

# Is your phone so smart to affect your state? An exploratory study based on psychophysiological measures

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## ABSTRACT

Traditional stress management techniques require significant professional training and expertise to administer as well as people, time, and resources, which can be difficult to achieve. Thanks to the recent progress and diffusion of mobile electronic devices, it is possible today to set up and test an effective self-help stress management program outside a clinical setting. Although the efficacy of mobile self-help approaches have been tested through several studies, and promising applications can be developed, as yet no study has tested the feasibility of mobile platforms to actually elicit core affective states. In this study we used an advanced approach to assess the efficacy of these mobile platforms by recording and processing many psychophysiological measures, which extend the capabilities of the standard self-report questionnaires, objectifying the subjective. Our results seem to show the efficacy of inducing positive and negative affective states, using smart phones.

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## 1. Introduction

According to Cohen and colleagues [1], psychological stress occurs when an individual perceives that environmental demands tax or exceed his or her adaptive capacity to cope with them. This definition integrates the traditional approaches to stress [2–5] emphasizing that a stressful experience could be conceptualized as a person–environment transaction. Strategies frequently used to cope with stress include relaxation techniques, promotion of a healthy lifestyle, and cognitive-behavioral therapies (e.g., stress inoculation therapy, rational emotive therapy, cognitive restructuring, and behavioral rehearsal). Traditionally, these strategies require significant professional training and expertise to administer as well as people, time, and resources, which can be difficult to achieve.

To overcome these limits, self-help approaches and telehealth-based treatments are being developed to enhance treatment fidelity, effectiveness, and accessibility [6–9]. Specifically, mobile phones are gaining particular importance in health care services [10,11]. In fact, the incredible diffusion of mobile electronic devices [12] has introduced the possibility of setting up and testing effective stress management techniques beyond a clinical setting [13,14]. In a recent work of research, Villani and colleagues [15] verified the efficacy of a stress management protocol supported by the use of mobile phones.

According to that study, the advantages of using a mobile approach to reduce stress could be an incremental acquisition of coping skills in an autonomous way [16], a ubiquitous and effective support in facing daily stressful situations, an enhancement of people's compliance [17], and the possibility of living graded exposure experiences while overcoming the difficulties related to the application of coping techniques within a clinical setting. Moreover, thanks to the recent progress in the sophistication and in the usability of biosensors technology wirelessly connected to mobile platform, today it is possible to set up a multimodal assessment of stress levels, including psychological, physiological, behavioral, and contextual data [18].

Although the efficacy of mobile self-help approaches have been tested through several studies and promising applications can be developed, there is as yet no study that has tested the feasibility of mobile platforms to actually elicit core affective states. An advanced approach to assess the efficacy of these mobile platforms is by the means of psychophysiological measures, which extend the capabilities of the standard self-report questionnaires, objectifying the subjective.

Thus a question arises, is it possible to induce positive or negative affective states using a smart phone? To answer this question, we focused on the bidimensional viewpoint from Lang [19] to identify affective states in terms of “activation,” namely physiological arousal and emotional valence. Fig. 1 offers intuitive identification of affective states based on these two dimensions [20]. Under this perspective, stress and relaxation could be considered as two opposite affective states, characterized by different physiological arousal and emotional valence; we are particularly

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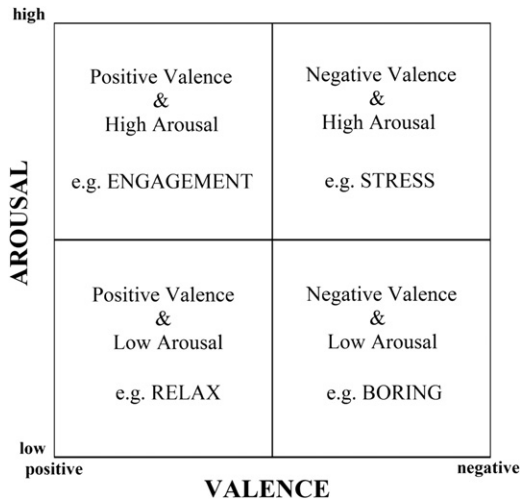


Fig. 1. The affective space, defined by the dimensions valence and arousal, based on Lang.

interested in those states because of their importance in stress management therapies [21,22].

In psychology, several methods exist to induce a relaxing state built on the exposure of emotion-eliciting materials, such as pictures [23], films [24,25], or music [26,27]. In particular, classical music also has been used as a tool for relaxation exercises, producing self-reported behavioral and physiological changes related to reduced stress [28]. For example, listening to classical music has been associated with a reduction in autonomic activity and self-reported tension and improved performance of surgeons [29]. Similarly, listening to classical music in still another study reduced self-reported fatigue, sadness, and tension [30]. Physiological changes associated with listening to classical music and related to decreased stress include a significant decrease in  $\beta$ -endorphin, following one session of combined progressive relaxation, classical music, and guided imagery conditioning [31].

On the other hand, several laboratory procedures have been tested to induce stress using the cognitive tasks that could be easily input into both a PC and a smart phone. According to Dickerson and Kemeny [32], several cognitive tasks have been used to elicit stress responses, including the stroop test, mental arithmetic tasks, vigilance-reaction time tasks, and other analytical tasks (e.g., [33–35]).

For example, in a recent study, Mauri and colleagues [36] used a Stroop task [37] to elicit stress reactions to investigate psychophysiological signals associated with different affective states.

The two dimensions of “activation” used to assess relaxation and stress, namely, physiological *arousal* and *emotional valence*, before described, can be accurately measured through biosensors to obtain signals that can offer considerable information following a signal processing procedure that utilizes multiple mathematical and computational techniques. Briefly, *physiological arousal* can be measured using an Electroencephalogram (EEG), Galvanic Skin Response (GSR), Electrocardiogram (ECG), and Respiration Signal (RSP). An *emotional valence* can be measured through EEG, self-reports, facial expression identification, eye-blink startle, and facial EMG corrugator and/or zygomatic. Cardio-respiratory activity is monitored as well to evaluate both the voluntary and autonomic effect of respiration on heart rate, analyzing the R–R interval (from the electrocardiogram) and respiration (from a chest strip sensor) and observing their interaction. Further, standard HRV spectral methods can be used to evaluate the autonomic nervous system response [38–42].

Spectral analysis can be performed using autoregressive (AR) spectral methods with custom software. The AR spectral decomposition procedure could, for example, be applied to calculate the power of the oscillations embedded in the series.

On the other hand, startle eye-blink reflex, and facial electromyography are related to the valence of the emotional response induced by a stimulus. Due to the dramatic increase in the use of the startle-blink response in research and clinical settings, Gregory Miller, while Editor of *Psychophysiology*, appointed a committee to consider the guidelines for startle-blink research in humans, and produced the “Committee Report: Guidelines for human startle eyeblink electromyographic studies”. The Committee demonstrated that facial EMG-CS (corrugator) is the best measure of emotion valence [43].

According to these premises, the goal of this study was to test the efficacy of inducing positive and negative affective states using smart phones measured by psychophysiological parameters. To achieve this goal we compared this innovative approach with a traditional one, represented by the induction of positive and negative affective states using a PC.

## 2. Materials and methods

### 2.1. Participants

Twenty-eight healthy subjects (16 females and 12 males) were included in this study aged from 19 to 55. They were all volunteers from Ospedale San Giuseppe di Piancavallo (VB) – Istituto Auxologico Italiano (ITALY) – and they were recruited among the hospital staff (hospital nurses, physicians, medical assistants, hospital keepers, laboratory technician, etc.). In order to be included in the study, subjects had to meet the following criteria: (1) absence of medical diseases; (2) absence of pharmacotherapy or other medications that might interfere with the measures being assessed; (3) absence of psychiatric disorders. More, they were requested not to assume caffeine or alcohol and not to smoke prior to the experimental test to avoid any effects of these substances on the nervous system.

### 2.2. Design

A within-subjects design was used to compare four experimental conditions, presented in a randomized way. In particular, two conditions involved the use of a PC and two conditions involved the use of a smart phone and each of them lasted five minutes.

1. Relax (R): participants were asked to relax for five minutes in front of a PC monitor watching a panoramic slideshow accompanied by a soft and relaxing music;
2. Stress (S): subjects were asked to execute a cognitive task implemented on a PC;
3. Relax Mobile (RM): participants were provided with a smart phone (Apple iPhone 3Gs) and they were asked to relax five minutes using a mobile application consisting of a panoramic slideshow accompanied by a soft and relaxing music;
4. Stress Mobile (SM): participants were provided with a smart phone (Apple iPhone 3Gs) and they were asked to execute another cognitive task using a mobile application.

In order to summarize, the protocol consisted of two relaxing and two stressful tasks. To promote recovery from experimental sessions, we included some breaks during which participants were asked to freely navigate in a website for about five minutes (Table 1).

**Table 1**  
Hypotheses based on the design.

Hypothesis	Comparison	Expected <i>p</i>
Hp1	Relax vs. Stress → R vs. S	$p < .05$
Hp2	Relax mobile vs Stress mobile → Rm vs. Sm	$p < .05$
Hp3	Relax vs. Relax mobile → R vs. Rm	$p > .05$
Hp4	Stress vs. Stress mobile → S vs. Sm	$p > .05$

2.3. Procedures

Participants who met the inclusion criteria were contacted via email and/or telephone to schedule a meeting at the Neurophysiology Laboratory, located in the Hospital at the Department of Neurology. A neurophysiologist and a physician assisted them for the duration of all the laboratory sessions. The experimenters were instructed to maintain a neutral voice tone and a neutral behavior during the exposure to experimental stimuli. When participants arrived at the Neurophysiology Laboratory, they were asked to sit down in front of a computer and the experimenters explained them the goals of the research and the general function of the electrodes. After they filled in the informed consent, they were prepared for the physiological parameters collection. Before the beginning of the experiment, participants were asked to stay completely relaxed in order to collect a 5-min baseline. After that, the experimental session started and physiological data were recorded until the end of the study. At the end of the experimental session, the experimenters helped subjects in removing all the electrodes and the patches, explaining the scientific rationale of the experiment.

2.4. Stimuli alignments

Every recording was marked through a synchronization algorithm realized (using Matlab) for the alignment of the stimulus with all the psychophysiological signals [20]. Furthermore this algorithm allows us to synchronize EEG with all other psychophysiological signals; since these two series of signals were recorded using different devices, it was necessary to align them. To improve the precision of such algorithm the subjects were asked to eye-blink rapidly five times before each stimulus; using electrodes near the eyes (EOG, namely Electrooculogram) connected to all other biosensors, and EEG with eyeblink detection, this operation guaranteed a precision of 1/100 of second. Once extracted, all biosignals were worked in Matlab and branched into four categories: Relax (R), Stress (S), Relax Mobile (RM), and Stress Mobile (SM). Each category contained all EEG and psychophysiological signals of that session and was able to be processed for signal processing procedure in order to extract a series of indexes for the statistical analysis.

2.5. Physiological signals

The responses of the central and peripheral nervous system were measured using an ECG (electrocardiogram), two facial EMG (electromyography), namely EMG corrugator and EMG zygomatic, EOG (electrooculogram), and RSP (chest respiration). Signals were acquired by means of a professional SOMNOscreen PSG device (SOMNOmedics GmbH, Randersacker, Germany), certified for medical use. Furthermore we used an Epop, a neuro-signal acquisition and processing wireless neuroheadset device for the acquisition of 14 EEG (electroencephalogram) channels (plus CMS/DRL references, P3/P4 locations). Channel names based on the International 10–20 locations are AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4.

All the physiological signals were then processed with custom software developed using MATLAB 7.10 (The Mathworks, Inc.; Natick, MA) and SPSS 17 (Statistical Package for the Social Sciences—SPSS for Windows, Chicago, Illinois, USA) to compute the statistical analyses. Every channel was synchronously acquired at 2048 Hz and exported at a 256 Hz sampling rate (256 records per second, one every 3.90625 millisecond).

The lab was equipped with two portable PCs, one for the EEG recording and delivering the stimuli (with a 120 Hz display) and the other for psychophysiological signal recording.

To make interpretation relevant to actual users' affective state and to avoid contaminations, light and temperature sensors have been used to monitor the conditions of the room and two three-axis accelerometer have been used to monitor subjects' stability (Fig. 2).

2.6. Signal processing

Collected data were analyzed using Matlab 7.10 (The Mathworks, Natick, MA). Cardiovascular and respiratory activities were monitored to evaluate both voluntary and autonomic effects of respiration on heart rate, analyzing R–R interval extracted from electrocardiogram and respiration (from chest strip sensor) and their interaction. Following the guidelines of Task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, typical Heart Rate Variability (HRV) spectral indexes were used to evaluate the autonomic nervous system response [20,40,44]. Spectral analysis was performed using Fourier spectral methods with custom software. The rhythms have been classified as very low frequency (VLF, <0.04 Hz), low frequency (LF, from 0.04 to 0.15 Hz), and high frequency (HF, from 0.15 to 0.5 Hz) oscillations. This procedure enabled us to calculate the LF/HF ratio, also known as the sympathovagal balance index. About the interpretation of these indexes, we can say that high-frequency reflects the parasympathetic effects on the respiration-mediated variability due to the vagal modulation of heart rate or the parasympathetic effects on the heart by respiratory sinus arrhythmia [45–48]. However, there is still controversy to the meaning of this band [49,50]. The low frequency reflect the interaction of both sympathetic and parasympathetic effects on the heart and is closely associated with baroreflex function [44]. However, it is still controversial as to what it truly reflects [41,49,51]. Thus LF/HF simply represent the ratio of LF and

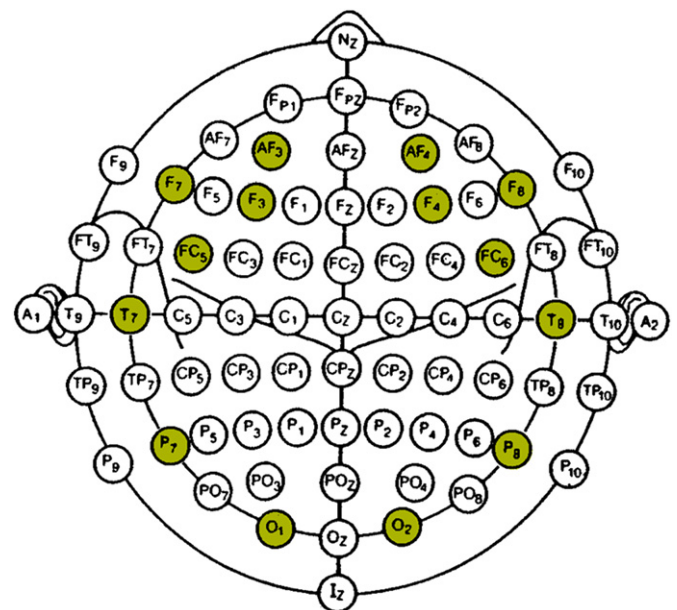


Fig. 2. The channels we used, following the International 10–20 locations.



HF band powers, which reflect the sympathovagal balance of the heart. Also the meaning of this index is still controversial [41,49].

Cardiovascular and respiratory activities interaction has been taken into account through Respiratory Sinus Arrhythmia (RSA) index [40,52]. As temporal domain measure of heart rate variability we calculated NN50 index, i.e. the number of interval differences of successive NN intervals greater than 50 ms. This index describe the short-term NN variability. Just to simplify NN intervals can be seen as a sort of beat-to-beat representation of heart rate; according to Malik and colleagues [40], “In a continuous ECG record, each QRS complex is detected, and the so-called normal-to-normal (NN) intervals (that is, all intervals between adjacent QRS complexes resulting from sinus node depolarizations) or the instantaneous heart rate is determined.”

The raw electromyography is a collection of positive and negative electrical signals, their frequency and amplitude give us information on the contraction or rest state of the muscle. Amplitude is measured in  $\mu\text{V}$  (micro-volts). As the subject contracts the muscle, the number and amplitude of the lines increases; as the muscle relaxes, it decreases. We considered the Root Mean Square (RMS) for rectifying the raw signal and converting it to an amplitude envelope. In this study, we were not interested in frequency related to muscle fatigue.

Matrixes have been computed to calculate 14 Slow Alpha EEG (7–10 Hz) bands, one per each channel recorded.

### 2.7. Data analysis

Data were analyzed with the aid of the statistical software SPSS, version 17 (Statistical Package for the Social Sciences—SPSS for Windows, Chicago, Illinois, USA). The measures considered are defined as follows: EMG Corrugator, EMG Zygomatic, HR, LF/HF, and NN50 (extracted from EMG-CS, EMG-Z, and ECG). A significant value for Mauchly's Test of Sphericity at  $p .05$  indicated that the assumption of homogeneity of covariances has been violated for several measures. Thus when appropriate, a Greenhouse–Geisser adjustment to the degrees of freedom was used in order to correct any potential inflation of the reported probability values [53]. In these cases, corrected  $p$  values were reported with the original degrees of freedom, along with the associated Greenhouse–Geisser correction.

### 3. Results

A repeated measures ANOVA with a Greenhouse–Geisser correction determined that mean scores for NN50 differed statistically

significantly between the four experimental conditions (R, RM, S, SM) [ $F(1.813, 63)=22.178, p < .001, \eta^2=.514$ ]; mean scores for LF/HF differed statistically significantly between the four experimental conditions [ $F(1.600, 63)=3.799, p < .042, \eta^2=.153$ ]; mean scores for HR differed statistically significantly between the four experimental conditions [ $F(1.730, 63)=21.469, p < .001, \eta^2=.506$ ]; mean scores for EMG Zygomatic differed statistically significantly between the four experimental conditions [ $F(1.593, 63)=14.172, p < .001, \eta^2=.403$ ]; mean scores for EMG Corrugator differed statistically significantly between the four experimental conditions [ $F(1.748, 63)=27.388, p < .001, \eta^2=.566$ ] (Tables 2 and 3).

### 4. Discussion

Since this study involves the interpretation of many complex psychophysiological measures we will detail now our results for each index used.

First of all, we used HR, i.e. heart rate, a well-known measure typically expressed as beats per minute (bpm). The typical healthy resting heart rate in adults is 60–80 bpm. In our experiment, we obtained about 70 bpm for Relaxing sessions (both mobile and PC) and an increase reaching about 80 bpm for Stress sessions, as can be seen in Fig. 5. This behavior of HR is quite normal and it is expected, in fact this represents a typical physiological arousal that prepares the subject to conditions of readiness to respond (and sensory alertness) due to action of brain's four neurotransmitters: norepinephrine, dopamine, acetylcholine, and serotonin. These results in our data confirm the hypothesis that a physiological arousal can also be generated using a smart phone.

HR is as simple as well as a useful measure in order to verify a typical physiological arousal but, sometimes it could be more informative to analyze the so called Heart Rate Variability, typically a set of indexes, in time domain or in frequency domain, that received many attentions by scientific community in the last 15 years, after a well known article of the *Task Force of the European Society of Cardiology* and the *North American Society of Pacing Electrophysiology*, entitled “Heart Rate Variability”, published in *Circulation* (1996;93:1043–1065).

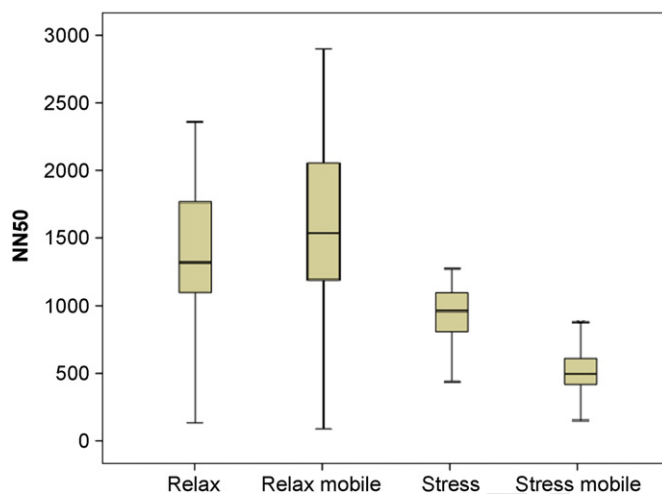
In our data, as we can see in Fig. 3, we obtained smaller value of NN50 in stress sessions (both PC and mobile), as expected. Moreover we can see that mobile session worked better than PC session in eliciting relax and stress, and in differentiating the two affective states; in fact, as can be seen in Fig. 3, we obtained highest value on NN50 for relax mobile session and lowest value for the stress mobile session.

**Table 2**  
Mean (and Std. deviation) of the psychophysiological measures of PC and mobile sessions.

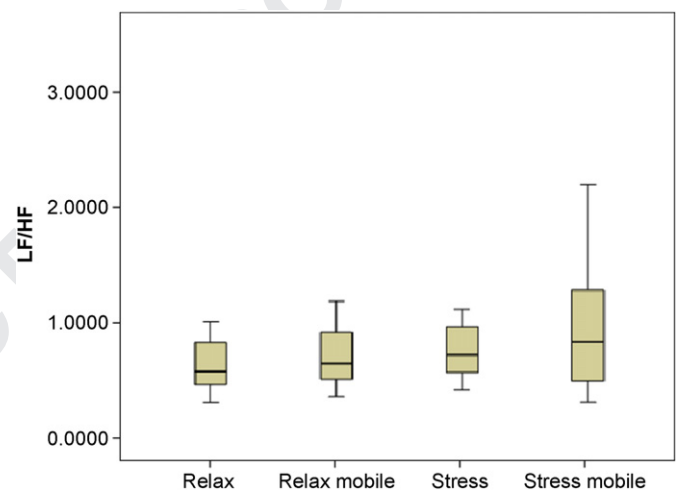
Methods	Session type mean (standard deviation)			
	Relax	Relax Mobile	Stress	Stress Mobile
<b>Stress</b>				
LF/HF	0.633 (0.057)	0.737 (0.058)	0.77 (0.051)	1.015 (0.144)
NN50	1426.16 (93.73)	1570.55 (167.21)	977.64 (70.33)	521.93 (33.82)
<b>Arousal</b>				
HR	70.184 (2.062)	70.547 (1.823)	80.368 (2.861)	81.243 (3.11)
Alpha Ch. AF3	0.014 (0.002)	0.013 (0.003)	0.01 (0.002)	0.009 (0.001)
Alpha Ch. F7	0.006 (0.001)	0.006 (0.002)	0.005 (0.001)	0.005 (0.001)
Alpha Ch. F8	0.007 (0.001)	0.007 (0.002)	0.007 (0.001)	0.005 (0.001)
Alpha Ch. AF4	0.014 (0.002)	0.018 (0.005)	0.011 (0.002)	0.012 (0.002)
<b>Valence</b>				
Zygomatic	0.175 (0.021)	0.204 (0.023)	0.092 (0.01)	0.101 (0.023)
Corrugator	0.088 (0.009)	0.102 (0.011)	0.187 (0.021)	0.229 (0.028)

**Table 3**  
The comparison based on the predefined hypotheses.

Measure	Hypotheses							
	R vs. S	Hp1	Rm vs. Sm	Hp2	R vs. Rm	Hp3	S vs. Sm	Hp4
<b>Stress</b>								
LF/HF	$p > .050$	No	$p > .050$	No	$p > .050$	Ok	$p > .050$	Ok
NN50	$p < .003$	Ok	$p < .001$	Ok	$p > .050$	Ok	$p > .050$	Ok
<b>Arousal</b>								
HR	$p < .001$	Ok	$p < .002$	Ok	$p > .050$	Ok	$p > .050$	Ok
Alpha Ch. AF3	$p > .050$	No	$p < .280$	Ok	$p > .050$	Ok	$p > .050$	Ok
Alpha Ch. F7	$p > .050$	No	$p > .050$	No	$p > .050$	Ok	$p > .050$	Ok
Alpha Ch. F8	$p > .050$	No	$p < .490$	Ok	$p > .050$	Ok	$p > .050$	Ok
Alpha Ch. AF4	$p > .050$	No	$p > .050$	No	$p > .050$	Ok	$p > .050$	Ok
<b>Valence</b>								
Zygomatic	$p < .001$	Ok	$p < .010$	Ok	$p > .050$	Ok	$p > .050$	Ok
Corrugator	$p < .001$	Ok	$p < .001$	Ok	$p > .050$	Ok	$p > .050$	Ok



**Fig. 3.** Lower values of NN50 would be a sign of higher mental stress.



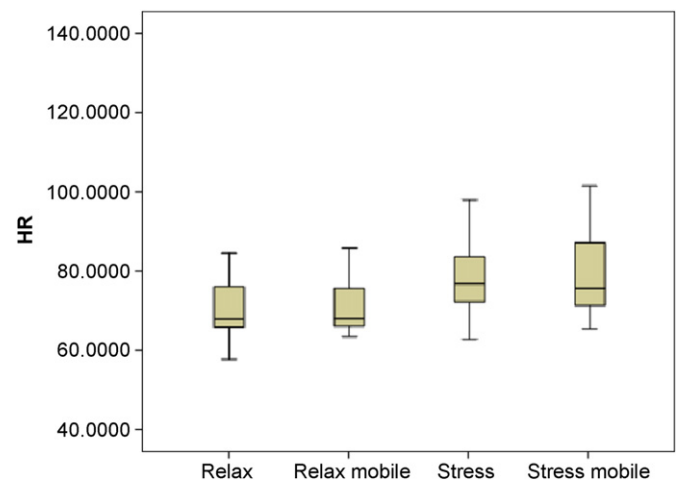
**Fig. 4.** Higher level of simpatovagal balance (LF/HF) would be a sign of higher mental stress.

The time domain methods are computationally simple, but they lack the ability to discriminate between sympathetic and parasympathetic contributions of Heart Rate Variability. In this study we also analyzed the LF/HF index, also known as Sympathovagal Balance.

As can be seen in Fig. 4, in our data, it is possible to see a general trend of higher values in stress sessions than in relax sessions, as expected. Nonetheless this index is not statistically significant comparing Relax Mobile (RM) with Stress Mobile (SM).

Finally we used in our analysis two facial EMG indexes, namely EMG Corrugator and EMG Zygomatic, already described in Section 2. From Figs. 6 and 7 it is possible to see that in relax sessions (both mobile and PC), corrugator is higher than in stress sessions (both mobile and PC) and zygomatic is lower than in stress sessions (both mobile and PC). This result confirms that both relax sessions show a positive valence of emotions, compatible with what expected, and stress sessions show a negative valence of emotions, as expected. Referring to the Lang model this exactly identifies the elicitation of affective states expected and makes possible the correct classification of such states using a smart phone.

EEG data analysis highlighted the strength of PC and mobile in generating a clear pattern in frontal area. In fact there are significant differences during the mobile sessions between Relax and Stress. In particular, since alpha waves are inversely related to cortex activation, higher cortex activation seems to be higher in the frontal area during stressful session, in fact as expected alpha waves are always lower in stress sessions.



**Fig. 5.** Heart Rate (HR) is accelerated in stress session, as expected.

## 5. Conclusion

Mobile phones have quickly evolved from only voice- and text-based devices, enabling minimal user-device interaction, to the personal digital assistant with digital camera, GPS and navigator, MP3 and video player, interactive agenda, clock and alarms, Instant

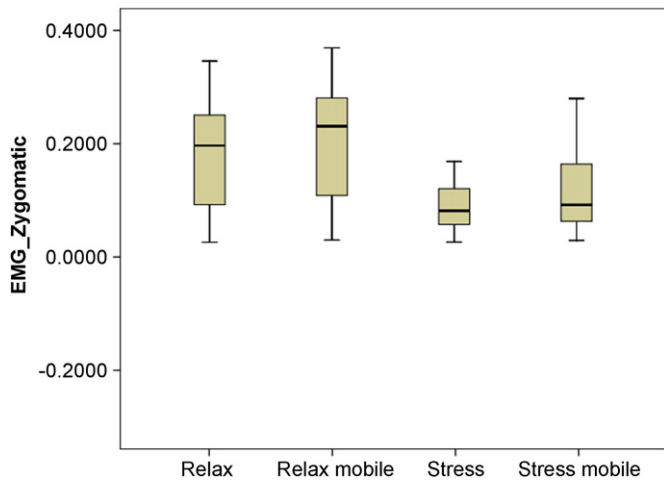


Fig. 6. Zygomatic is positively correlated to positive emotional valence.

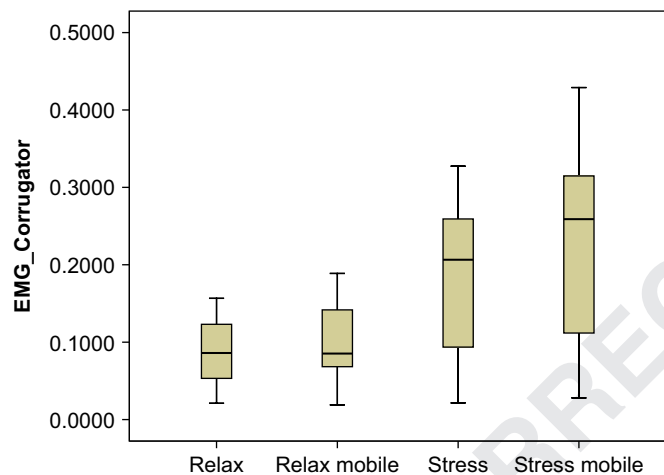


Fig. 7. Corrugator is negatively correlated to positive emotional valence.

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Messaging, and Internet Browser [12]. Based on to these features, mobile devices are becoming more and more useful also in health care services [10,11]. In particular, thanks to recent development and diffusion of mobile platforms wirelessly connected to wearable sensors, stress management protocols could be extended beyond the traditional clinical setting to deliver real-time support during daily activities. Although the efficacy of mobile self-help approaches have been tested through several studies [13–15], there is as yet no study that has tested the feasibility of mobile platforms to actually elicit core affective states. The present study is aimed at testing the possibility of inducing positive and negative affective states using smart phones and will compare this innovative approach with a traditional one, represented by the use of a PC.

Our results encourage the use of mobile self-help protocol to reduce psychological stress levels, helping people to effectively manage their stressful daily situations, when and where it is most needed.

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