

# Physiological Impact of Vibro-Acoustic Therapy on Stress and Emotions through Wearable Sensors

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**Abstract**—Stress represents one of the dominant factors of young adults’ health, negatively affecting emotional, mental and physical aspects. There are several works in the literature aimed at detecting stress levels and conditions through the use of wearable devices. In this paper we investigated the effects of vibro-acoustic therapy (VAT) on physiological signals in a small group of young adults, trying to detect its positive effect on their stress condition. VAT has its origin in 1980s with basic instruments able to transmit music and vibrations. Here, we exploited AcusticA, an innovative VAT solution represented by a wooden chaise longue developed by following the principles of a big soundboard, and thus implementing a whole-body approach. Therapeutic sessions are accompanied by selected relaxing melodies, appropriately composed by a music therapist. We recruited 8 volunteer subjects, working in the same environment and characterised by similar stress conditions. We analysed the main components of ECG and GSR signals in order to highlight physiological responses and their variations between a rest baseline phase and a 20 minute therapy. Results show a general decreasing trend in HR, SCRs and their amplitude, confirming the relaxing component of the therapy.

**Index Terms**—stress detection, wearable sensors, physiological signals

## I. INTRODUCTION

Stress is a physiological response to mental, emotional, or physical challenges that we encounter. Nowadays, people declare that their stress level is continuously increasing, and concerns about money, work, and family responsibilities represent the main sources of stress, with higher average stress levels reported by females [1]. In the long term, high stress conditions can generate serious health problems. Currently, there is no specific or standardised therapy to manage psychophysical stress, except from customised pharmacological treatments, which can highly impact the subject’s capabilities to execute even daily living activities. However, several works in the literature suggest that music listening and music therapy can represent an effective treatment, without collateral effects [2]. Specifically, they show a beneficial effect of the vibro-acoustic therapy, while listening relaxing music or reproducing natural sounds. This generates a quicker recovery from stress conditions and from their physiological impact, as demonstrated by measuring, for example, urine and blood cortisol levels [3]. In addition, vibration frequencies are known for their beneficial effects on the muscle-skeletal system, central and peripheral nervous systems, by using high and low

frequencies, alternatively. There are also works in the medical literature that show the positive effects of the whole-body vibration therapy on chronic syndromes such as osteoporosis and neurodegenerative disorders. For example, emerging research is proposing segmental muscle vibration as a powerful tool for the treatment of focal spasticity in Parkinsonian and post-stroke patients [4]. However, there is less evidence of music and vibro-acoustic therapies on the emotional spectrum, which includes both the neurovegetative and psychological responses. This work aims at investigating the sympato-vagal physiological response during a vibro-acoustic stimulation based on a whole-body approach implemented by a specific device called AcusticA [5]. In this case, we exploit wearable sensors to monitor Galvanic Skin Response (GSR), Heart Rate (HR) and Heart Rate Variability (HRV) to obtain an empirical evaluation of the impact of vibro-acoustic therapy on psychological and physical stress. Specifically, we conducted a pilot study with a group of young adults subjects, co-workers, and affected by similar stress conditions (both related to work and familiar responsibilities). This study would like to support also the current trend of big companies to provide employees with instruments and dedicated places to manage stressful situations in the working environment. Vibro-acoustic therapy could represent an innovative solution to improve personal conditions and the working life.

## II. THE VIBRO-ACOUSTIC THERAPY

Vibro-acoustic therapy (VAT) started to be used in the 1980s as the concept of using vibrations as a form of treatment for a variety of conditions [6] [7]. It was originally based on the use of sinusoidal, low-frequency sound pressure waves between  $30Hz$  and  $120Hz$  blended with music for therapeutic purposes [8]. Initial studies involved children and adults with different disabilities, ranging from people with neuro-disabilities or chronic pain disorders, to children with autism, providing encouraging results on the relaxing effect of the therapy. It is based on some basic principles of the potential effects of music on the general population:

- Low frequencies generally cause relaxation in subjects, while high frequencies commonly induce tension.
- Rhythmically neutral music at slow tempos can induce calmness, while strong rhythmic beats potentially induce energy and activity.

- Soft music tends to pacify and relax, while loud music (with high amplitude) causes arousal.

In addition, VAT exploits frequencies within the hearing range, but at a specific pitch where the vibrating effect of the tone can be felt as a sensed vibration in the body. In fact, any sound vibration works on the principle of sympathetic resonance, where an object has a resonant frequency at which it vibrates in sympathy with the sound. The same can happen with the human body, in specific conditions. In fact, initial studies exploited some preliminary solutions as bed units or chairs, equipped with sub-woofers and acoustic speakers, and they focused on the identification of the vibration frequencies causing generalised and localised sensations of vibration of the body. In 2005, an innovative solution have been proposed by *MagicMusic* company as a wooden chaise longue called AcousticA, based on their patent "Harmonic Vibro-Message Unit" [5]. Figure 1 shows a picture of AcousticA chaise longue. It has been developed following the principles of a big sound-board, on which users can lie and their body is pervaded by vibrations emitted by specific music and melodies, composed by a music therapist. Specifically, the transduction technology used in AcousticA covers sound frequencies in the range of  $20Hz$  to  $17kHz$ , with a solicitation power of  $216 lb * ft/s$ . In this way, the therapy is able to stimulate a physiological response in humans and to directly act on muscles and the nervous system to induce a relaxation and improve the subject reactivity. AcousticA is currently used in several multisensorial environments dedicated to patients characterised by neurological and behavioral disorders. Specifically, medical researchers are currently conducting a pilot study on VAT therapy in parkinsonian patients by using AcousticA, and they observed an improvement in sleep quality, moods and anxiety rate in most patients. To further support their research, they are interested in investigating the physiological response to VAT with particular reference to healthy young adults as a reference population. This category is generally characterised by significant stress levels and VAT therapy could help improve this condition, especially if applied in working environments. For this reason, we decided to exploit wearable sensors technology to observe the physiological parameters in a group of healthy volunteers while experiencing the use of AcousticA during a break in their working environment. In the last few years, several big companies (like Google, Promega Inc., Yahoo and others) invested in the renewal of buildings and offices to provide a more comfortable workplace, defining also specific areas dedicated to relax and recovery, sometimes also meditation, in order to improve employee efficiency, attention, emotional balance and to facilitate interpersonal interest and teamwork<sup>1</sup>. Therefore, the idea of applying a relaxing therapy in a working environment could be the next step.

### III. PHYSIOLOGICAL PARAMETERS AND STRESS

Medical knowledge demonstrated that the correlation of two main physiological parameters provides an objective indication

<sup>1</sup>[https://www.huffingtonpost.com/2013/07/11/mindfulness-capitalism\\_n\\_3572952.html](https://www.huffingtonpost.com/2013/07/11/mindfulness-capitalism_n_3572952.html)



Fig. 1. AcousticA chaise longue.

of the stress level. Specifically, it is known that under acute stress, the Sympathetic Nervous System (SNS) causes an increase in the heart rate, respiration activity, sweat gland activity, body temperature and blood pressure. Then, when the stress condition is finished, the Parasympathetic Nervous System (PNS) reverses the stress response. Therefore, a non-invasive measurement of the heart activity can provide useful information. Today, through the use of wearable commercial devices, it is quite easy to measure the ECG signal. However, it is important to use devices able to extract accurate measurement of the following parameters: (i) the RR interval, as the time interval between two R peaks and used to calculate the heart rate, and (ii) the Heart Rate Variability (HRV), referring to the beat-to-beat variation in the RR interval. HRV analysis methods can be categorised into time-domain, spectral and geometrical methods [9]. As far as the time-domain analysis is concerned, we refer to the following parameters as indices of the signal variability:

- mean HR: mean heart rate (beats per minute);
- mean RR: mean heartbeat interval (msec);
- SDNN: standard deviation of RR-intervals between normal beats;
- RMSSD: root mean square of the difference between successive RR-intervals;
- pNN50: the percentage of consecutive RR-intervals with a difference greater than  $50msec$ .

For the spectral-domain analysis, we refer to the following three main components of the HRV power spectrum:

- VLF ( $0,003 - 0,04Hz$ ): very low frequency component mediated by SNS;
- LF ( $0,04 - 0,15Hz$ ): a low-frequency component that is mediated by both the SNS and PNS;
- HF ( $0,15 - 0,4Hz$ ): a high-frequency component mediated by the PNS;
- LF/HF: LF to HF ratio that is used as an index of the autonomic balance.

For the geometrical analysis, we selected HRV triangular index, which is based on the NN interval histogram computed using bins width of  $7,8125msec$  [10]. The triangular index is computed as the total number of NN intervals divided by the height of the histogram.

Galvanic Skin Response (GSR) is a measure of the electrical resistance of the skin. A transient increase in skin conductance is proportional to sweat secretion [11]. When an individual is under mental stress, sweat gland activity is activated and it increases the skin conductance. Since the sweat glands are also controlled by the SNS, skin conductance acts as an indicator for sympathetic activation due to the stress reaction [11]. There are two major components for GSR analysis. Skin conductance level (SCL) is a slowly changing part of the GSR signal, and it is generally considered as the baseline portion of the signal. Skin Conductance Response (SCR) is a faster changing component, and its behaviour can be related to specific or not specific stimuli. Widely used parameters for GSR include the amplitude and latency of SCR and the average SCL value.

#### A. ECG and GSR Wearables Devices

After an accurate market analysis of the available commercial wearable devices to measure ECG and GSR signals, we chose the following as the most accurate available solutions. As far as the ECG signal is concerned, we selected Zephyr Bioharness 3 (BH3)<sup>2</sup> shown in Figure 2(a). It is a light and compact device, minimally invasive, consisting of a module attached to a chest strap, integrating sensors for ECG, respiration rate and a 3D accelerometer for activity recognition. Among the various configuration, we chose an ECG sampling rate of  $1KHz$  and  $100Hz$  for the accelerometer. ECG signal is processed on board to extract the heart rate and to define HRV, derived from the temporal distance between RR peaks (in msec).

Shimmer 3 GSR<sup>3</sup> (Figure 2(b)) consists of a wrist-worn unit and two electrodes to be applied to 2 fingers of the non-dominant hand. GSR values can be expressed in terms of resistance ( $K\Omega$ ) or conductance ( $\mu S$ ). In addition, the device is equipped with two 3D accelerometers, a gyroscope and a 3D magnetometer. In this case we used a default sampling frequency, suggested by the vendor, for all the sensing devices, and equal to  $51.2Hz$ . All the temporal series have been initially analysed to remove not valid values, mainly due to the execution of on board processing algorithms, according to the vendor specification. In addition, as far as HRV is concerned, we considered only values in the range  $[250ms, 2400ms]$ , while for HR, each value is associated with a confidence percentage (i.e., HRConfidence) that indicates the measurement reliability. Therefore, we removed HR values with HRConfidence  $\leq 20$ . This analysis represents a preliminary evaluation of the signals' quality and consistency, confirming a percentage of valid samples between 90% and 100% for all the collected signals.

#### IV. RELATED WORKS

Stress detection has been investigated in previous works under various conditions and during the execution of different tasks. These works mainly rely on HRV and GSR signals,

<sup>2</sup><https://www.zephyranywhere.com/system/components>

<sup>3</sup><http://www.shimmersensing.com/products/gsr-optical-pulse-development-kit>

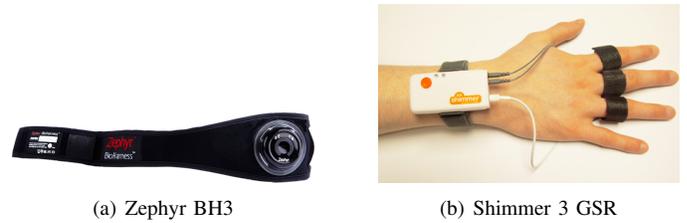


Fig. 2. Wearable devices.

but some of them investigated also the use of other signals and methods, like EMG, EEG, skin temperature (ST), blood volume pulse (BVP), facial expression recognition, speech data and eye tracking. In [12] a list of measures, empirically ranked according to their significance for stress detection and stress classification, is reported. The work of Tso-Jun et al. [11] used a combination of GSR and HRV, to perform stress detection during the execution of the Stroop Color-word interference test and mental arithmetic problems in different conditions (i.e., seated, standing and walking). They also evaluated the accelerometer's features to better highlight its contribution in improving the accuracy performance during a stress detection phase. A similar approach was adopted by Giakoumis et al in [13], which combined ECG and GSR data with accelerometer and video recordings features to improve automatic stress detection during the execution of a customised version of the Stroop test. Kurniawan et al. in [14] combined information from GSR and speech data to perform stress classification by using the Stroop test and arithmetic tests as stressors. This work showed that speech data is a good indicator for stress detection in controlled settings. On the other hand, several works demonstrated that GSR alone cannot always lead to reliable result and it should be accompanied by other physiological measures. These findings about GSR are also confirmed by [15], which used only GSR to perform long-term stress detection on subjects during their daily lives. To overcome this issue, Healey and Picard implemented SmartCar [16], a sensor system made of GSR, ECG, EMG and respiratory sensors to be applied on the subject to detect drivers stress during pre-scheduled driving routes.

Even though in the last few years, several attempts have been made for stress detection during various mental workloads, to the best of our knowledge there is no work in the literature focused on the analysis of the physiological signals as indicators of induced relaxation by VAT therapy.

#### V. THE PILOT STUDY

This study has been conducted as a pilot to understand the possible correlation among VAT, stress conditions, and physiological signals. We involved a small group of subjects, homogenous in sex and age, selected from the same working context (i.e., IT researchers). Subjects have been asked to experience the use of AcousticA during a brief break from their work activity in two different days, by using two different melodies characterised by different sound and vibration fre-

TABLE I  
PILOT STUDY POPULATION

Subject	Sex	State-Trait Anxiety scores	
		Negative	Positive
#1	F	72/80	40/80
#2	M	42/80	68/80
#3	M	80/80	38/80
#4	F	64/80	36/80
#5	M	44/80	66/80
#6	M	40/80	78/80
#7	F	48/80	66/80
#8	F	44/80	72/80

quencies, aimed at generating different sensorial stimulations but always relaxing. AcousticA has been placed in a dedicated room, characterised by an average temperature of  $22^{\circ}C$  and 53.5% humidity, and with a dim light. During each session, subjects were asked to wear Zephyr and Shimmer devices to monitor the physiological parameters. Figure 3 shows an example of a session. The day before the first session, a doctor collected the medical history of each subject and the results of the *State-Trait Anxiety Inventory* test [17] [18], as reported in Table I. Then, after the two sessions, we asked the subjects to answer to a customised satisfaction survey including questions about their perceptions of the therapy.

The population of the study consists of 8 young adults (4 men and 4 women), aged between 30 and 41 years old, 6 of them married with children at scholar age, and 2 not married. Only 2 women have a past experience with a neurological or psychiatric disease in their family, 2 women characterised by anxiety and one of them with a previously diagnosed autoimmune thyroid disease. One man and a woman presented an anxiety condition related to the health status of their family. Only the woman with the thyroid disease follows a pharmacological treatment.

Each session consists of 5 minutes of baseline, in which the subject lies on the chaise longue, in a rest silent condition, wearing earphones to isolate from external noise. Then, the VAT therapy starts with a melody lasting for 20 minutes, followed by a recovery phase of 5 minutes.



Fig. 3. An experimental session

## VI. METHODS

Features extraction from HR and HRV signals have been conducted by using Matlab (version R2017b), while GSR signal has been processed by using the software Ledalab

version 3.4.9<sup>4</sup>, especially for the method CDA (Continuous Decomposition Analysis), able to decompose the GSR signal in the SCR and SCL components [19]. Physiological signals collected in each session have been divided into the following temporal phases: (i) baseline, (ii) vibro-acoustic stimulation, (iii) recovery. The feature extraction has been applied to each phase.

As far as HRV analysis is concerned, it is important to analyse the power spectral density (PSD), which provides basic information about how the power of HRV signal is distributed with respect to frequency. Generally, it is important to implement an initial interpolation of HRV signal to transform it in a signal with a fixed sampling rate, in order to avoid the noise generated by additional harmonic components of the original signal. However, the Lomb-Scargle algorithm [20] allows the PSD evaluation on a not uniformly sampled signal, requiring a sampling time vector monotonically increasing. This algorithm is implemented in Matlab through `plomb()` function, and we decided to use it in our analysis.

As far as GSR analysis is concerned, we applied a Butterworth 1st-order low-pass filter with  $5Hz$  cut-off frequency. This operation is essential to remove the high frequency noise generated by the high sampling rate (i.e.,  $51.2Hz$ ), considering that the signal dynamic for both components is in the range  $[0, 5]Hz$  [21] [22]. After this step, we adopted different approaches in the baseline and stimulation phases. In the first case, we analysed the signal for the whole time window (i.e., 5 min) to evaluate the global activation level of each subject in rest conditions. In this case, the measured activation, in terms of number of SCRs, is not related to any external stimulus, referring thus to it as *Non Specific Skin Conductance Responses* (NS-SCRs). Instead, during the stimulation phase, we made an event-related analysis based on a sequence of vibro-acoustic events inside each melody, appropriately defined by the music therapist. Specifically, 15 events characterise the first melody (i.e., Relaxing 1) and 22 the second one (i.e., Relaxing 2), including the initial event. We selected a time window of  $4sec$  after the identification of each event, in order to include the physiological latency of a SCR to a specific stimulus, which is generally considered in the range of  $[1, 3]sec$  [21] [22]. However, the time window should not exceed this value to reduce the probability to include later SCRs, not related to the specific stimulus. We conducted two different analysis, considering different values of the minimum threshold to detect an activation. Recently technological advances allow the use of thresholds in the range of  $[0.01, 0.05]\mu S$ . We decided to use a preliminary threshold set to  $0.01\mu S$  and, subsequently, to repeat the analysis by using the average value of the phasic signal component computed over the entire time window. The second approach should better highlight the variability among different subjects. We evaluated GSR parameters, in terms of number of SCRs, latency and cumulative amplitude, by using both CDA analysis and a TTP ('Trough-To-Peak') standard approach. Specifically,

<sup>4</sup><http://www.ledalab.de/>

in order to provide a global analysis of the event-related signal activation, the number of SCR and their cumulative amplitude has been summed for all the events, while we considered the maximum value of the phasic component. For the other parameters we considered the average value of all the events.

## VII. DATA ANALYSIS AND DISCUSSION

From a general analysis of the entire population on the two experimental sessions (i.e., Relaxing1 and Relaxing2), we noticed that physiological signals do not highlight significant differences with the two melodies. In fact, the music therapist declared that those melodies partially differ in rhythm and emotional stimuli, while maintaining a general relaxing feature. This has been demonstrated also by a statistical analysis based on the comparison of independent samples through the use of t-Student, Welch or Wilcoxon tests ( $\alpha = 0.01$ ), depending on the results of the normality test. Figure 4 shows the temporal variation of GSR signals for the same subject during the two independent sessions.

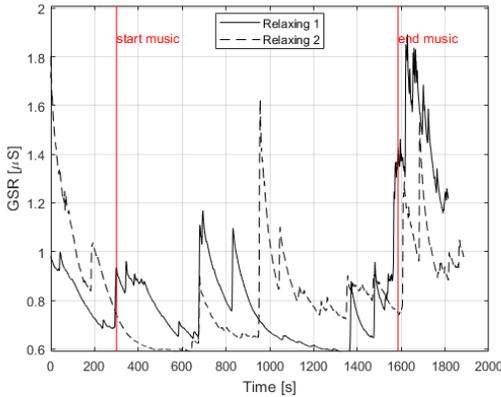


Fig. 4. GSR signals for subject #2 in the two sessions.

To better highlight the physiological response of subjects to the VAT therapy, and the general trends, we show in Table II the main HR, HRV and GSR parameters evaluated during a single session (i.e., Relaxing1). As we expected, we can note a general relaxing trend between the baseline and the music stimulation phases. Specifically, from HR e HRV analysis, we note that there is a decreasing trend in HR, even though in some subjects there is a minimal variation. Coherently, we can note an increase of the mean HRV in most part of the subjects. pNN50 strictly depends on the width of the considered time window and, in this particular case, in order to be able to compare pNN50 in baseline and VAT phases, we divided the VAT phase in 4 windows of 5min (the same width of the baseline window) to compute pNN50 values, and then we report the average value.

In terms of spectral analysis, we refer to HF and LF components of HRV power spectrum. Specifically, LF is considered as mediated by the activity of both sympathetic and parasympathetic nervous systems (SNS and PNS), while HF is considered as mediated only by PNS. Thus, the ratio

LF/HF represents a measure of the sympato-vagal balance, i.e., between the two components of the Autonomous Nervous System. It is known in the literature that an increase of the activity of SNS generates a physiological reaction called '*fight or flight*', with consequent physiological variations as HR and SCRs increase. Instead, the prevalence of the activity of PNS generates a general relaxation with opposite physiological responses. Considering normalised LF and HF values in our analysis, we notice a decrease in the signal power in both frequency bands, moving from the baseline to the VAT phase. Since the ratio LF/HF shows an increasing trend in the two phases, we can assume that HF decreases less than LF, witnessing an increasing influence of PSN over SNS, and confirming a relaxing behaviour during the therapy.

GSR analysis highlights a general decrease in the number of SCRs and of their cumulative amplitudes, which confirms a reduced global activation level in the VAT phase with respect to the baseline.

Therefore, both signals confirm a general basic relaxing influence of the VAT therapy, which should be further investigated through long-term experimentations.

However, there are some subjects who present a different behaviour. Specifically, subject #3 presents an inverse evolution with respect to the majority of the population, with an increase of HR, and a decrease of HRV. As far as GSR analysis, in this case the number of SCRs decreases but their cumulative amplitude increases in the VAT phase. This can be due to the personal stress condition of the subject, detected also by the State-Trait Anxiety test (as reported in Table I). In this case, the subject presents a maximum negative score in the test, which represents a significant anxiety and stress condition. Therefore, in this case, a long-term application of the VAT therapy would be necessary to better highlight its potential beneficial on high stressed subjects, compared to the general population. Instead, in subject #6 we can note a high reduction in the number of SCRs and their amplitude in the VAT phase, even maintaining stable values for HRV values. The same subject is considered stable in terms of anxiety and stress. In this case, the VAT therapy seems to have an immediate impact on the GSR activation, demonstrating a relaxing condition of the subject.

Finally, we evaluated the subjects' reply to the customised satisfaction survey. All the subjects reported a feeling of muscular relaxation, they all experienced the most part of the vibration on the chest and nobody experienced paraesthesia and discomfort. Everybody declared an iperarousal condition in the first session and a more relaxed condition in the second one, asking to repeat the treatment if possible. They all agreed that it would be useful to have this type of treatment on a regular basis, especially exploiting small breaks during the working day.

## VIII. CONCLUSIONS AND FUTURE WORKS

In this work we present a pilot study on the impact of VAT therapy on physiological signals in young adults in order to reduce their stress condition. The study has been conducted

TABLE II  
DATA ANALYSIS

	ECG analysis						GSR analysis					
	MEAN HRV		MEAN HR		PNN50		LF/HF HRV		# SCRs		Cumulative Amplitude	
	Baseline	VAT	Baseline	VAT	Baseline	VAT	Baseline	VAT	Baseline	VAT	Baseline	VAT
# 1	948,28	1007,1	63,33	59,683	29,968	52,031	0,545	0,502	3	0	0,0048	0
# 2	937,27	987,76	64,06	60,768	25,545	32,843	1,019	1,116	43	16	0,4202	0,05946
# 3	984,19	951,26	61,037	63,158	24,262	19,529	1,069	1,161	27	18	0,0790	0,13926
# 4	771,36	798	78,143	75,24	4,884	3,231	1,026	2,164	76	5	0,9623	0,01055
# 5	1047,7	972,2	57,857	62,2	33,798	24,769	1,656	3,024	23	6	0,0870	0,01060
# 6	1052,9	1051,3	57,103	57,363	23,86	17,767	0,736	2,855	143	20	1,5017	0,14981
# 7	929,04	997,44	64,573	60,199	21,981	19,816	0,975	0,855	17	1	0,0346	0,00112
# 8	1144,8	1114	52,893	54,484	62,595	65,932	0,339	0,398	6	0	0,0095	0

by using a specific device called AcousticA, a chaise longue designed to emit music and vibrations implementing a whole-body approach of VAT. We experiment the therapy on a small group of subjects and for a limited number of sessions based on different melodies composed by a music therapist. Through the use of wearable sensors monitoring ECG and GSR signals, we confirmed that there is a physiological response to vibroacoustic stimulation. However, it is necessary a long-term application of the therapy to highlight its potential beneficial on the reduction of the stress levels. For this reason, we are designing an additional experimental campaign to involve different subjects' categories for a period of 2-3 months, with regular VAT sessions. In this way, we should be able to notice both changes in individuals and in different groups, through the use of statistical analysis.

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