SNS and PNS work together to maintain physiological homeostasis in the presence of environmental and emotional changes. The sympathetic input is catabolic and it prepares for emergencies i.e. fight-or-flight responses [9]. The SNS increases heart rate and blood pressure, activates sweat glands, causes pupil dilation, constricts blood vessels and increases muscular strength [10]. In contrast, the parasympathetic system slows heart rate, decreases blood pressure and breathing rate to restore balance [11], [12].

Stress stimulates the SNS, which in turn affects various physiological responses as described above. Long sustained stress causes the SNS to stifle the influence of the PNS, which in turn leads to over stimulation of the SNS. This causes imbalances, which can affect physical health. Several investigations suggest that the disequilibrium between these two systems leads to dysfunctioning of the autonomic system [13]. Therefore, to maintain normal functionality of physiological mechanisms it is imperative that PNS and SNS function synergistically [14].

B. *Anatomy of Breathing*

The literature describes two modes of breathing: abdominal breathing and chest (or thoracic) breathing. In abdominal breathing, the diaphragm moves freely, causing air to rush into the depths of the lower 13% part of the lungs. The lower part of the lungs are 6-7 times more effective in oxygen transport than the upper part. Research also suggests that this type of breathing transports 40-60 ml of oxygen per minute. Thus it maintains blood oxygen level in the body and

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activates the PNS [3], [15]. Thoracic breathing, in contrast, uses intercostal muscles for breathing. It is relatively shallow and fast as compared to the abdominal breathing. It transports less than 6 ml of oxygen per minute in the body [16] and thus, stimulates the SNS [4].

C. The Effect of Breathing on the Autonomic Nervous System

Metabolic and autonomic breathing can be altered by various behavioral influences. Hypertension and stress collectively function through the imbalance between the parasympathetic and sympathetic nervous system, favoring the latter. Thoracic/chest breathing is one of the major causes of breathlessness, dysfunctional breathing and hyperventilation which stimulates SNS and is pathogenesis of stress, anxiety, and other emotional and physical conditions. On the contrary, deep/abdominal breathing shifts the autonomic balance towards the parasympathetic tone [3], [17]. Deep breathing has been very effective and useful for the treatment of patients suffering from cardiovascular diseases [18], CODP [19], hypertension, stress and other physical and physiological disorders [3].

III. MATERIALS & METHODS

A. Subjects

25 participants (15 male, 10 female) aged 18-35 volunteered to take part in the study. All volunteers underwent a medical examination by a medical doctor to assess their suitability for the study and 22 healthy people selected. Each participant was briefed on the experimental procedure and gave their written consent on forms approved by the TAMU Institutional Review Board. The subjects were not trained for any of the activities including the deep/abdominal breathing prior to the study.

B. Hardware

Heart Rate Variability (HRV), respiration and electrodermal activity (EDA) are good quantitative indicators of stress and how well the body maintains equilibrium. For these reasons, these variables have a long history of utilization in physiology, psychology, neuroscience and clinical research. We incorporated these sensors into a wireless, minimally invasive monitoring system [8].

We recorded heart rate variability with a heart rate monitor strap, and respiratory activity with pressure-based sensor; both sensors were integrated together into a single chest band. To measure EDA we applied small AgCl electrodes on the middle and index fingers of the non-dominant hand, which were connected to a wireless EDA module; see [8].

C. Protocol

As part of the experiment, participants were asked to perform a set of activities designed to induce stress. These activities were interleaved with deep breathing (DB) segments, intended to relax the subject; see Fig.1. After calibrating the system for each individual, we recorded an initial deep breathing activity to establish a baseline. During each deep breathing session, participants were asked to pace their breathing by inhaling for 4 seconds and then exhaling for 6 seconds. The duration of each breathing session was 3 minutes while each stress activity was 5 minutes long. Participants were asked to rate the stress and difficulty levels of the activities, first following each activity and then again at the end of the overall experiment.

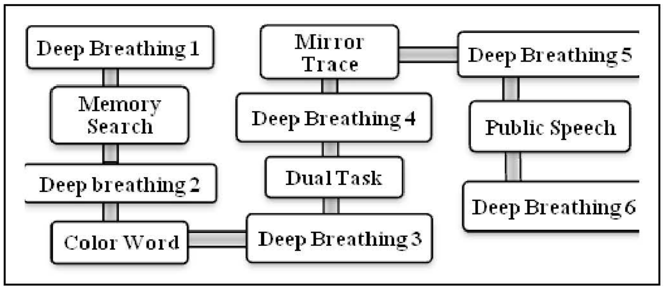

Figure. 1. Sequence of all the activities performed by the subjects during the experiment.

IV. DEEP BREATHING ANALYSIS & RESULTS

We extracted six parameters from the physiological sensors for the analysis: (1) AVNN: average of time interval between normal sinus beats; (2) pNN25: percentage difference between adjacent NN intervals greater than 25msec [20] ; (3) RMSSD: root mean square of successive difference in milliseconds [21]; (4) HRV-HF: High Frequency power of Heart Rate Variability; (5) Resp-LF: low frequency respiratory power [21], [22]; and (6) SCR: the mean of rapid varying phasic skin conductance response. We selected HRV-HF because it is influenced by cardiovagal tone and increases as the person relaxes [22]. Resp-LF provided information about their breathing technique in the frequency range of the prescribed rate of 0.1 Hz. SCR refers to the variation in skin conductance which perseveres for short time intervals of a few seconds and then returns to the baseline level [8]. Due to the short duration of the deep breathing activities, we selected the faster varying SCR instead of the mean of the slower varying tonic skin conductance (SCL), which measures the conductivity over longer time intervals [23].

After filtering the outliers and the missing data, we were left with the data from 15 subjects for the final analysis. We analyzed each subject data over the whole protocol individually. We observed that the parameters of some subjects displayed high stress during DB with values consistent with those observed during the stressful activities. Whereas, there was another set of subjects whose parameters showed variation during the stress and relaxing activities. Based on this observation we determined that subjects responded in two distinct ways during the DB activities. To

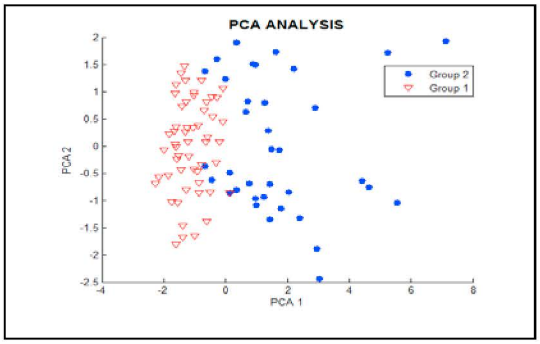

Figure. 2. PCA of all the subjects across 6 features during the deep breathing activities.

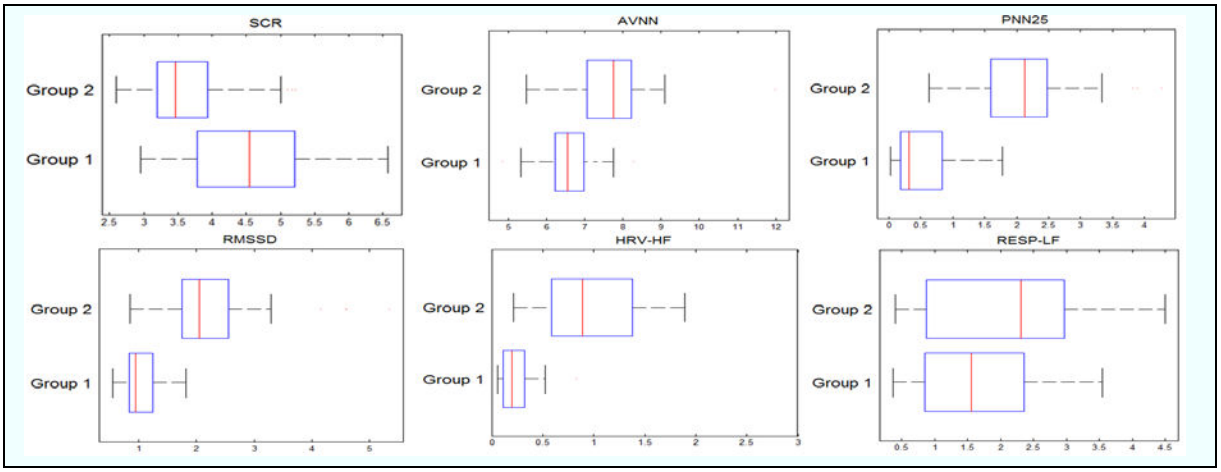

Figure. 3. Box Plots of 6 features describing the response of the two groups of subjects to the physiological sensors during relaxing DB activity.

visualize the data we used Principal Component Analysis (PCA) and reduced it from six down to two dimensions. The data also showed two distinct groups among the subjects who responded differently to the deep breathing activities, as shown in Fig. 2. Each marker in the figure represents a deep breathing session for a subject. The labels identified from the PCA analysis were used for the grouping of the data.

To validate the classification by PCA, we then used box-plots to individually examine each feature value over each subject in the two groups while performing DB exercise; see Fig. 3. As SCR is independent of respiratory changes, it provides an important marker of stress in our experiment. The increased SCR of group 1 subjects indicate a higher value as compared to that of group 2 subjects. The HRV box plots also support the results of SCR. Though HRV values are partially reflective of the respiratory variations, coupled together with the SCR response, the higher values of the HRV features of Group 2 indicate that parasympathetic tone is dominant and the subjects are relaxed [22], while Group 1 members with low HRV values are stressed out. Thus, skin conductance and HRV features support the PCA findings i.e. One group of subjects (group 1; 9 subjects) had increased stress levels during deep breathing, while the other (group 2; 6 subjects) was relatively relaxed during the DB activity

In the RESP-LF whisker plot, the median of both the groups are consistent with the results obtained from HRV and SCR. The median of low frequency respiratory component of Group 1 is less as compared to that of group 2. Group 2 distribution in this case has a large variation but the data is skewed left indicating that some subjects of group 2 had high SNS tone. This box plot data analysis confirms that subjects responded differently, splitting them into two groups. Table 1 shows the mean SCR and pNN25 values of each subject. The values in the table clearly illustrate the difference in the response the subject in each group. The data in group 1 has an average SCR and pNN25 of 535.55 and 0.065, whereas the average SCR and pNN25 in group 2 is 433.19 and 0.258 respectively.

Table I. Mean SCR & PNN25 of The Subjects in The Two Groups

Group	**Mean of pNN25 per Subject**								
1	***S1***	***S2***	***S3***	***S4***	***S5***	***S6***	***S7***	***S8***	***S9***
SCR	558.1	454.3	519.4	575.8	660.8	709.5	388.12	396.7	557.1
pNN25	0.123	0.068	0.056	0.025	0.082	0.088	0.071	0.026	0.045
2	***S1***	***S2***	***S3***	***S4***	***S5***	***S6***			
SCR	453.6	376.3	561.9	399.4	431.4	376.6			
pNN25	0.402	0.206	0.243	0.283	0.165	0.250			
Ave SCR	Group 1 = 535.55				Group 2 = 433.19				
Ave pNN25	Group 1 = 0.065				Group 2 = 0.258				

We also compared the deep breathing response of subjects from each group with their respective stressful activities. Fig. 4 (a-b) shows the raw deep breathing data of one subject from each group. We can see that the subject in Group 1 is not breathing regularly while the subject in group 2 is breathing regularly at the rate prescribed in the experimental protocol i.e. 0.1 Hz. This shows that there was a link between irregular breathing and higher stress levels in Group 1 subjects. Fig. 4 (c) displays the PCA of that subject from Group 1; the data illustrates that there is no separation between the deep breathing relaxing activities and mentally stressful activities. In contrast, Fig. 4 (d) shows that the deep breathing activities of the Group 2 subject can easily be

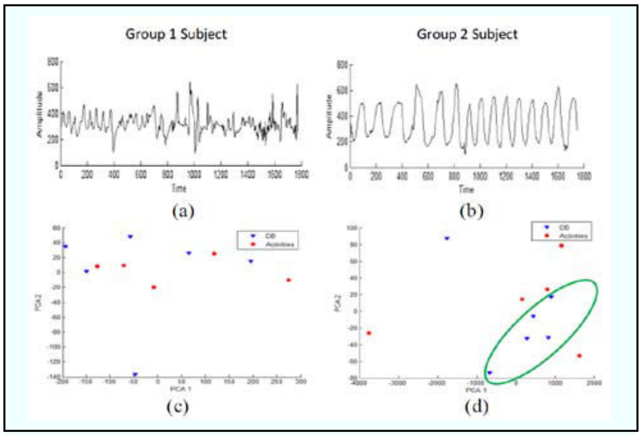

Figure. 4. (a) & (b) shows the raw respiratory data deep breathing activity of a subject from group 1 & 2

separated. There is no baseline for stress and relaxed states but as we have compared the DB activities with mentally stressful activities, we can state that there was no separation of activities in Group 1 subjects where as we can separate out the DB activities in Group 2 subjects; see Fig. 4 (c-d). Thus this verifies the results that some subjects were not breathing properly therefore their stress level increased during the breathing activity as opposed to relaxing.

An independent sample t-test was applied on the first component of the PCA to test the hypothesis that there was no difference in the response of the subjects during the deep breathing exercises. The test resulted in $t = 1$, i.e. the null hypothesis is incorrect. The t-test also yielded $p=1.6\times10^{-17}$, thus proving that there is a significant difference between the two groups of subjects.

V. CONCLUSIONS

As breathing is an autonomic physiological process with no effort required for inhalation and exhalation in healthy people, little importance is given to proper respiratory practice. Studies have shown that autonomic regulation of breathing can be voluntarily controlled [24]. Our results indicate that despite deep breathing being used as a relaxation tool for centuries [25], it is not effective unless performed correctly. In our study, HRV and EDA parameters are consistent with sympathetic dominance during the relaxation activity. After the data analysis we found that 60% of the subjects showed increased stress levels due to improper breathing; see Fig. 4 (a). Thus it is necessary to train people to improve their breathing. In this way they would better be able to deal with stress inducing activities by maintaining the balance of PNS and SNS.

In our study, neither the subjects were trained on how to perform regular timed inhalation and exhalation prior to the experiment, nor were they briefed about the different styles of breathing i.e. thoracic and abdominal breathing. We can thus conclude that it is fundamental to train the subjects prior to the experiment to obtain measurable variation in the subjects' physiological response to stressful and relaxing activities. Our study also shows that our device can be used to identify proper breathing techniques and their impact. Thus, it can be used to provide feedback to individuals on how to use abdominal breathing to relax. Educating individuals about the importance and effects of breathing techniques can not only help avoid physiological ailments but also psychological diseases such as depression and anxiety. Further research is required on the feasibility of using wearable sensors for improving breathing and maintaining it as a habitual process and also to study the response of the entire population over all the activities to effectively evaluate the stress and relaxed states.

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