The Mindfulness Meditation Effect on Brain Electrical Activity: Stress Assessment, Concentration State and Quality of Life

Pedro Morais[1,2,3] [1] and Carla Quintão[1,2] [2]

[1]*Department of Physics, Faculty of Sciences and Technology, Universidade NOVA de Lisboa, Lisbon, Portugal*

[2]*Laboratory for Instrumentation, Biomedical Engineering and Radiation Physics, UNL, Lisbon, Portugal*

[3]*Biomedical Engineering Doctoral Program, UNL, Lisbon, Portugal*

1 RESEARCH PROBLEM

Modern societies are oriented towards a model of life that is increasingly competitive, agitated and demanding. A large part of the population responds, on a daily basis, quickly and under a great amount of stress to their professional responsibilities and household chores, with little time to relax. A pre-programmed way of life, constantly pressed, where there is no opportunity to think, rest or contemplate everything that is good around us, imposes timings, which are contrary to one's natural rhythms. The consequences of this, at first, include changes in the quantity and quality of sleep; in food intake habits, that tend to become inadequate and unhealthy; and in fatigue, that becomes chronic. Over time, the harmful effects to one´s health are numerous. Heart problems; body aches; weight loss or gain; hormonal changes; or even difficulty in social relationships, with concomitant isolation from others are common complaints (Institute of Medicine, 2006). Psychological disorders as depression, anxiety and stress begin, either alone or together, to take a significant role in our daily lives. In Europe, Portugal stands out as a country in which these types of health problems are prevalent. One third of its population reports some degree of health perturbations caused by accelerated life styles (Health General Directorate, 2017). This vulnerable and sickly way of living contributes to an increasingly depressed and anxious society. It leads also to the rise of drug consumption, often self-medicated, relieving the symptoms in certain cases, but not addressing the source of the problems.

The aforementioned scenario constitutes a serious public health concern, requiring urgent measures. We believe that such measures should involve the development of brain mechanisms of self-regulation. Mindfulness meditation emerges as a part of the solution, easily accessible to the average citizen, not only from a therapeutic viewpoint, but mostly as a proactive way to prevent and respond to some of the health disturbances that affect that part of the population. Such approach is a mental technique for controlling the individuals' mental state and, in consequence, their own well-being. Mindfulness is rooted on the principle that the non-judgmental observation of the present, disconnected from past experiences and future expectations, calms down one´s own mind.

Recent studies have identified brain areas correlated with the positive effects of meditation (Davidson, R.J et al, 2003). However, the underlying neuronal mechanisms of such correlates are still unclear, and it is evident that rigorous and systematic scientific research is needed, to fully understand the role of meditation onto mental states and neuronal positive adaptation. Hence, future studies should address the relation between conscious Mindfulness meditation and neuronal circuit changes. In addition, most published work, in this area, perform only comparative studies between experimental and control groups at one single instant, disregarding the intrinsic dynamic nature of the training and use effects of meditation. Besides, electrophysiologic signals, such as electroencephalogram (EEG), electrocardiogram (ECG) and electrodermal activity (EDA) are often studied individually (Tang, Y.Y. et al, 2015), whereas we believe that the information produced by each technique may validate and potentiate the understanding of the phenomena at study. Finally, self-assessment surveys are often not included in studies, preventing a reliable relation between neurophysiologic data and changes in quality-of-life, which could be easily and unequivocally reported by the participants.

[1] https://orcid.org/0000-0002-1774-7093
[2] https://orcid.org/0000-0003-1015-4655

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Thus, an integrated and longitudinal research, including personal surveys, is required to accurately assess potential mental health benefits of Mindfulness meditation.

2 OBJECTIVES

The current PhD study, in Biomedical Engineering, intends to show that Mindfulness meditation practice, with its goal of being "*here and now*", improves one's mental health, as demonstrate via attentive self-regulation and a decrease in anxiety, depression and stress. Through a thorough data collection and analysis strategy, we aim to conclude that this type of meditation can be used as a valid approach to deal with clinical disorders, which affect a large portion of the population.

3 STATE OF THE ART

Mindfulness meditation emerges as an easy-to-use way to promote an individual's well-being, as well, as a technique to prevent and treat a specific range of widespread mental illnesses. It has evolved throughout the world, and gave its practitioners a significant improvement in quality of life (Kabat-Zinn, J., 2003). Due to the good results achieved, it was adopted in some countries as a curricular discipline in secondary education and used in medical care (Center for Mindfulness in Medicine Health Care and Society, 2018).

Research made in this area, in particular those using functional MRI during cognitive tasks, identified individual regions, associated to specific functional changes after meditation, including the prefrontal cortex; insula; hippocampus; and amygdala (Kilpatrick, L.A., 2011). These areas were also mentioned in brain volumetric studies using structural MRI, in which variations of brain mass were reported. However, the published research did not always agree. In some cases, the conclusions were even contradictory.

EEG, with its particularly high temporal resolution, has also been used as a non-invasive technique to analyse spatiotemporal data from brain electrical activity, providing relevant information about neural networks (Michel, C.M et al, 2004). These studies showed that practicing Mindfulness meditation leads to an alpha power increase and also showed that focusing one's attention can be associated with an increased gamma activity (Hinterberger, T., 2014).

Although, there has been significant progress and maturation in Mindfulness meditation research, a careful review of the reported outcomes, reveals that it is necessary to deepen the neuroscientific knowledge about brain function changes and how Mindfulness can be effectively used in the context of mental disorders and to improve one's quality of life (Van Dam, N.T. et al, 2018).

4 METHODOLOGY

The current study is based on a set of tasks, involving visual stimuli, concentration tests and stress-inducing challenges. 30 individuals were submitted to a Mindfulness Based Stress Reduction (MBSR) course and evaluated at regular intervals, in a period of 12 weeks (Mindfulness Based Stress Reduction, 2018). In 4 scheduled sessions, EEG, ECG and EDA signals were recorded, while subjects performed the aforementioned tasks. In each session, subjects filled in three questionnaires, assessing their current quality of life; mood state profile; and depression, anxiety and stress levels. Through exploration of the recorded physiological data, we will search for functional changes that may occur in the autonomic and central nervous systems, as a result of the Mindfulness practice. After attending the course, each subject may experience one or several of the following: changes in their heart rate and sweating levels; the ability to concentrate; as well as in the control of individual emotional responses to their surroundings. Assuming that such effects are established, it will be important also to assess how they can be operationalized, not only to treat mental disorders, but also to help prevent them. In addition, it is important to note that the proposed strategy would have the added benefits of a low-cost intervention, in a positive life-changing approach, with no known negative side effects.

4.1 Participants Recruitment and Characterization

Since this project is being conducted in the Faculty of Sciences and Technology of Nova University of Lisbon, the recruiting information for the study was made available via a poster in one of the most affluent places of the school, and an announcement made via e-mail for all students, teachers and staff. Both contained a link where all interested volunteers could obtain more detailed information about the MBSR course (duration, name of the instructor, schedule…), as well as the kind of award certificate of attendance.

An immediate pre-selection was made after completing a small inquiry, which excluded candidates who had already Mindfulness training or who did not have total availability to attend the complete course, spanning the 12 weeks, and participate in the 4 sessions of data collection. After 15 days, 30 healthy candidates were selected, filling all vacancies.

During the MBSR 5 subjects gave up, due to health problems or with no explicit justification, so the final population for the study comprised 25 subjects (mean age = 26.0, SD = 7.07, 9 of which were male), consisting of 23 university students and 2 university staff. The latter had higher education.

4.2 Self-Assessment Surveys

Three self-assessment surveys were used in this research: World Health Organization Quality of Life (WHOQOL); Profile Of Mood States (POMS); and Depression, Anxiety and Stress Scale (DASS). All answers were given through online forms, specifically created for this study and with authentication by assigning a unique and non-transferable identification code.

4.2.1 World Health Organization Quality of Life

WHOQOL stems from a collaborative project, assessing individual quality of life from an international perspective. It emerged from a definition statement that quality of life is "*the individual's perception and position in life in a cultural context and value system in which he lives and in relation to his goals, expectations, standards and concerns*" (World Health Organization, Measuring Quality of Life, 1995). The WHOQOL-100 consists of 100 questions, in this case adapted to Portuguese population, that assess six dimensions: physical, psychological, independence level, social relations, personal environment and spirituality beliefs. The inquiry begins with 42 questions determining whether the individual has already experienced certain things related to positive feelings of happiness and contentment. It is classified as "*Nothing*" to "*Most*", corresponding to a scale of values of 1 to 5, respectively. The next 13 questions are related to the daily activities, evaluating whether the subject has experienced, or was able to do certain things, such as washing or eating, with the qualitative classification of "*Nothing*" to "*Completely*". The 3rd phase of the survey includes personal life qualification, with 34 questions assessing whether the individual felt happy, satisfied or good about various aspects of their life, ranging from "*Very Unsatisfied*" to "*Very Satisfied*". The friendship support is assessed through the following three questions, referring to the frequency with which one felt or experienced things like friends' support or the sensation of insecurity. "*Never*" to "*Always*" are the limits of their qualitative evaluation. The work-related analysis is assessed through 4 questions, about the daily activities, which are most time and energy consuming. It includes volunteer work, full time, paid or not, and also housework. Here the classification goes from "*Nothing/Very dissatisfied*" to "*Completely/Very satisfied*". The 6th survey group, comprises 4 questions, addressing mobility, and refers to individual's physical ability to move on his own and accomplish things that he wants and needs to do. The questions are answered on a scale between "*Very Bad/ Nothing/Very Unsatisfied*" and "*Very Good/Very Much/Very Satisfied*". Finally, 4 questions regarding religious beliefs, principles and personal values are addressed, varying the return between "*Nothing*" to "*Many*". The answers to the 100 questions are given based on the last two weeks of the individual's experience. The quality of life is evaluated quantitatively in the six domains, from 1 to 5. The greater the result obtained (the sum of all answers) the healthier the subject.

4.2.2 Depression, Anxiety and Stress Scale

DASS was designed with 42 items and adapted to Portuguese with a subset of 21 items (Pais-Ribeiro, J. L. et al, 2004). This scale was developed for adults, evaluating a set of feelings and emotions, grouped in 3 basic structures: anxiety, depression and stress. Anxiety includes skeletal muscle effects, autonomic system arousal, subjective experiences, and situational anxiety. Depression encompasses lack of interest or involvement, discouragement, life devaluation, self-deprecation, and inertia. Finally, stress encompasses the nervous excitement, agitation, irritability, impatience and difficulty in relaxation. The questions are put up via an online form, evaluating each symptom separately, and addressing only the last week, on a scale of points from 0 to 3. The final evaluation is calculated on the 21 answers divided into three groups. The minimum value is 0 and the maximum value is 21, corresponding to the most negative emotional and affective state. The final assessment assigns the grade "*Normal*", "*Soft*", "*Moderate*", "*Severe*" and "*Severe extremity*".

4.2.3 Profile of Mood States

POMS assesses emotional variations and psychological well-being of an individual (McNair, D. M., Lorr, M., & Droppleman, L. F, 1971). This evaluation instrument, initially used in psychiatric populations, has been used in non-clinical populations since it is easy to answer and quick to use. In the advanced survey, the Portuguese adaptation was used with 42 adjectives, identifying six mood state factors: Tension/Anxiety, represents increased musculoskeletal tension and concern; Depression/Melancholy, describes the emotional state of sadness, loneliness, unhappiness and discouragement; Hostility/Anger, portrays a mood of anger or antipathy towards others; Vigour/Activity, represents the state of energy and physical and psychological vigour; Fatigue/Inertia, expresses a state of fatigue, inertia and reduced energy; and finally Confusion/Disorientation, corresponds to a low lucidity and confused state. All questions, put through an online form, evaluate the person's state during the last week, in a scale from 0 to 4, with the correspondence: 0 - "*Nothing*", 1 - "*A little*", 2 - "*Moderately*", 3 - "*Enough*" and 4 - "*Very much*". After completed, the level of disturbance in mood state of an individual is calculated, via the sum of the tension states, depression, hostility, fatigue and confusion, from which the state of vigour is subtracted. To avoid a negative final result, the value 100 is added. Hence, 74 and 244 will correspond to the minimum and maximum limits of the scale, respectively. The state of humour is so much healthier the smaller the final result obtained.

4.3 Psychological Challenges and Stress Factors - Cognitive, Motor and Visual

Auditory and visual stimulations, as well as stress challenges elicit in a given person a specific emotional reaction and, consequently, different biological signals. After Mindfulness practice it is expected that these outcomes vary, when compared to those recorded before meditation training. In particular, Mindfulness experts report greater latency in reactions to stimuli, as well as less intensification in the emotions, which should be reflected somehow in the electrophysiological signals recorded. A set of three tasks were developed specifically to evaluate the differences in performance, within the recorded signals before and after Mindfulness practice.

During the study, 4 data collection instances were set: the first, in the week before the beginning of the Mindfulness course; the second, 4 weeks after that; the third, in the last week of the course, 4 weeks after the beginning of the recordings; and the fourth session, 2 months after completing the MBSR course.

In these four sessions participants were subject to the same type of stimuli and recorded the same bio signals.

4.3.1 Cognitive Stimuli

The first approach used is a 5 minutes cognitive task. The subject is sitting comfortably, with his eyes closed, and is asked to remain the first 30 seconds with his head free of any thoughts. After a sound notification, in the next 30 seconds, the subject should perform a mental countdown from 100, with a 3-in-3 step. It is not intended to be fast in this counting procedure, but rather to keep concentrated in the task. These two 30-second cycles are repeated 5 times.

4.3.2 Motor Challenge

The second stimulus is a motor challenge, which also lasts 5 minutes. A Python application was developed to build a winding path (Figure 1), which will be presented in a monitor. The subject has a cursor, which should be made to go through the path, using the mouse, without transposing its limits. If this happens, the process is reset, returning the cursor to the departure place, with a concomitant stress sound to be heard.

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Figure 1: Stress Route application, designed to evaluate motor behaviour under stress conditions. The task lasts for 5 minutes.

As an addition stress factor, the cursor movement is artificially deformed, using a sine trigonometric function, to deviate it from the root. This stressor is applied in order to avoid cursor "*jump*" impulses, whenever the user moves the mouse after few moments of inactivity. The cursor trace is stored in a CSV file for further analysis.

4.3.3 Visual Stimuli

There are several types of images that negatively influence an individual. Records of violence, erotic scenes and wild animals, such as snakes or spiders, often annoy those who visualize them. In this work, the International Affective Picture System (IAPS) database, developed by the National Institute of Mental Health Center for Emotion and Attention, at the University of Florida, will be used (ILang, P.J., Bradley, M.M., & Cuthbert, B.N., 2008). A Stress-Image Python application was developed to present the respective images to the subjects. From the 1200 images that compose IAPS, 300 stress images were chosen, divided into 4 experimental sessions and maintaining the same sequence. The idea is that subjects will be facing equally disturbing images throughout sessions, without repeating them, which could lead to some level of habituation. For 10 minutes, the subject stays sitting comfortably in front of a monitor, and observes each image, which is shown for 6 seconds, followed by 2 seconds of a black background interval between images.

4.4 Neurophysiologic Signals Acquisition (EEG, ECG, EDA)

During all tasks described above, neurophysiologic data were collected through EEG, ECG and EDA. Electroencephalographic signals were recorded using a 32 active channels *gTEC Nautilus* system, with an acquisition rate of 250Hz (g.tec Nautilus, 2018). The raw data was saved using the proprietary software *gRecorder*. The electrodermal activity and electrocardiogram were acquired using a wireless 4-channel *BioSignalsPlux* system (BioSignalsPlux, 2018). This device collects and digitizes the signals from each sensor and transmits them via Bluetooth to a computer to be recorded, with a 16-bit resolution and a 500Hz sampling frequency per channel. The raw data was recorded via the *OpenSignals* software, also from BioSignalsPlux. All three signals can be visualized in real-time, which allows identifying, already during the recording stage, possible problems with the data, such as signal loss or electric artifacts.

4.5 Processing and Data Analysis

The three surveys, WHOQOL, POMS and DASS, were processed, to determine the various scores for mental states of each subject. The data acquired through *gNautilus* and *BioSignalsPlux* was converted to a format compatible with *Matlab*. With the stored information, which amounted to 7GB, it was necessary to perform a first visual analysis. Thus, a dedicated interface was developed that allows the combined visualization of all four sessions signals at once. Figure 2 displays the ECG and EDA signals, of one particular subject, recorded during the visualization IAPS task.

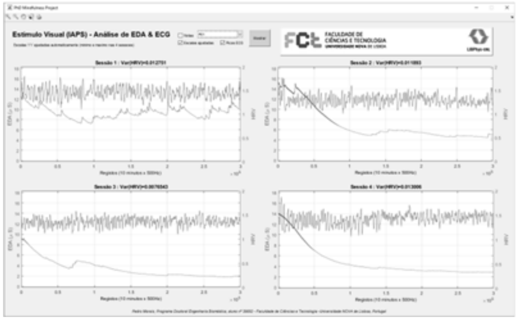

Figure 2: Matlab interface to visualize, per subject, EDA and ECG results in all four sessions of the study.

This interface also gives the possibility to use an algorithm for the detection of ECG peaks, which allows for the calculation of the Heart Rate Variability (HRV). The procedure is shown in Figure 3. Regarding the EDA data analysis, *Ledalab*, a very useful function from *Matlab*, allowed the differentiation between Skin Conductance Response (SCR) and Skin Conductance Level (SCL), which in turn is paramount to identifying relevant EDA peaks, and calculating their respective amplitude (see Figure 4) *(Ledalab, 2014)*.

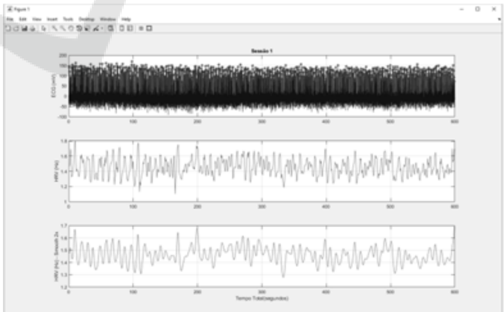

Figure 3: ECG peak detection and HRV calculation.

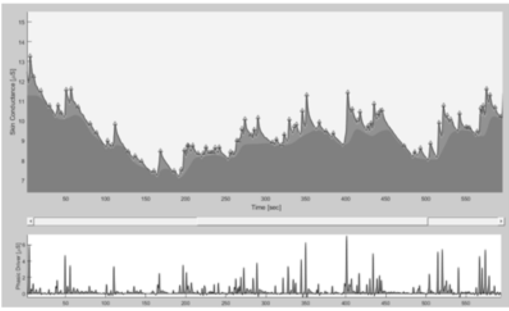

Figure 4: Area identification for SCR and SCL, together with the estimated EDA peaks, using the Ledalab Matlab module.

Finally, and to explore data collected during motor stimulation, an application was built to calculate the number of times the subject failed their trailing task; identifies where the failures occurred; and displays the total average distance reached (all illustrated in Figure 5).

Figure 5: Mouse recorded tracking during motor stimulation, with the location and identification of fails and total distance reached.

By comparing the various recordings made throughout all four sessions, one may assess the benefits of the proposed MBSR course.

5 EXPECTED OUTCOMES

Figure 6 illustrates, in a schematic form, the workflow presented in previous sections. The process used in this research project consists of the collection of neurophysiologic data, via EEG, ECG and EDA, throughout four sessions, occurring in different phases of a MBSR course.

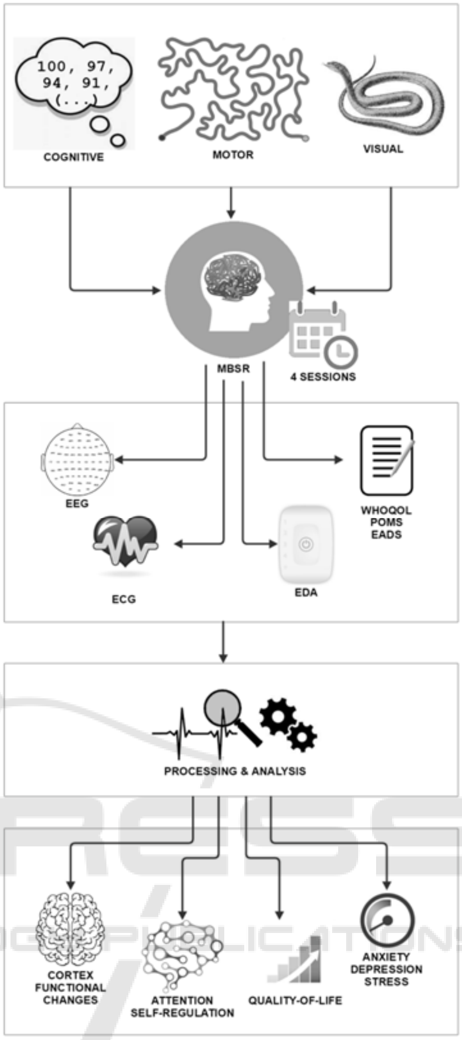

Figure 6: Proposed Biomedical Engineering PhD methodology, intended to show the effects of Mindfulness meditation practice to well-being surrogate electrophysiological data.

In each session, patients are subjected to three different stimuli: Cognitive, Motor and Visual. At the same time, each patient completes three surveys: WHOQOL, POMS and DASS contributing to the differentiation of pathologies and consistency of the results obtained. Finally, the expected functional changes in the cerebral cortex are studied, as well as the possible advantages of practicing this meditation technique, such as an increase in attention self-regulation, a decrease in levels of anxiety, depression and stress and an increase in quality of life.

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6 STAGE OF THE RESEARCH

After the 25 patients collection phase, it was possible to conclude that the results obtained in the 3 inquiries, during the 4 sessions, immediately gave rise to an optimistic confirmation of the expected conclusion: Mindfulness meditation can be useful to prevent and to respond to some psychological health disturbances. The analysis of the 3 surveys, for each session, allow the identification of different groups of participants, defined by their mental general state. Knowledge of this may help the analysis of the respective neurophysiologic signals, as their behaviour is expected to differ from one another. This work stage is still in progress.

In parallel, the first study performed in EDA, using visual stimuli, shows a general average tendency for a greater emotional control after Mindfulness meditation training (see Figure 7).

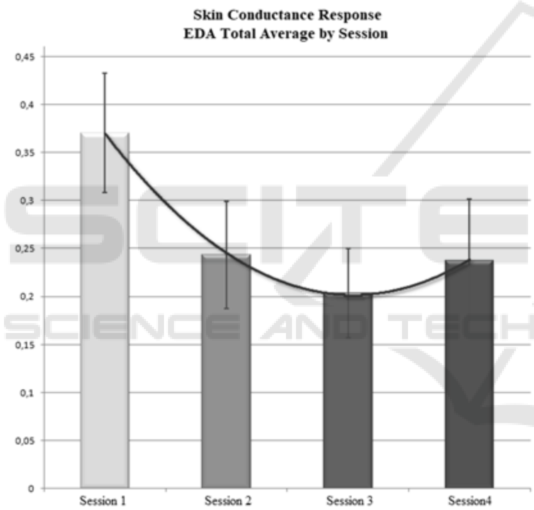

Figure 7: Average EDA results, using visual stimuli, from the 25 subjects and in each of 4 recording sessions.

EDA values decrease with the evolution of the course, which is a good indicator of the aforementioned increased control. Similarly, it is expected that, after ECG processing and analysis, one observes a decrease in heart rate, as the MBSR course progresses.

Then, the EEG analysis will be performed, observing if any spatial-temporal alteration occurs within the typical EEG bands: theta, alpha, beta and gamma.

Finally, it is expected that the integration of all available information will bring new insights on the effects of Mindfulness practice in the brain function and in coping with stress.

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