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Physiological response to Vibro-Acoustic stimulation in healthy subjects: a preliminary study

F. Cavallo, *Member, IEEE,* E. Rovini, *Member, IEEE, EMBS,* C. Dolciotti, L. Radi, R. Della Ragione, P. Bongioanni, and L. Fiorini, *Member, IEEE, EMBS.*

***Abstract* - Over the last decade Vibro-Acoustic Therapy (VAT) was used for several clinical applications. This paper investigates the use of AcusticA®, an innovative VAT solution represented by a wooden chaise longue that follows the construction principles of a "*musical instrument that stimulates the whole body*" in relation to the sound frequencies produced by the music tracks. Ten healthy young subjects were enrolled for this study. Wearable sensors were used to monitor the human physiological response during the VAT session but also during a traditional acoustic therapy (AT) to highlight similarity and differences of those stimulations. Signals from heart activity, brain activity and electrodermal activity were analyzed to investigate the response during the non-stimulated and the stimulated phases. Additionally, two supervised classification algorithms were used to investigate whether the extracted instances could be grouped into two different groups. The results identify a trend of the attention and meditation features extracted from brain activity, which pointed out the relax efficacy of the VAT.**

***Clinical Relevance* - There are not significant differences ($p<0.05$) in the physiological response between the VAT and the AT stimulation, but during the VAT the alpha coefficients were significant different during the stimulated phase. Finally, the classification algorithms were able to classify the groups with an accuracy equal to 100% in the best case.**

I. INTRODUCTION

The Vibro-Acoustic Therapy (VAT) was defined as the "*therapeutic use of VibroAcoustic (VA) equipment and software that emit low frequency sound signals mixed with special audio. It is a process in which vibrations are applied directly to the body in the form of low frequency sinus tones in combination with selected music*" [1]. It was used since 1980s based on the use of sinusoidal, low-frequency sound pressure waves between 30 Hz and 120 Hz used in combination with music as auditory stimulation. Recently, the scientific community shows a growing interest in incorporating VAT in patient care practices. Different models of VAT technology could be administered in nursing care for treatment of physical and mental disorders [2]. For instance, another study supports the efficacy of VAT to reduce chronic pain, muscle tension, anxiety and sleep disorders [3]. Additionally, in a pilot study, conducted in subjects with autism, the results revealed that VAT reduced self-injurious, stereotypic movements, and aggressive-destructive behaviors in the participants [4]. Koike et al. [5] showed that VAT led to relaxation in the elderly people Nursing Home residents, decreasing depression and improving quality of sleep. Another research suggested that VAT stimulation could play a key role to maintain brain connectivity, regulating neural oscillatory activity and cognition, thus acting as a therapeutic support for people suffering from clinical conditions like Parkinson's disease, Alzheimer's dementia and depression [6]. In summary, VAT represents an innovative approach based on non-pharmacological treatments. Indeed, it could be new adjuvant therapy alongside standardized therapy. In the other hand, music therapy has been used widely in the past to treat behavior and mood disorders, such as depression, and psychiatric syndromes, such as schizophrenia [7], [8]. Regarding alternative medicine, VAT could have a larger therapeutic impact rather than music therapy, because of the deep sensory stimulation. However, for the best of Authors' knowledge, any research papers do not yet fully explore physiological impact and therapeutic potential of VAT stimulation.

Therefore, the aims of this paper were: i) to investigate whether the VAT and traditional music therapy (AT) impact differently on the human physiological response; and ii) to investigate similarity and differences of the stimulated phase respect to the rest condition (absence of any stimulus). In this paper, we stimulated 10 healthy young subjects with VAT or with AT in two different sessions measuring the heart activity, the electrodermal activity and the brain activity. Particularly, the AcusticA® chaise longue was used to administrate the VAT, instead of using a more traditional approach. Indeed, AcusticA® allows the vibratory stimulation of the human body just as a music instrument might do, faithfully respecting the harmonics and frequencies present in the music tracks. Finally, statistical analysis was conducted and two supervised classification algorithms (i.e. Decision Tree and Support Vector Machine, SVM) were used to investigate similarity and differences in the physiological response between these stimulations.

II. MATERIAL AND METHODS

A. Participants

Ten healthy young subjects, 7 males and 3 females (mean age: 28.10 ± 3.07 years old), were enrolled for this study among employees of the Scuola Superiore Sant'Anna (Pisa, Italy). The recruited subjects had an average weight of 71.8 ± 12.23 kg, an average height of 1.75 ± 0.10 m and a Body Mass Index of 22.75 ± 1.06 kg/m^2. Two participants were smoking, and all participants used to drink coffee. Exclusion

F. Cavallo, E. Rovini, L. Radi, and L. Fiorini are with the BioRobotics Institute, Scuola Superiore Sant'Anna, Pontedera (Pisa), Italy (corresponding author: phone: 0039-050-883478; e-mail: laura.fiorini@santannapisa.it).

C. Dolciotti is with the Department of Traslational Research and new technology in Medicine and Surgery, University of Pisa, Pisa, Italy.

P. Bongioanni is with the Severe Acquired Brain Injuries Dpt Section, Azienda Ospedaliero-Universitaria Pisana, Pisa, Italy.

R. Della Ragione is with the NeuroCare Livorno onlus, Livorno, Italy.

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TABLE I. EXTRACTED FEATURES IN THE TIME (T) AND FREQUENCY (F) DOMAIN FOR EACH DEVICE (BH, SH, MW)

Acronym	*Description*	*VAT*	*AT*
IBI	Mean of inter-beat interval corresponding to R-to-R interval	899.14 ± 102.72	905.09 ± 138.74
SDNN	Standard deviation of all normal RR intervals (NN intervals)	87.74 ± 46.93	93.32 ± 35.97
HR	Average Heart Rate	68.70 ± 8.19	69.70 ± 10.90
pNN50	Percentage of differences between adjacent normal RR intervals exceeding 50 ms	1.91 ± 1.19	1.97 ± 1.18
Alfa	Ratio between low frequency and high frequency powers	3.46E9 ± 1.09E10	3.85E11 ± 1.22E12
ATT	Attention, NeuroSky index for user's level of mental "concentration" [0–100](n.u.)	51.81 ± 5.80	49.41 ± 3.82
MED	Meditation, NeuroSky index for user's level of mental "relaxation" [0–100](n.u.)	54.05 ± 5.08	54.08 ± 6.38
BWA	Breathing Wave Amplitude	13.43 ± 15.27	15.37 ± 15.42
SDBWA	Standard Deviation of BWA	8.15 ± 9.03	10.40 ± 10.48
SA	Value of a startle amplitude	0.06 ± 0.08	0.05 ± 0.09
RT	Value of a startle rise time duration	2.09 ± 0.48	1.69 ± 0.56
FT	Value of a startle fall time duration	2.88 ± 0.60	2.52 ± 0.69
PS	Value of the phasic signal	0.0013 ± 0.0014	0.0013 ± 0.0016
OFT	Sum of all detected startles fall time	224.66 ± 90.74	144.29 ± 91.40
ORT	Sum of all detected startles time duration	165.52 ± 73.42	100.50 ± 68.47
#S	Number of detected startles	80 ± 32	54 ± 29

criteria for this study were: tattoo or piercing; assumption of drugs or hormones; prosthesis or metal clips; previous episodes of epilepsy. In order to assess the sleep quality and the stress level, two questionnaires were administrated during the recruitment process: the Pittsburgh Sleep Quality Index (PSQI) and the Perceived Stress Scale (PSS). For the recruited test group, the average PSQI score was equal to 5.20 ± 1.03 and the average PSS was equal to 17.50 ± 4.35. These results showed that all enrolled subjects report a satisfactory sleep quality and a low level of perceived stress, respectively [9], [10]. At the beginning of the experimental session, the users were requested to sign the informed consent form. All the tests took place at the facility of the Biorobotics Institute of the Scuola Superiore Sant'Anna (Pisa, Italy). Additionally, since we are investigating the human physiological response, we asked the participants not to drink coffee and not to eat for at least 2 hours before starting the test.

B. Instrumentation

The system used for the physiological data acquisition during the sessions consisted of three commercial devices, namely Bioharness (BH), Shimmer (SH) and Mindwave (MW), capable of measuring electrocardiogram activity, electrodermal activity and brain activity, respectively. BH (Zephyr, Maryland, USA) is a chest belt capable of monitoring electrocardiogram at a frequency of 250 Hz and breathing wave amplitude (frequency: 1 Hz) among other parameters. SH (Shimmer, Ireland) measures the galvanic skin response (GSR) signal at a frequency of 51.2 Hz. The MW headset (Neurosky, California, USA) is a wearable device able to monitor the brain activity at a frequency of 51.2 Hz by using a frontal lobe channel. Additionally, it provides an index of user's attention and meditation using the frequency power spectrum density (sample rate: 1 Hz). All signals from these sensors were acquired and stored for post-processing analysis on a computer with an Intel i7 processor and 4GB RAM. A dedicated multithread application was developed with Visual Studio (Microsoft Corporation, Washington, USA) to handle the connection and the data saving for the post-processing [11]. In order to apply VAT, the AcusticA® wooden chaise longue was used (see Fig. 1) (Magic Music s.a.s., Italy). It is able to stimulate the human body thanks to transducers which convert the music into sound frequencies ranged from 20 Hz to 17 kHz, with a solicitation power of $216\ lb \cdot ft/s$. AcusticA® is currently used in multisensorial settings dedicated to patients with cognitive and physical disorders. In 2018, Delmastro at al. [12] induced VAT using AcusticA® and measured physiological parameters related to GSR and heart activity in 8 healthy subjects. Finally, auricular thermometer, namely Termoscan3 Braun IRT3030, an electronic sphygmomanometer from Visiomat and a pulsoxymeter from LifeMED SAT200 were used to measure the body temperature (BT), the blood pressure (BP) and the oxygen saturation (SpO_2), respectively, before and after the stimulation.

C. Experimental Protocol

AcusticA® has been placed in a dedicated room, characterized by a controlled temperature of 20 °C and controlled light. Each participant was asked to undergo VAT and AT tests. Half of the subjects performed first the AT and then the VAT and vice versa. The first test was assigned randomly. Before to start each test, BT, BP and SpO_2 were measured. Then the subject was asked to wear BH, SH and MW and to relax on AcusticA®. In the first part of the test, the participants were requested to relax on the chaise longue for 5 min without any stimulus or external sounds, thus acquiring the baseline values. Then the music (composed *ad hoc* by the Music Therapists R. Della Ragione and P. Pazzagli) was activated, and - in the case of VAT - also the vibro-acoustic stimulation. This stimulated phase lasted 20 min. The subjects were stimulated using a harmonic vibration directly derived from the frequencies present in the music. In



Figure 1. Subjects during the test wearing the sensors to monitor the physiological parameters.

TABLE II. VITAL PARAMETERS MEASURED BEFORE AND AFTER THE TESTS

Features	VAT		AT	
	Before	*After*	*Before*	*After*
Diastolic BP (mmHg)	71.5	71.2	70.9	71.5
Systolic BP (mmHg)	114.8	112.1	114.8	113.1
SpO_2 (%)	98.0	98.5	98.6	97.9
BT (°C)	36.7	36.7	36.6	36.6

order to standardize the procedure, the solicitation power was medium/light (level 5). In the first 6.50 min music had a high percentage of frequencies between 20 Hz and 500 Hz, rhythmic events cadenced on the heartbeat rhythm and it was characterized by sweet harmonic melodies. In the remaining part, the musical track had frequency stimulation between 20 Hz up and 12.5 kHz; it added a riding and positive rhythm maintaining a sweet and carefree harmony.

At the end, BT, BP and SpO_2 were measured again. Finally, the subjects were asked to qualitatively describe the mood felt during the test by using only two adjectives and if she/he liked the treatments. The subject was requested to perform the other test (VAT or AT) after 48 h. To minimize undesirable changes in the physiological response each subject was recorded at the same daily timetable for both the tests. As soon as he/she performed both tests, we asked to remark if they find (or felt) any differences between the two tests. If he/she answered yes, we asked to indicate the preferred stimulation.

D. Features Extraction

Data from BH, MW and SH were preprocessed and analyzed as described in [13], to extract the following parameters to be included in the analysis with Matlab 2019b (MathWorks, Massachusetts, USA). A total of 16 parameters were extracted from the signals (see Table I). As far as BH is concerned, 7 parameters were extracted. In this analysis the inter-beat (RR) interval sequence was considered to extract the IBI, SDNN, HR, pNN50 in the time domain; additionally, Power Spectral Density (PSD) was computed to calculate the Alpha; other two features were computed from BH: the BWA and the SDBWA (they are the mean breathing amplitude acquired at 1 Hz and its standard deviation). As far as MW is concerned, only attention (ATT) and meditation (MED) parameters were considered, and they were extracted from the device at 1 Hz. A total of 7 features were extracted from the GSR signal after the conversion into galvanic skin conductance (SC): this signal was filtered with a fourth-order Butterworth low- pass filter with a cut-off frequency of 2 Hz, to erase all components not linked with the SC signal. More details on preprocessing and features extraction procedures is reported in our previous work [13]. The first 2.5 min of the baseline acquisition were considered as actual baseline; the remaining 2.5 min were considered as rest phase. Average values of all the described features were computed for the baseline, the rest and for the stimulated phase (VAT or AT).

E. Quantitative and qualitative data analysis

In order to manage the inter-subject variability, each feature was expressed as in (1):

$$\Delta\% = \frac{|F_S - F_b|}{F_b} \cdot 100 \qquad (1)$$

TABLE III – EVALUATION OF THE CLASSIFIERS OVER THE THREE DATASETS (VAT, AT, ALL). ACC. = ACCURACY

		Acc.	Fmeasure	Precision	Recall	Spec.	AUC
AT	***Tree***	0.95	0.95	0.95	0.95	0.95	0.95
	SVM	0.65	0.64	0.66	0.65	0.65	0.56
VAT	***Tree***	1.00	1.00	1.00	1.00	1.00	1.00
	SVM	0.85	0.85	0.85	0.85	0.85	0.77
ALL	***Tree***	0.98	0.97	0.98	0.98	0.98	0.97
	SVM	0.80	0.80	0.80	0.80	0.80	0.77

Where F_s is the feature computed during the stimulated (VAT, AT or rest) phase and F_b is the same feature computed during the baseline. At the end of the analysis, for each subject two Δ% values for each feature were computed: one for the rest phase and one for the stimulated phase. Then, three different datasets containing the relax and the stimulate values of VAT, AT and both tests were organized. Similarly, for BT, BP and SpO_2, the Δ% was computed between the pre and the post test, considering the pretest as baseline values.

The normal distribution of the features was verified using the Kolmogorov-Smirnov test of normality. As all raw scores were not normally distributed, consequently the Mann-Whitney U-test for non-parametric independent variables was carried out to investigate similarity and differences of physiological response during the two stimulations. Then the Machine Learning and Pattern Recognition Matlab Toolboxes (Matlab®R2019b, The MathWorks, Inc., Natick, MA, USA) was used to investigate similarity and differences between the two groups of instances (i.e., relax and stimulated). In this paper, two commonly used supervised classification algorithms (i.e. Decision Tree and SVM) were used. Regarding SVM, a second-order polynomial kernel was applied; for the Tree the Gini's diversity index and maximum number of split equals to 20 were used. A 5-fold cross-validation method was applied. The performances of the classifiers were evaluated in terms of recall, specificity, precision, accuracy, F-measure and Area under Curve (AUC) as detailed in [11]. Additionally, Principal Component Analysis (PCA) was used to reduce the number of features and visualize the features space of the complete dataset (VAT and AT). Finally, from qualitative point of view the description of the emotion felt during the sessions were also considered.

III. RESULTS

The final features array was composed of 16 parameters. Table I reports the average values and the standard deviations of each feature computed during the tests. Table II shows the average values of the vital parameters before and after the tests. The Mann-Whitney U-test confirms a not significant difference ($p>0.05$) among the Δ% of these vital parameters during the VAT and the AT. There are also not significant differences between the features measured during the AT stimulation and its correspondent relax values. Whereas, as far as the VAT stimulation is concerned, alpha value is significantly different ($p<0.05$) between the stimulated and the rest phase. Again, there are not differences between the VAT and AT stimulated phases. It is worth to notice an inverse trend between ATT and MED parameters (see Table I). During the AT, ATT values are higher than MED ones,

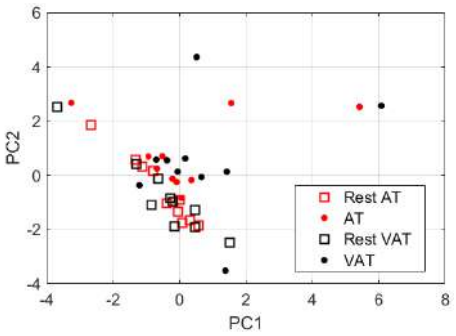


Figure 2. Distribution of the ALL instances in the PC space during the VAT and the AT test.

while during the VAT, the MED values are higher than the ATT ones.

The classifiers show a high accuracy level for the considered datasets (see Table III). Particularly, the VAT dataset shows better performance respect to the AT performance. Fig. 2 depicts the bi-dimensional representation of the extracted features. Particularly, the first and the second principal components (PCs) explain the 37% of variance. As far as the qualitative feedback at the end of the VAT is concerned, a total of 20 adjectives were collected. All the involved subjects declared that the VAT stimulation was relaxing (10 votes for *relax* word). Another selected adjective is *enjoyable* (6 votes). Other two adjectives with two votes are *sleepy* and *engaging*. All the participants preferred the vibro-acoustic stimulation.

IV. Discussion and Conclusion

This paper aims to investigate the human physiological response to the VAT and verify potential difference respect to the traditional AT, and to highlight similarity and differences between the stimulated and not stimulated instances' groups. The enrolled subjects were requested to perform both stimulations, and vital parameters were measured before, during and after the treatment. According to the previous presented results, VAT does not cause harmful or adverse effects: vital parameters measured before and after the tests present values that fall within the normal range (Table II). There are not significant differences between VAT and AT regarding those vital signs. As far as the physiological signals monitored during the tests are concerned, we can likewise say that no adverse or potentially harmful effects can be detected. Indeed, there is no any difference in body physiological response between the AT and the VAT stimulation.

As regards Alpha feature, which is the ratio between the low frequency (LF) and the high frequency (HF) values, a measure of the sympatho-vagal balance, we can make the following issue: since the ratio LF/HF shows an increasing trend (Table I), we can assume that HF decreases less than LF, witnessing an increasing influence of vagal over sympathetic [14]. It is to notice that during the AT treatment there is not a significant variation of this parameter. These results could suggest that the relax trend is higher in VAT rather than in AT. As far as the other parameters extracted from BH and SH signals are concerned, the results suggest that VAT produces relaxation in subjects, but it is only a trend (Table I). As regards brain electrical activity, the helmet provides data already processed, i.e. in VAT there is an increase in MED and in AT an increase in ATT. Again, there are no significant differences between VAT and AT, but it is only a trend [6]. Supervised learning algorithms are able to classify the two groups of instances (relax and stimulated) achieving a good performance of the evaluation measures. It means that the two groups were well speared into the features space. It is worth to underline that, even from visual inspection (Fig. 2), the relax instances are separated from the stimulated ones, but the VAT and the AT stimulated status are not separated, which is aligned with the results presented in the previous Section. The limitations of this work are related to the limited number of people involved. However, our results lead the direction of future studies on subjects with physical and/or cognitive problems to evaluate their fluctuation of the physiological response.

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