Biomedical Signal Processing and Control 86 (2023) 105314

Contents lists available at ScienceDirect

Biomedical Signal Processing and Control

journal homepage: www.elsevier.com/locate/bspc

Effects of mindfulness-based stress reduction meditation on the emotional reaction to affective pictures assessed by electrodermal activity

Pedro Correia [a,b,*], Cláudia Quaresma [a,b], Pedro Morais [a,b], Miguel Fonseca [c], Ricardo Vigário [a,b], Carla Quintão [a,b]

[a] *Physics Department, NOVA School of Science and Technology, NOVA University of Lisbon, 2829-516 Caparica, Portugal*

[b] *Laboratory of Instrumentation, Biomedical Engineering and Radiation Physics (LIBPhys-UNL), Physics Department, NOVA School of Science and Technology, NOVA University of Lisbon, 2829-516 Caparica, Portugal*

[c] *Center for Mathematics and Applications, NOVA School of Science and Technology, NOVA University of Lisbon, Lisbon, Portugal*

ARTICLE INFO

Keywords:
Mindfulness meditation
MBSR
Electrodermal activity
Emotional reactions
Visual affective stimuli
IAPS

ABSTRACT

Objective: In recent years the psychophysiological benefits of Mindfulness meditation on emotional processing have drawn great interest in scientific research. Currently, the effects of this meditation practice on stress, anxiety and well-being have been mostly evaluated using self-reporting questionnaires, which lead to a quite subjective assessment. This study assesses the effect of Mindfulness practice on the reaction to emotionally charged visual stimuli through Electrodermal Activity (EDA) data.

Methods: Twenty-five healthy volunteers, without any previous experience of meditation techniques completed a 12-week Mindfulness-Based Stress Reduction (MBSR) course. EDA and psychological measures were collected longitudinally in 4 scheduled sessions. Statistical analysis was performed to find changes in the most relevant EDA parameters throughout the 4 sessions of data collection.

Results: We found an increase in response latency, and a decrease in amplitude, area, number of specific responses, and skin conductance level along Mindfulness training. Both outcomes might suggest a reduction in the reactivity to the presented stimuli and an improvement in the emotional well-being of the practitioners. Furthermore, this study showed preliminary evidence that women improve more their attitude towards stressful stimuli than man, after the mindfulness practice.

The statistical analysis also showed a correlation between the main EDA parameters and the scores reported by each participant in the depression, anxiety, and stress scale (DASS) questionnaire.

Conclusion and Significance: This study contributed to a more objective evaluation of the physiological changes observed during Mindfulness practice, and so to understand the underlying mechanisms that explain the benefits of meditation training.

1. Introduction

Nowadays, mental health is at the centre of the debate in modern societies. Mental disorders are indeed linked to higher mortality rates, as an example, people that suffer from depression have a 40% to 60% greater chance of dying prematurely. Suicide is a leading cause of death due to mental health problems and is the second cause of death among young people worldwide [1].

With this problem in mind, mental health became such an urgent issue that the World Health Organization (WHO) defined the Mental Health Action Plan 2013–2030, which aims to develop strategies for promotion, prevention, treatment, and recovery from mental disorders [1].

In the last years, some alternative therapies aiming at the promotion of well-being through the prevention of mental health disorders have been developed. Mindfulness meditation and some mindfulness-based approaches have gained special attention in this field [2]. This meditation practice has been shown to induce positive behavioural changes and improvements in brain function and connectivity [3,4].

Mindfulness training is usually described as the ability to pay non-judgmental attention to the present moment [4,5]. The learning of Mindfulness techniques involves adopting an attitude of openness and

---

* Corresponding author at: Physics Department, NOVA School of Science and Technology, NOVA University of Lisbon, 2829-516 Caparica, Portugal.
E-mail address: pml.correia@campus.fct.unl.pt (P. Correia).

https://doi.org/10.1016/j.bspc.2023.105314
Received 23 May 2022; Received in revised form 7 July 2023; Accepted 24 July 2023

acceptance of one's experiences, which empowers the individual to react more consciously, and without automatic reactions to internal or external distractors [6].

Regarding the psychological benefits of Mindfulness meditation, several studies pointed out declines in loneliness, depression, anxiety, stress, sleeping problems and rumination [7]. Furthermore, Mindfulness meditation has also shown interesting benefits in non-clinical contexts, such as reducing stress and anxiety in school [8,9], work [10], or in competitive sports' settings [5] (see [7,8,11,12] for more detailed views on those applications). Some studies have also found correlations between the practice of mindfulness meditation and other psychophysiological benefits including improvements in functional connectivity [4], emotion elicitation [13] and effectiveness in handling cognitive load [14].

Mindfulness meditation has shown beneficial outcomes even when applied in clinical contexts such as chronic pain [15,16], fibromyalgia [17] and cancer [18,19].

The great majority of those studies concerning the psychological benefits of mindfulness meditation have assessed the effectiveness of this practice using subjective metrics through self-reported questionnaires. Despite being comparatively easier to employ in different experimental setups the lack of objectivity presented by the results of such questionnaires can overestimate the effects of mindfulness meditation. The main disadvantage of using these kinds of metrics is that one cannot measure objectively the improvement of the psychological state of each patient. Thus, electrophysiological measures may be a powerful solution to assess unconscious emotional reactions and, therefore, overcome the limitations of self-reported questionnaires mentioned above [20].

Aiming an objective measurement of the benefits promoted through mindfulness practices, some authors have turned their attention to functional and electrophysiological studies. While the former evidenced functional changes in brain regions responsible for self-awareness, emotion regulation, and attentional control, in meditators [4] the latter revealed that mindfulness practice evokes changes in the Autonomic Nervous System (ANS), which result in changes of heart and respiratory rates and Electrodermal Activity [21,22].

The Sympathetic Nervous System (SNS) is the branch of the ANS that is responsible for the fight or flight response thus SNS is the system that commands the automatic reaction to an external stimulus.

Electrodermal Activity (EDA) is an electrophysiological signal used to describe the electrical properties of the skin which are modulated by the sweat production [23]. The activity of sweat glands and, consequently, the skin conductance are exclusively controlled by the SNS [24], which makes of EDA one of the most suitable measures to assess the SNS activity [25].

Thus, the analysis of EDA responses, elicited by a stimulus, allows us to access the workings of the SNS and, in that way, the emotional reaction a person presents to said stimulus [26–28].

EDA can be described as the sum of a slow varying tonic component (also called Skin Conductance Level, SCL) and a phasic one that includes all the skin conductance responses (SCR), as depicted in Fig. 1[23].

The phasic component is the one that relates the most with the activation of the SNS, when the person is exposed to an external stimulus. The analysis of this component is often done via the computation of a set of quantitative measures such as the amplitudes, areas, number of specific skin conductance responses (nSCRs), latencies, among others. Fig. 2 illustrates some of these quantitative metrics, extracted from an individual SCR.

These set of quantitative metrics describe the dynamics of each EDA response and therefore can be used to quantify objectively the emotional interference elicited by a stimulus.

The area of each SCR can be calculated through the integration of each electrodermal response and is considered by some authors as the EDA parameter that measures the "strength of effect" of a stimulus [23].

EDA has also drawn high interest in studying the effects of Mindfulness meditation on the activation of the SNS. Some studies found an inverse relation between Mindfulness and the affective reactivity to external stimuli [31–35]. That inverse correlation results from avoiding psychological stress and explains the inverse relation between Mindfulness and stress experienced in daily life, which is reported by participants.

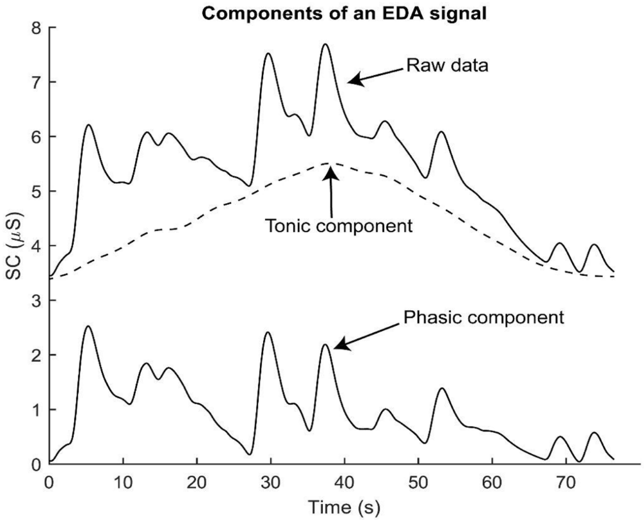

Fig. 1. Tonic and phasic components of an EDA signal [29].

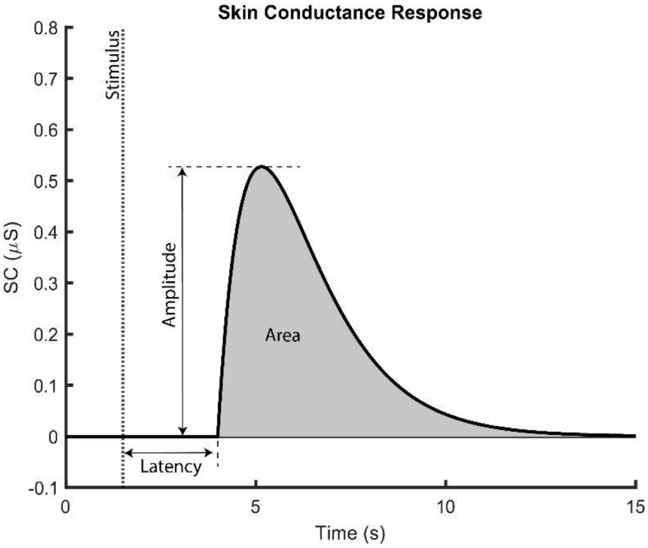

Fig. 2. An illustration of a typical SCR component, together with some metrics extracted from it [30].

That said, this work aims to investigate, longitudinally, the effects of a 12-week MBSR program on the response to different kinds of emotional eliciting visual stimuli through EDA analysis. We are also interested in studying whether this MBSR program is more effective in males or females and how EDA metrics can be related to the subjective results of self-reported scores of depression, anxiety and stress.

Based on those previous findings, it was expected that Mindfulness practice might promote emotional regulation and the capacity to avoid impulsive reactions to negative stimuli [4,28]. The development of these emotional skills is expected to evoke physiological alterations at the ANS level that may be confirmed by changes in the number and magnitude of electrodermal responses over the Mindfulness training. Hence, the current work hypothesizes that:

(1) MBSR leads to reduced reactions to emotionally charged visual stimuli, and consequently, to fewer and less intense electrodermal responses.
(2) MBSR presents distinct effectiveness in reducing the reaction to different types of emotionally charged visual stimuli.
(3) MBSR presents differentiating outcomes for males and females, in the context of the emotionally charged visual stimulation setup.
(4) The main EDA parameters are correlated with the perception of anxiety, depression and stress reported by the participants.

Despite the vast state of the art reporting positive psychophysiological benefits elicited by mindfulness meditation, we have identified a lack of studies examining longitudinally the effects of MBSR meditation through electrophysiological data. Beyond bringing novel knowledge about the objective assessment of the effects of mindfulness, this study correlates, for the first time, objective parameters with the subjective assessments currently employed in clinical procedures.

This study adds significant knowledge to understand the underlying mechanisms that explain the effectiveness of meditation. Furthermore, it presents an objective, reliable and easy to employ method to monitor the outcome of such practice, which therefore could overcome the bias presented by subjective data and allow the optimization of its subject-specific beneficial effects.

2. Methodology

As mentioned in the previous section we developed a longitudinal study in which 25 healthy individuals without any previous meditation experience were monitored in 4 moments temporally distributed over a mindfulness course. Since the healthiness of the subjects was used as an inclusion criterion, all participants had no known disease, neither of cardiovascular nor neurological nature.

As depicted in Fig. 3, the first data collection session (S1), occurred right before the Mindfulness course. In this session participants had no Mindfulness meditation experience, so can be seen as our baseline. The second (S2) coincided around the middle of the course. At the end of the course, when the participants had already learned all the Mindfulness skills intended took place the third recording session (S3). After the course we followed-up the practitioners for 2 months, which finished with the fourth and last monitoring session (S4).

In each session EDA was recorded while participants were stimulated with a set of 75 emotionally charged pictures. After collecting this electrophysiological signal each participant filled in the depression, anxiety and stress scale questionnaire (DASS).

2.1. Sample

All the participants of this study were recruited in the scholar community of NOVA School of Sciences and Technology through voluntary registration.

A total of 25 volunteers (mean age = 26.0, standard deviation = 7.1) who met the pre-selection condition of no previous meditation practice completed the mindfulness course. Thus, the sample used in this work comprise 16 females and 9 males.

2.2. Mindfulness meditation course

All volunteers completed a course of MBSR, with a duration of 8 weeks, which comprised a total of 26 h of meditation practice. In addition to the meditation sessions, all participants were encouraged to include short duration Mindfulness exercises in their daily lives, for which audi o recordings were made available. More details about the MBSR course employed were available in supplementary material.

2.3. Visual stimulation

During each data collection session, volunteers watched a sequence of 75 pictures from the International Affective Picture System (IAPS) database [36,37]. Each affective picture was displayed for 6 s and most of the 75 images had a negative valence. Each set of 75 pictures was composed of 6 different categories of images: animals, facial expressions, human body suffering, erotic content, human threats and shock and repulsion.

To avoid habituation phenomena, each subset of pictures was composed by different images, however, to guarantee the uniformity of emotional charge, we maintain the average of valence, arousal and dominance of each session throughout the experimental setup. Table 1 presents the average and the standard deviation (SD) of the valence, arousal and dominance content of the set of pictures used in each session of data collection.

In the supplementary data we present the reference number of the IAPS pictures used in each sample.

2.4. Depression anxiety and stress scale questionnaire

The Depression Anxiety Stress Scale, developed by Lovibond and Lovibond [38], is a self-reported tool to quantify depression, anxiety and stress felt by the subject [39].

In this study we used a particular version of the aforementioned scale, the DASS-21, adapted to the Portuguese language [40], which assesses 21 negative emotional symptoms. This 21-items scale is consistent and valid when compared to the original version [41].

The subjects answered the DASS questionnaire by rating the severity or the frequency to which they have experienced each described symptom, in the last week, on a 4-point rating scale (from 0 – "did not apply to me at all" – to 3 – "applied to me very much or most of the time").

Several studies confirmed DASS-21 as reliable assessment scale for depression, anxiety and stress feelings in several samples of adults

Table 1
Mean valence, arousal, and dominance of each subset of pictures.

	Valence		Arousal		Dominance	
	Mean	SD	Mean	SD	Mean	SD
S1	3.36	1.54	5.68	0.78	4.12	0.89
S2	3.24	1.26	5.56	0.83	4.02	0.8
S3	3.43	1.36	5.6	0.89	4.21	0.96
S4	3.57	1.38	5.53	0.98	4.29	0.99

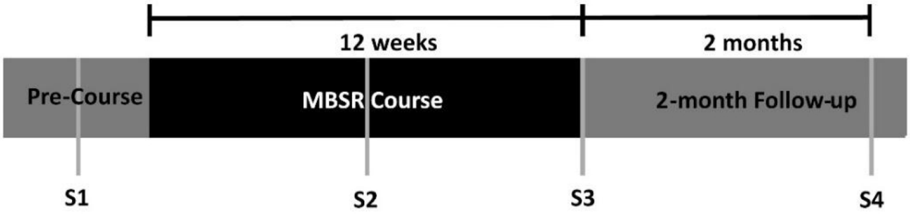

Fig. 3. Timeline of the study.

[41–44]. The total score obtained on each scale – Depression, Anxiety and Stress – ranges from 0 to 42 and can be classified as "normal", "medium", "moderate", "severe", and "extremely severe" [45].

2.5. Data collection

We collected the EDA signal on the palm of the right hand of each subject with a BioSignals Plux wireless system, Fig. 4 [46]. The EDA was sampled at 500 Hz with a resolution of 16-bit.

2.6. Processing and extraction of EDA parameters

One of the most challenging aspects of processing EDA data is the accurate separation of the phasic and tonic components of EDA from the raw data. This work used the discrete decomposition analysis implemented in Ledalab software [44]. Ledalab allow the separation of the components tonic and phasic present in the EDA signals and thus the calculation of a set of EDA parameters.

Ledalab assumes that the dynamics of the concentration of sweat in the skin is modulated by the laws of diffusion, based on the poral valve model [45,46]. Those dynamics can then be modelled by the biexponential Bateman function (1):

$$b(t) = e^{-\frac{t}{\tau_1}} - e^{-\frac{t}{\tau_2}} \tag{1}$$

Where τ_1 and τ_2 are time constants that control the steepness of the onset and recovery of each SCR [45,46].

This biexponential model is then used as the response function of each SCR allowing the separation of the phasic and tonic component through deconvolution analysis. This separation is a crucial processing step for the calculation of the EDA parameters.

After inspecting the raw EDA data, we decided to discard some signals due to electrode connection problems or saturation. In addition, some volunteers did not attend the fourth data collection session. The number of EDA signals considered in the current study are presented in Table 2, for each session, highlighting also the gender distribution of the retained volunteers.

2.6.1. Preprossessing

Considering the slow temporal dynamics of the EDA we decided to filter each signal using an antialiasing gaussian filter with a window of 400 samples, a mean of 200 and a standard deviation of 50 and then each signal was downsampled to 10 Hz.

2.6.2. Discrete decomposition analysis

The electrodermal model proposed by Benedek and Kaernbach [46] uses the Bateman function as an impulse response. One can assume that the activity of sudomotor neurons is nonnegative and presents discrete bursts that should be compact in time. Are these discrete bursts that trigger an SCR.

Fig. 4. The BioSignalsPlux device.

Table 2
Number of EDA signals considered in each session of this study.

Session	Female	Male	Total
S1	14	6	20
S2	14	8	22
S3	16	6	22
S4	11	5	16

Discrete Decomposition Analysis was used to separate the tonic and phasic components and to identify each skin conductance response (SCRs) separately.

Discrete decompositions analysis uses nonnegative deconvolution to compute the driver function which represents the activity of sudomotor neurons. Furthermore, by employing this methodology one can consider the variability of EDA shapes since each driver impulse is computed separately, this fact is one of the advantages of using discrete decomposition analysis [46].

Ledalab uses an iterative optimization procedure to compute the time constants $\tau 1$ and $\tau 2$. This optimization process is based on a gradient descent method that minimises the root-mean-square error (RMSE) and at the same time maximises the compactness of impulses in the driver function.

After the aforementioned data processing, we used Ledalab to extract amplitudes, areas, number of specific skin conductance responses (nSCRs), latencies and skin conductance levels (SCL).

2.7. Statistical analysis

The statistical analysis of the evolution of the EDA parameters, collected throughout the 4 data collection sessions was performed using a Linear Mixed-Effects Model (LMM, [47]).

In this work, we did not employ LMM models to modulate the evolution of each EDA parameter nor to predict the EDA parameters along each session. We chose this kind of statistical treatment to find statistically significant differences between session of physiological data collection because it is the most suitable to evaluate differences of an EDA parameter in repeated measures, with some missing values.

The chosen model considers independent effects or predictor variables (called fixed effects) and some variations that can be present in the data (random effects). Those variables will be defined below, for each LMM applied. In this statistical model, a p-value below 0.05 indicates significant correlational evidence of a relation between progress in the Mindfulness meditation course and results in the ability to cope with stress, as displayed by the electrophysiological signals. We performed this statistical test applying the *lmer* function provided by the *lme4* package in R environment [48].

Since in the linear space the residuals of the models applied to the amplitude, area, latency and skin conductance level data did not present a normal distribution we decided to transform the data to a logarithmic scale, which improved the normality of the residuals – an assumption of applicability of LMM.

Despite being impossible to extrapolate any conclusion obtained in the logarithm scale to the linear one, considering the monotonicity of the logarithm transformation we can conclude that a significant reduction of a parameter in a logarithm scale implies a reduction in the linear scale of the data.

To analyse the impact of Mindfulness meditation on EDA, we performed several statistical studies. First, we analysed the overall effect of the Mindfulness practice, considering all participants and all types of visual stimuli. Then, we evaluated the impact of Mindfulness meditation on each kind of stimuli separately, and finally, we statistically confronted the effectiveness of this meditation course by gender.

To perform the statistical tests, we use three different LMM tests. First, we included one fixed effect - the sessions – and one random effect – the interindividual variability of the Mindfulness condition of each subject, at the pre-course moment (i.e., a random interception for each subject). In this LMM we confronted the correlation between the session and each EDA parameter separately.

In addition, to determine whether Mindfulness practice had distinct effectiveness for male and female participants, we calculated the difference between each EDA parameter from pre-course to post-course – (S3 – S1). Then, since the normality of the data was rejected by the application of a Shapiro–Wilk test we performed a Kruskal-Wallis test to compare whether males and females present different distributions of the difference between each EDA parameter from pre-course to post-course course condition.

Finally, we performed a correlation of repeated measures in R environment using the *rmcorr* function provided by the *rmcorr* package to evaluate whether there is any association between the scores of depression, anxiety, and stress, as reported subjectively by each participant and the parameters of the electrodermal responses, elicited by emotional pictures [49].

Additionally, we employed an effect size analysis for the statistical tests, considering the eta squared measure (η^2) using the function

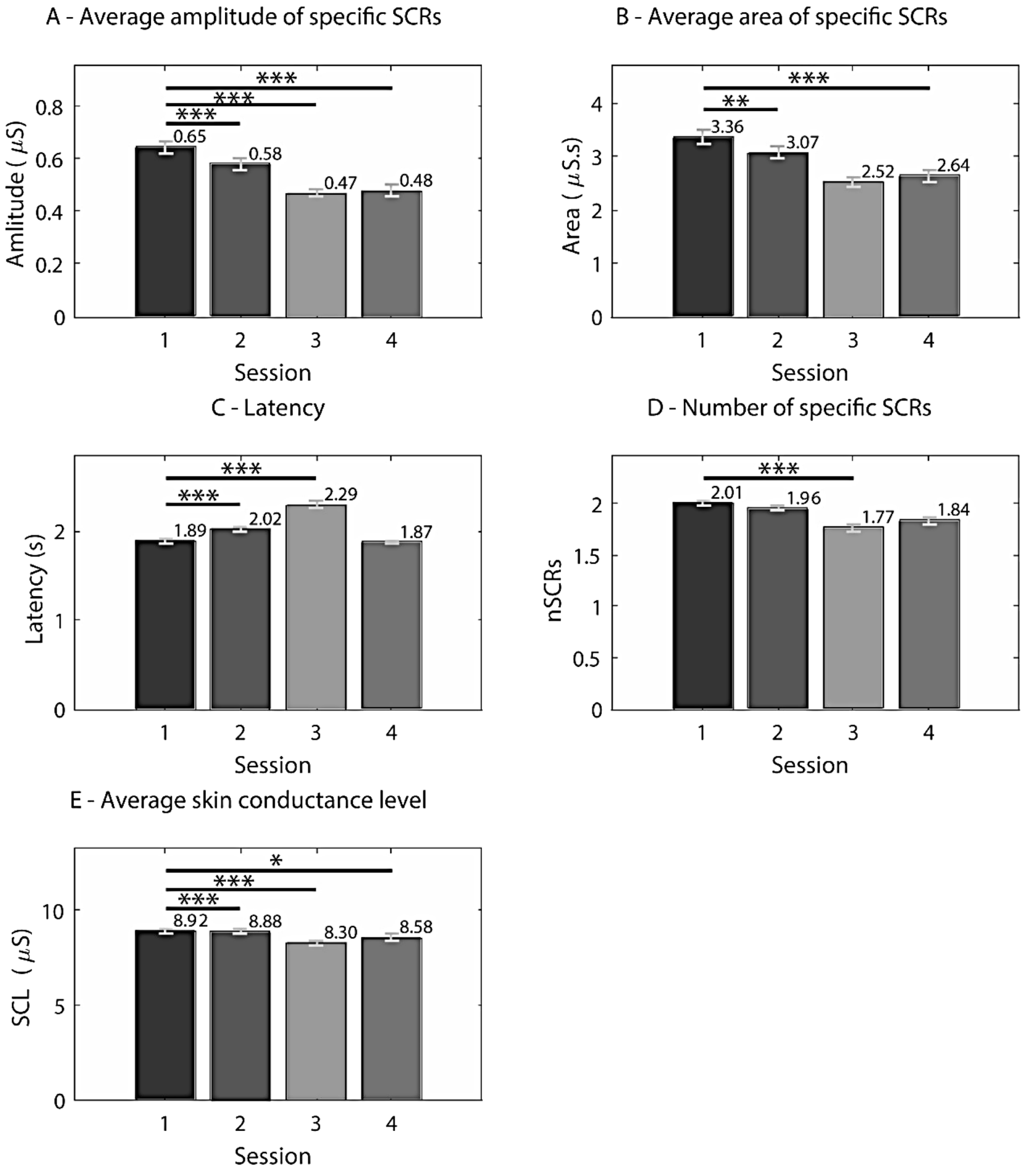

Fig. 5. Evolution of EDA parameters throughout the 4 sessions of data collection (graph A- amplitude, graph B – area, graph C – nSCRs, graph D – Latency, and graph E – SCL). The error bars represent the standard error of the means. In each graph are marked with asterisks the statistically significant variations (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

eta_squared of the *effectsize* package [50]. The effect sizes of the Kruskal-Wallis tests were computed using the *kruskal_effsize* function provided by *rstatix* package [51]. The effect sizes obtained are available in the supplementary material.

Most of the LMM applied showed a small effect size concerning the fixed effect “session”, which is understandable since the mindfulness state is not the unique factor that explains the magnitude of each EDA response. Nevertheless, the variable “session” revealed a moderate effect size in some LMM applied, particularly for the amplitude and area of the SCRs related to *human body suffer* and *erotic* content stimuli.

Since we are interested in inspecting statistically significant differences between sessions, the next section will only focus on the p-value analysis.

3. Results

3.1. Electrodermal activity

3.1.1. General study, considering the overall sample and all stimuli

Fig. 5 illustrates the evolution of EDA parameters throughout the Mindfulness practice. Statistically significant changes in relation to the baseline reference (S1) which were computed after a logarithmic transformation of the data, are indicated with markers and asterisks.

First, we obtained an overall p-value for the evolution of each EDA parameter largely lower than 0.001, which clearly indicates that, from a global point of view, the dynamics of the EDA is highly associated with the course of Mindfulness.

As expected, there is a reduction of the amplitudes, areas, numbers of specific SCRs skin conductance levels and an increase of latency times in reaction to visual stimuli throughout Mindfulness practice. In addition, all the aforementioned pre- to post-course changes in EDA parameters are statistically significant in a logarithmic scale, with a p-value lower than 0.001, except for the area of specific responses that only showed statistically significant changes in sessions 2 and 4. Furthermore, this statistical treatment indicates a recovery of the initial values of the parameters when the individuals stopped the Mindfulness practice, since the estimated parameters in session 4 are closer to those in session 1, when compared to the post-course moment (S3).

3.1.2. Effects of a MBSR course in different kinds of stimuli

To simplify the analysis we will only present in this chapter the variation of the logarithm of the amplitude throughout the 4 sessions of data recordings. Nonetheless, Table A.1 in the Appendix section shows the overall results for the different kinds of stimuli used, being the main analysis for the remaining parameters similar to that carried out for the amplitude.

Table 3 shows the statistical analysis of the SCRs’ amplitude in the logarithm scale for each type of stimulus separately. In this table is presented the estimated logarithm of amplitude value for each stimulus at the pre-MBSR moment – *Intercept (S1)* -, and then, *S1 → S2*, *S1 → S3* and *S1 → S4* correspond to the variation of the amplitude over the three subsequent sessions, considering S1 as the baseline reference. Therefore, a negative estimated value for the logarithm of the amplitude indicates a decrease in the amplitude relatively to S1. The p-values indicate the statistical significance for each comparison.

In line with the previous analysis (see section 3.1.1), we obtained an overall p-value for the evolution of SCRs’ amplitude largely lower than 0.001, which clearly indicates that the dynamics of this parameter is highly associated with the course of Mindfulness, in a global point of view.

Comparing those results, we can observe that only the stimuli of Erotic and Shock and Repulsion contents showed a statistically significant pre- to post-course decrease of area.

We can also see that the stimuli of animals and facial expressions did not exhibit any statistically significant difference in terms of SCRs’ area between session 1 and each one of the subsequent sessions. For these kinds of stimuli, the LMM models applied presented lack of statistical power. Hence, we cannot infer that mindfulness had a significant effect on the responses for these subsets of stimuli.

Table 3
Evolution of the mean SCRs’ amplitude (Estimate, standard error (SE) and p-value) for each type of stimulus throughout the 4 sessions of data collection.

log(Amp)[log(μS)]		Estimate	SE	p-value
Animals	**Intercept (S1)**	**−0.26**	**0.07**	**< 0.001**
	S1 → S2	−0.01	0.05	0.80
	S1 → S3	0.00	0.05	0.99
	S1 → S4	−0.07	0.06	0.22
Facial Expressions	**Intercept (S1)**	**−0.47**	**0.08**	**< 0.001**
	S1 → S2	0.00	0.05	0.92
	S1 → S3	−0.07	0.05	0.11
	S1 → S4	−0.03	0.05	0.52
Human Body Suffer	**Intercept (S1)**	**−0.42**	**0.09**	**< 0.001**
	S1 → S2	−0.07	0.04	0.09
	S1 → S3	−0.08	0.05	0.08
	S1 → S4	**−0.34**	**0.05**	**< 0.001**
Erotic	**Intercept (S1)**	**−0.35**	**0.08**	**< 0.001**
	S1 → S2	**−0.12**	**0.05**	**< 0.05**
	S1 → S3	**−0.21**	**0.05**	**< 0.001**
	S1 → S4	**−0.36**	**0.06**	**< 0.001**
Human Threats	**Intercept (S1)**	**−0.47**	**0.08**	**< 0.001**
	S1 → S2	−0.05	0.05	0.30
	S1 → S3	−0.09	0.05	0.08
	S1 → S4	**−0.14**	**0.06**	**< 0.05**
Shock and Repulsion	**Intercept (S1)**	**−0.50**	**0.08**	**< 0.001**
	S1 → S2	**−0.10**	**0.03**	**< 0.001**
	S1 → S3	**−0.16**	**0.04**	**< 0.001**
	S1 → S4	**−0.12**	**0.04**	**< 0.001**

3.1.3. Effects of a MBSR course in males and females

We analysed the behaviour of the EDA parameters throughout the follow-up period. The results, presented in the Appendix (Table A.2), indicate that Mindfulness meditation had more influence on the dynamics of the EDA in the female cohort. Furthermore, the analysis of the overall EDA parameters by gender suggests a longer-term effect of Mindfulness meditation in women.

Fig. 6 shows the mean variation of each parameter from pre- to post-course in males and females. Since each sample does not follow a normal distribution, we decided to apply the Kruskal-Wallis test to analyse whether females and males present different distributions of each EDA parameter. Significant differences, from a statistical perspective were highlighted in the figure with black lines and asterisks. In general, we verified that the amplitudes and areas decreased more in women than in men and that latency times increased more in women due to Mindfulness meditation.

When we statistically correlate the mean variation of each parameter, we verified that only the number of specific responses did not show a statistically different variation between genres.

3.2. Relationship between DASS and EDA

As mentioned earlier, the analysis of the evolution of the subjective measures are out of the scope of our paper. However, to study the reliability of EDA metrics, as objective measures of psychological states, we should confront EDA with the subjective data provided by the questionnaires, which are common practice in clinical contexts, adapted from [52]. Table 4 shows the mean values reported by all subjects for the anxiety, depression, and stress scales of the DASS questionnaire.

In Table 5 is presented the repeated measures correlation between the main EDAparameters (amplitude, nSCRs, nSCRs, SCL and latency) and the scores of depression, anxiety and stress obtained by the overall sample on the DASS questionnaire.

As presented above, only the number of specific skin conductance responses and the depression showed a moderate association. The

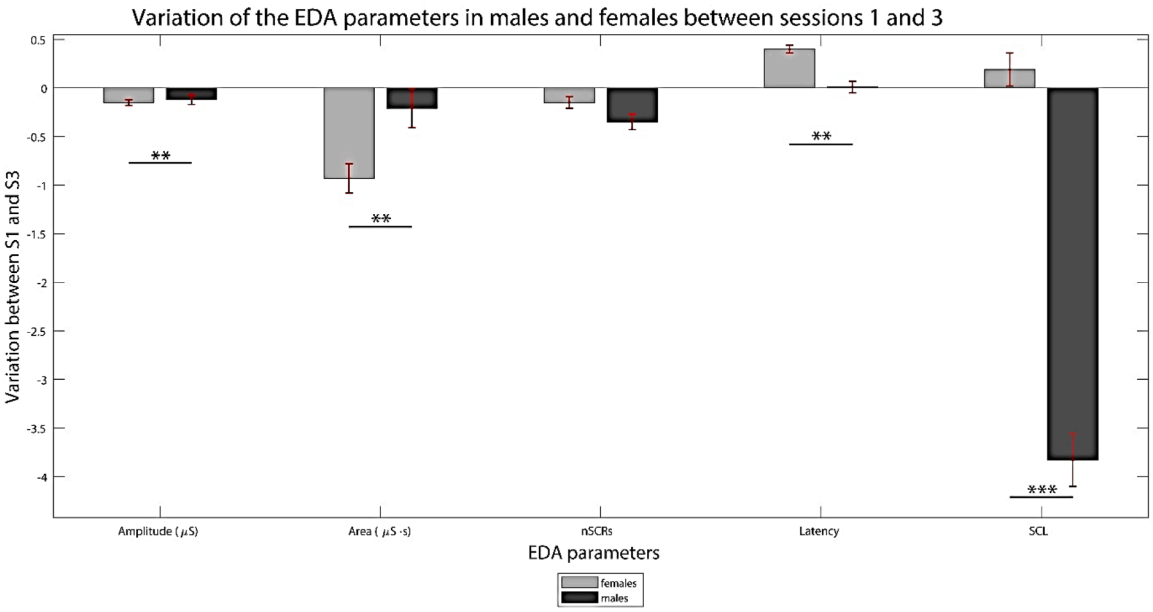

Fig. 6. Mean variation of each parameter of EDA from Mindfulness training in males (light grey bars) and females (dark grey bars). The error bars represent the standard error of the means and statistically significant variations are marked with lines and asterisks (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

Table 4
Mean scores of Anxiety, Depression and Stress based on DASS questionnaire [52].

DASS Survey	S1		S2		S3		S4	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Anxiety	10.3	± 1.5	6.8	± 0.9	3.5	± 0.7	6.2	± 1.5
Depression	10.4	± 1.7	7.6	± 1.2	5.1	± 1.0	7.4	± 1.6
Stress	19.6	± 1.3	15.8	± 1.2	9.4	± 1.3	12.9	± 2.1

Table 5
Correlation between the parameters Amplitude, nSCRs and Latency of electrodermal responses elicited by emotional charged visual stimuli and the Anxiety, Stress and Depressions scores provided by the DASS questionnaire and the respective p-value.

	Anxiety		Stress		Depression	
	r	p-value	r	p-value	r	p-value
Amplitude	0.09	0.46	−0.03	0.82	−0.11	0.35
Area	0.06	0.65	0.06	0.61	0.04	0.78
nSCR	−0.07	0.56	0.00	0.97	0.40	**<0.001**
SCL	0.02	0.86	0.03	0.83	0.01	0.94
Latency	−0.14	0.31	−0.13	0.35	−0.07	0.59

remaining pairs of EDA and DASS parameters presented a negligible coefficient of association.

4. Discussion

The current study provides evidence for the beneficial effect of MBSR practice on emotional processing as manifested through the activity of the Sympathetic Nervous System.

We hypothesised that this 12-weeks MBSR course would decrease the reactions to emotional response visual stimuli, and consequently, lead to less and reduced specific electrodermal responses to emotional stimuli, especially for unpleasant ones.

When addressing the evolution of the EDA parameters, taking all the sample and stimuli types into account, one observes the expected evolution throughout the 4 data collection sessions [31]. The mean values of the amplitude, nSCRs, and SCL decrease with the progression of the Mindfulness course (Fig. 5), which might be a good indicator of the development of Mindfulness abilities such as attentional control and acting with awareness and without judgment [28,53–55]. In addition to that pattern of evolution, the increase in latency of the response, also as a function of the Mindfulness training, patent in Fig. 5, suggests the development of efficient emotional regulation and the capacity to avoid automatic reactions [54], therefore these results are in line with the inverse relation between Mindfulness and the affective reactivity to visual stimuli found in previous studies [31,32]. Yet, the results of our study only suggest a transient effect of short Mindfulness courses such as this 12-week MBSR (Fig. 5), since the reaction to affective stimuli seems to recover to the pre-course situation when individuals interrupt the regular practice, as is clearly shown in Session 4.

The recovery trend in the direction of the pre-course condition, observed in Session 4 suggests that the habituation phenomenon did not interfere with the conclusions. If there was habituation to the presented stimuli, we should expect a constant decrease in the reactivity to the stimuli in subsequent sessions. In fact, two months after completing the Mindfulness interventions the individuals experienced higher emotional reactivity to the stimuli, which suggests that the reduction of electrodermal responses verified in the second and third sessions are directly correlated to Mindfulness learning.

When we studied the variations in EDA parameters throughout the four data collection sessions, for each type of visual stimulus individually, we found that not all types exhibit the expected evolution pattern. *Shock and repulsion* was the stimulus type that shows the closest evolution pattern to those depicted in Fig. 5, for each EDA parameter. Conversely, the results suggest that Mindfulness had no significant positive effect on the emotional process for stimuli of *animals* and *facial expressions*. This finding may be associated with the lower emotional charge of these images. Stimuli with high emotional impact, such as *human body suffering*, show only a small and insignificant positive effect of Mindfulness practice, which may be associated with a lower ability to emotionally detach and accept more disturbing images. Maybe a longer Mindfulness course would improve the aforementioned effects and, thus, achieve better results in this kind of negative stimuli [28,56].

As we hypothesised in the introduction, the results of our study suggest that this MBSR course has distinct effects reducing the emotional reaction to different kinds of affective stimuli.

In addition, the effectiveness of Mindfulness training is significantly different for female and male participants, as evaluated via the evolution of EDA parameters as depicted in Table A.2 of the Appendix.

These differences in the evolution of the EDA parameters might suggest that there should be some gender-specific physiological mechanisms that explain the differentiated benefits of Mindfulness meditation which have been reported in the literature [9,57,58].

In addition, the current study suggests the existence of a longer-term effect of Mindfulness meditation in women, in contrast to the faster recovery to baseline values of EDA parameters after the meditation course, displayed by the men participants.

Average changes in EDA parameters, throughout the Mindfulness training (i.e., between sessions 1 and 3), presented in Fig. 6, are more accentuated in the direction of reducing the emotional reactivity to visual stimuli in women. That result is particularly relevant for the area of the SCRs. Moreover, since that EDA parameter can be considered as a value of “strength of affect”, it suggests that this MBSR training program was more effective for the women cohort. This result is in line with reports that women benefit more than men from Mindfulness interventions [9,57,58].

Considering the small sample size employed in our study these differentiated correlation between EDA and Mindfulness meditation should be carefully analysed and seen as a preliminary result. To overcome this limitation further research with great and gender-balanced samples are needed to increase the statistical power of the analysis.

Finally, we did not find any strong linear correlation between EDA and the scores of depression, anxiety, and stress provided by the DASS questionnaire, however the number of SCRs presented a moderate correlation with the depression scale. We did not assed non-linear correlations between EDA and DASS measures.

Further research should be employed to find correlations between psychological states and electrophysiological measures. Knowing such relation would be important to estimate objectively the emotional reaction that a particular stimulus triggers in an individual and overcome the intrinsic subjectivity bias of self-reported measures.

5. Strengths and limitations

The present study has several strengths. First, the study is based on a longitudinal design that allows for the follow-up of the effects of Mindfulness meditation course during and after its practice. The assessment of the emotional reaction to stimuli through electrophysiological data, such as EDA, is another strength of our study. Since we can use EDA to measure the unconscious emotional reactions to an induced stimulus and, consequently, predict the emotional state of an individual, we may reduce the inherent subjectivity of self-reported assessments that might bias the results.

The lack of a control group is the greatest limitation of our study. Changes in EDA parameters that may result from the stimulation protocol, by other confounding factors or even by chance cannot be discarded without a control group. The employment of such control group would be essential to increase the reliability of our study by ensuring that the changes in EDA parameters reported were, in fact, a benefit of Mindfulness practice.

Despite the small sample size used in this study ($n = 25$), we performed a statistical test quite suitable to the longitudinal nature of the data, which lead to results with great statistical significance.

The current study showed that Mindfulness presented different effects for distinct kinds of stimuli. However, to understand what can explain this variation of effectiveness, further research should analyse if the decrease of the reaction to emotional pictures, elicited by an MBSR course, is influenced by the emotional content of the stimuli (i.e., arousal and valence scores).

Further research should integrate more physiological measurements and therefore accurately assess the mental health benefits of Mindfulness meditation. It would also be interesting to perform a comparative study of the effects of different types of Mindfulness meditation programmes and analyse how the duration of the training influences its long-term benefits. These studies should be relevant to optimise the positive effect of Mindfulness practice.

6. Conclusion

Our findings suggest that MBSR programs can reduce the magnitude of the unconscious emotional reactions to visual affective stimuli, which can be verified by statistically significant decreases in the mean values of amplitude, area, SCRs, and SCL and an increase of the latency of SCRs. Mindfulness may lead to reductions in the depression, anxiety, and stress states of individuals and, thus, improve the quality of their lives.

In agreement with previous studies, this work suggests that Mindfulness meditation improves the cognitive appraisal of stressors in healthy individuals [59]. Therefore, these findings present preliminary support to use MBSR programs as a preventive intervention for mental disorders such as depression and anxiety.

One should note that most of the positive effects of practising Mindfulness meditation, as reported in this study, diminish drastically in the last recording session, 2 months after the end of the course. This suggests the need for continuing meditation practises, in order to secure longer lasting effects.

In summary, the results reported in this paper suggest that Mindfulness meditation can promote the emotional regulation necessary to control the reactivity to negatively charged stimuli in our daily lives and consequently improve our well-being. Also, Mindfulness training may be adapted to specific clinical situations, to prevent or even treat specific mental health disorders.

Compliance with Ethical Standards: The study was performed following the ethical standards of the 1964 Helsinki Declaration and its later amendments. Ethical approval for this research was obtained from the Ethics Committee of NOVA School of Science and Technology - NOVA University of Lisbon, Portugal and informed consent was obtained from all subjects included in this study.

Funding: This work was supported by the Fundação para a Ciência e Tecnologia [UIDB/FIS/04559/2020] and [UI/BD/151321/2021].

Compliance with Ethical Standards: The study was performed following the ethical standards of the 1964 Helsinki Declaration and its later amendments. Ethical approval for this research was obtained from the Ethics Committee of NOVA School of Science and Technology - NOVA University of Lisbon, Portugal and informed consent was obtained from all subjects included in this study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A

(See Table A1-A2).

Table A1
Evolution of EDA parameters throughout the 4 sessions of data collection for each kind of stimulus (value ± standard error). Statistically significant variations are highlighted in bold and marked with asterisks. (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

		log(Amp) [log(μS)]		log(Area) [log(μS·s)]		nSCRs		log(Latency) [log (s)]		log(SCL) [log(μS)]	
Animals	Intercept (S1)	**−0.26***	**±0.07**	**0.47***	**±0.06**	**1.90***	**±0.12**	**0.26***	**±0.02**	**1.00***	**±0.03**
	S1 → S2	−0.01	±0.05	0.01	±0.05	−0.01	±0.14	−0.01	±0.02	0.03	±0.02
	S1 → S3	0.00	±0.05	**0.11***	**±0.05**	**0.54***	**±0.14**	**0.07***	**±0.02**	−0.01	±0.02
	S1 → S4	−0.07	±0.06	0.02	±0.06	0.13	±0.15	0.02	±0.02	**0.06***	**±0.02**
Facial Expressions	Intercept (S1)	**−0.47***	**±0.08**	**0.26***	**±0.07**	**1.86***	**±0.13**	**0.28***	**±0.10**	**0.95***	**±0.04**
	S1 → S2	0.00	±0.05	0.03	±0.04	**0.22***	**±0.11**	0.00	±0.09	**0.04***	**±0.02**
	S1 → S3	−0.07	±0.05	0.03	±0.04	**0.33****	**±0.11**	0.02	±0.09	−0.02	±0.02
	S1 → S4	−0.03	±0.05	0.03	±0.05	0.09	±0.12	−0.01	±0.11	**0.07***	**±0.02**
Human Body Suffer	Intercept (S1)	**−0.42***	**±0.09**	**0.31***	**±0.52**	**1.75***	**±0.13**	**0.27***	**±0.02**	**0.95***	**±0.75**
	S1 → S2	−0.07	±0.04	−0.05	±0.30	**0.24***	**±0.10**	0.00	±0.02	−0.03	±0.02
	S1 → S3	−0.08	±0.05	0.00	±0.31	0.01	±0.10	0.03	±0.02	**−0.09***	**±0.33**
	S1 → S4	**−0.34***	**±0.05**	**−0.26***	**±0.34**	−0.04	±0.11	0.01	±0.02	0.00	±0.36
Erotic	Intercept (S1)	**−0.35***	**±0.08**	**0.39***	**±0.07**	**1.86***	**±0.14**	**0.25***	**±0.02**	**0.94***	**±0.04**
	S1 → S2	**−0.12***	**±0.05**	**−0.09***	**±0.05**	0.12	±0.10	**0.03***	**±0.02**	−0.04*	±0.02
	S1 → S3	**−0.21***	**±0.05**	**−0.13****	**±0.05**	−0.13	±0.10	**0.07***	**±0.02**	**−0.08***	**±0.02**
	S1 → S4	**−0.36***	**±0.06**	**−0.30***	**±0.05**	−0.05	±0.11	−0.01	±0.02	**−0.06****	**±0.02**
Human Threats	Intercept (S1)	**−0.47***	**±0.08**	**0.27***	**±0.06**	**2.05***	**±0.16**	**0.24***	**±0.02**	**0.88***	**±0.05**
	S1 → S2	−0.05	±0.05	−0.04	±0.05	−0.07	±0.10	**0.04***	**±0.02**	0.02	±0.02
	S1 → S3	−0.09	±0.05	−0.03	±0.05	**−0.36***	**±0.10**	**0.05***	**±0.02**	−0.04	±0.02
	S1 → S4	**−0.14****	**±0.06**	**−0.12***	**±0.05**	−0.08	±0.12	0.01	±0.02	−0.01	±0.02
Shock and Repulsion	Intercept (S1)	**0.50***	**±0.08**	**0.23***	**±0.07**	**2.13***	**±0.15**	**0.24***	**±0.02**	**0.89***	**±0.84**
	S1 → S2	**−0.10***	**±0.04**	**−0.08****	**±0.03**	−0.12	±0.07	**0.03***	**±0.01**	**−0.07***	**±0.20**
	S1 → S3	**−0.16***	**±0.04**	**−0.07***	**±0.03**	**−0.46***	**±0.07**	**0.08***	**±0.01**	**−0.11***	**±0.19**
	S1 → S4	**−0.12****	**±0.04**	−0.06	±0.04	**−0.18***	**±0.08**	0.01	±0.01	**−0.05***	**±0.21**

Table A2
Evolution of EDA parameters throughout the 4 sessions of data collection for the overall stimuli in females and males (value ± standard error). Statistically significant variations are highlighted in bold and marked with asterisks. (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

		Amp (μS)		Area (μS·s)		nSCRs		Latency (s)		SCL (μS)	
Females	Intercept (S1)	**0.69***	**±0.09**	**3.78***	**±0.41**	**2.02***	**±0.13**	**1.91***	**±0.11**	**8.65***	**±0.95**
	S1 → S2	0.00	±0.03	−0.19	±0.20	**0.25***	**±0.05**	**0.17***	**±0.04**	**0.64***	**±0.16**
	S1 → S3	**−0.18***	**±0.03**	**−1.00***	**±0.19**	−0.07	±0.05	**0.45***	**±0.04**	**0.30***	**±0.15**
	S1 → S4	**−0.19***	**±0.03**	**−0.83***	**±0.22**	**−0.13***	**±0.06**	0.07	±0.05	**−0.47****	**±0.17**
Males	Intercept (S1)	**0.56****	**±0.18**	**2.41***	**±0.63**	**1.95***	**±0.19**	**2.09***	**±0.17**	**12.17***	**±1.25**
	S1 → S2	**−0.07***	**±0.03**	0.03	±0.16	**−0.40***	**±0.06**	0.00	±0.05	**−2.94***	**±0.21**
	S1 → S3	**−0.09****	**±0.04**	−0.10	±0.17	**−0.40***	**±0.07**	**0.12***	**±0.06**	**−3.88***	**±0.23**
	S1 → S4	0.05	±0.04	0.22	±0.18	0.00	±0.07	−0.14	±0.06	−0.13	±0.24

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bspc.2023.105314.

References

[1] World Health Organization, "Comprehensive mental health action plan 2013-2030," 2021. https://www.who.int/publications/i/item/9789240031029 (accessed Apr. 20, 2022).

[2] J.R. Infante, et al., Catecholamine levels in practitioners of the transcendental meditation technique, Physiol. Behav. 72 (1–2) (2001) 141–146, https://doi.org/10.1016/S0031-9384(00)00386-3.

[3] Y.Y. Tang, R. Tang, M.K. Rothbart, M.I. Posner, Frontal theta activity and white matter plasticity following mindfulness meditation, Curr. Opin. Psychol. 28 (2019) 294–297, https://doi.org/10.1016/j.copsyc.2019.04.004.

[4] Y.Y. Tang, B.K. Hölzel, M.I. Posner, The neuroscience of mindfulness meditation, Nat. Rev. Neurosci. 16 (4) (2015) 213–225, https://doi.org/10.1038/nrn3916.

[5] A.H. Mehrsafar, et al., The effects of mindfulness training on competition-induced anxiety and salivary stress markers in elite Wushu athletes: A pilot study, Physiol. Behav. 210 (112655) (2019) 1–10, https://doi.org/10.1016/j.physbeh.2019.112655.

[6] I. Zollars, T.I. Poirier, J. Pailden, Effects of mindfulness meditation on mindfulness, mental well-being, and perceived stress, Curr. Pharm. Teach. Learn. 11 (10) (2019) 1022–1028, https://doi.org/10.1016/j.cptl.2019.06.005.

[7] P.J. Geiger, et al., Mindfulness-Based Interventions for Older Adults: a Review of the Effects on Physical and Emotional Well-Being, Mindfulness (N Y) 7 (2) (2016) 296–307, https://doi.org/10.1007/s12671-015-0444-1.

[8] J.C. Felver, C.E. Celis-de Hoyos, K. Tezanos, N.N. Singh, A Systematic Review of Mindfulness-Based Interventions for Youth in School Settings, Mindfulness N Y), 7 (1 (2016) 34–45, https://doi.org/10.1007/s12671-015-0389-4.

[9] Y. Kang, et al., Gender differences in response to a school-based mindfulness training intervention for early adolescents, J. Sch. Psychol. 68 (2018) 163–176, https://doi.org/10.1016/j.jsp.2018.03.004.

[10] R.A. Heckenberg, M.W. Hale, S. Kent, B.J. Wright, An online mindfulness-based program is effective in improving affect, over-commitment, optimism and mucosal immunity, Physiol. Behav. 199 (2019) 20–27, https://doi.org/10.1016/j.physbeh.2018.11.001.

[11] P. Grossman, L. Niemann, S. Schmidt, H. Walach, Mindfulness-based stress reduction and health benefits: A meta-analysis, J. Psychosom. Res. 57 (1) (2004) 35–43, https://doi.org/10.1016/S0022-3999(03)00573-7.

[12] P. Salmon, S. Sephton, I. Weissbecker, K. Hoover, C. Ulmer, J.L. Studts, Mindfulness meditation in clinical practice, Cogn. Behav. Pract. 11 (4) (2004) 434–446, https://doi.org/10.1016/S1077-7229(04)80060-9.

[13] N. Jadhav, R. Manthalkar, Y. Joshi, Effect of meditation on emotional response: An EEG-based study, Biomed. Signal Process. Control 34 (2017) 101–113, https://doi.org/10.1016/j.bspc.2017.01.008.

[14] S.S. Gupta, R.R. Manthalkar, S.S. Gajre, Mindfulness intervention for improving cognitive abilities using EEG signal, Biomed. Signal Process. Control 70 (2021), 103072, https://doi.org/10.1016/j.bspc.2021.103072.

[15] P. la Cour, M. Petersen, Effects of Mindfulness Meditation on Chronic Pain: A Randomized Controlled Trial, Pain Med. 16 (4) (2015) 641–652, https://doi.org/10.1111/pme.12605.

[16] J. Kabat-Zinn, L. Lipworth, R. Burney, The Clinical Use of Mindfulness Meditation for the Self-Regulation of Chronic Pain, J. Behav. Med. 8 (2) (1985) 163–190, https://doi.org/10.1007/bf00845519.

[17] P. Grossman, U. Tiefenthaler-Gilmer, A. Raysz, U. Kesper, Mindfulness training as an intervention for fibromyalgia: Evidence of postintervention and 3-year follow-up benefits in well-being, Psychother. Psychosom. 76 (4) (2007) 226–233, https://doi.org/10.1159/000101501.

[18] L.E. Carlson, S.N. Garland, Impact of Mindfulness-Based Stress Reduction (MBSR) on Sleep, Mood, Stress and Fatigue Symptoms in Cancer Outpatients, Int. J. Behav. Med. 12 (4) (2005) 278–285.

[19] M. Speca, L.E. Carlson, E. Goodey, M. Angen, A randomized, wait-list controlled clinical trial: The effect of a mindfulness meditation-based stress reduction program on mood and symptoms of stress in cancer outpatients, Psychosom. Med. 62 (5) (2000) 613–622, https://doi.org/10.1097/00006842-200009000-00004.

[20] L. Verastegui-Tena, A. Schulte-Holierhoek, H. van Trijp, B. Piqueras-Fiszman, Beyond expectations: The responses of the autonomic nervous system to visual food cues, Physiol. Behav. 179 (2017) 478–486, https://doi.org/10.1016/j.physbeh.2017.07.025.

[21] P.S. Nijjar, et al., Modulation of the autonomic nervous system assessed through heart rate variability by a mindfulness based stress reduction program, Int. J. Cardiol. 177 (2) (2014) 557–559, https://doi.org/10.1016/j.ijcard.2014.08.116.

[22] Y.Y. Tang, et al., Central and autonomic nervous system interaction is altered by short-term meditation, PNAS 106 (22) (2009) 8865–8870, https://doi.org/10.1073/pnas.0904031106.

[23] W. Boucsein, Electrodermal Activity, 2nd ed. Wuppertal: Springer, 1992. doi: 10.1007/978-1-4757-5093-5.

[24] B.G. Wallin, Sympathetic Nerve Activity Underlying Electrodermal and Cardiovascular Reactions in Man, Psychophysiology 18 (4) (1981) 470–476, https://doi.org/10.1111/j.1469-8986.1981.tb02483.x.

[25] D.J. van der Mee, M.J. Gevonden, J.H.D.M. Westerink, E.J.C. de Geus, Validity of electrodermal activity-based measures of sympathetic nervous system activity from a wrist-worn device, Int. J. Psychophysiol. 168 (2021) 52–64, https://doi.org/10.1016/j.ijpsycho.2021.08.003.

[26] H. Sequeira, P. Hot, L. Silvert, S. Delplanque, Electrical autonomic correlates of emotion, Int. J. Psychophysiol. 71 (1) (2009) 50–56, https://doi.org/10.1016/j.ijpsycho.2008.07.009.

[27] V. Sharma, N.R. Prakash, P. Kalra, Depression status identification using autoencoder neural network, Biomed. Signal Process. Control 75 (2022), 103568, https://doi.org/10.1016/j.bspc.2022.103568.

[28] A. Sobolewski, E. Holt, E. Kublik, A. Wróbel, Impact of meditation on emotional processing-A visual ERP study, Neurosci. Res. 71 (1) (2011) 44–48, https://doi.org/10.1016/j.neures.2011.06.002.

[29] H.F. Posada-Quintero, K.H. Chon, Innovations in electrodermal activity data collection and signal processing: A systematic review, Sensors 20 (2) (2020), https://doi.org/10.3390/s20020479.

[30] C. Kappeler-Setz, F. Gravenhorst, J. Schumm, B. Arnrich, G. Tröster, Towards long term monitoring of electrodermal activity in daily life, Pers Ubiquitous Comput 17 (2) (2013) 261–271, https://doi.org/10.1007/s00779-011-0463-4.

[31] C.N.M. Ortner, S.J. Kilner, P.D. Zelazo, Mindfulness meditation and reduced emotional interference on a cognitive task, Motiv. Emot. 31 (4) (2007) 271–283, https://doi.org/10.1007/s11031-007-9076-7.

[32] B.D. Ostafin, J.J. Brooks, M. Laitem, Affective reactivity mediates an inverse relation between mindfulness and anxiety, Mindfulness (N Y) 5 (5) (2014) 520–528, https://doi.org/10.1007/s12671-013-0206-x.

[33] E. Lampinen, et al., Electrodermal Activity, Respiratory Sinus Arrhythmia, and Heart Rate Variability in a Relationship Enrichment Program, Mindfulness (N Y) 9 (4) (2018) 1076–1087, https://doi.org/10.1007/s12671-017-0843-6.

[34] M.J. Kadziolka, E.A. Di Pierdomenico, C.J. Miller, Trait-Like Mindfulness Promotes Healthy Self-Regulation of Stress, Mindfulness (N Y) 7 (1) (2016) 236–245, https://doi.org/10.1007/s12671-015-0437-0.

[35] B. Brady, C. Gonsalvez, I.I. Kneebone, E. Wufong, P.E. Bailey, Age-related differences in instructed positive reappraisal and mindful attention, Mindfulness (N Y) 12 (3) (2021) 646–658, https://doi.org/10.1007/s12671-020-01523-2.

[36] M.M. Bradley, P.J. Lang, The International Affective Picture System (IAPS) in the Study of Emotion and Attention, in: J. Coan, J. Allen (Eds.), HandBook of Emotion Elicitation and Assessment, Oxford University Press, 2007, pp. 29–46, https://doi.org/10.1088/1751-8113/44/8/085201.

[37] University of Florida, The Center for the Study of Emotion and Attention -International Affective Picture System (IAPS), (accessed Feb. 14 (2016) 2021). https://csea.phhp.ufl.edu/media.html#topmedia.

[38] P.F. Lovibond, S.H. Lovibond, The structure of negative emotional states: Comparison of the depression anxiety stress sclares (DASS) with the Beck Depression and Anxiety Inventories, Behav. Res. Ther. 33 (3) (1995) 335–343, https://doi.org/10.1007/BF02511245.

[39] I.N. Beaufort, G.H. De Weert-Van Oene, V.A.J. Buwalda, J.R.J. De Leeuw, A. E. Goudriaan, The Depression, Anxiety and Stress Scale (DASS-21) as a Screener for Depression in Substance Use Disorder Inpatients: A Pilot Study, Eur. Addict. Res. 23 (5) (2017) 260–268, https://doi.org/10.1159/000485182.

[40] J.L. Pais-Ribeiro, A. Honrado, I. Leal, Contribuição para o estudo da adaptação portuguesa das escalas de ansiedade, depressão e stress (EADS) de 21 itens de Lovibond e Lovibond, Psicologia, Saúde & Doenças 5 (2) (2004) 229–239, https://doi.org/10.1016/j.ajp.2020.102014.

[41] S.J. Sinclair, C.J. Siefert, J.M. Slavin-Mulford, M.B. Stein, M. Renna, M.A. Blais, Psychometric Evaluation and Normative Data for the Depression, Anxiety, and Stress Scales-21 (DASS-21) in a Nonclinical Sample of U.S. Adults, Eval. Health Prof. 35 (3) (2012) 259–279, https://doi.org/10.1177/0163278711424282.

[42] M.M. Antony, B.J. Cox, M.W. Enns, P.J. Bieling, R.P. Swinson, Psychometric properties of the 42-item and 21-item versions of the Depression Anxiety Stress Scales in clinical groups and a community sample, Psychol. Assess. 10 (2) (1998) 176–181, https://doi.org/10.1037/1040-3590.10.2.176.

[43] K.N. Tonsing, Psychometric properties and validation of Nepali version of the Depression Anxiety Stress Scales (DASS-21), Asian J. Psychiatr. 8 (1) (2014) 63–66, https://doi.org/10.1016/j.ajp.2013.11.001.

[44] J. Vasconcelos-Raposo, H.M. Fernandes, C.M. Teixeira, Factor structure and reliability of the depression, anxiety and stress scales in a large Portuguese community sample, Span. J. Psychol. 16 (2013) 1–10, https://doi.org/10.1017/sjp.2013.15.

[45] J.R. Crawford, J.D. Henry, The Depression Anxiety Stress Scales (DASS): Normative data and latent structure in a large non-clinical sample, Br. J. Clin. Psychol. 42 (2) (2003) 111–131, https://doi.org/10.1348/014466503321903544.

[46] PLUX Wireless Biosignals, “OpenSignals (r)evolution - User Manual,” 2019. https://bio-medical.com/media/support/biosignalsplux_explorer_user_manual_v.1.0.pdf (accessed Apr. 10, 2020).

[47] J.C. Pinheiro, D.M. Bates, Mixed-Effects Model in S and S-PLUS, Springer, New York, 2000.

[48] D. Bates, M. Mächler, B.M. Bolker, S.C. Walker, Fitting linear mixed-effects models using lme4, J. Stat. Softw. 67 (1) (Oct. 2015), https://doi.org/10.18637/jss.v067.i01.

[49] J. Z. Bakdash, L. R. Marusich, “Repeated measures correlation,” Front Psychol, vol. 8, no. MAR, Apr. 2017. doi: 10.3389/fpsyg.2017.00456.

[50] M. Ben-Shachar, D. Lüdecke, D. Makowski, effectsize: Estimation of Effect Size Indices and Standardized Parameters, J Open Source Softw 5 (56) (Dec. 2020) 2815, https://doi.org/10.21105/joss.02815.

[51] A. Kassambara, Practical Statistics in R for Comparing Groups: Numerical Variables, Independently Published (2019).

[52] P. Morais, A. Pinheiro, M. Fonseca, C. Quintão, The Mindfulness Meditation Effect on States of Anxiety, Depression, Stress and Quality of Life, in: Proceedings of the 15th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC), 2022, pp. 573–582, https://doi.org/10.5220/0010854900003123.

[53] G. Desbordes, L.T. Negi, T.W.W. Pace, B. Alan Wallace, C.L. Raison, E.L. Schwartz, Effects of mindful-attention and compassion meditation training on amygdala response to emotional stimuli in an ordinary, Nonmeditative State, Front. Hum. Neurosci. 6 (OCTOBER) (2012) 1–15, https://doi.org/10.3389/fnhum.2012.00292.

[54] A. Moore, T. Gruber, J. Derose, P. Malinowski, Regular, brief mindfulness meditation practice improves electrophysiological markers of attentional control, Front. Hum. Neurosci. 6 (2012) 1–15, https://doi.org/10.3389/fnhum.2012.00018.

[55] L. Roemer, S.K. Williston, L.G. Rollins, Mindfulness and emotion regulation, Curr. Opin. Psychol. 3 (2015) 52–57, https://doi.org/10.1016/j.copsyc.2015.02.006.

[56] H. Uusberg, A. Uusberg, T. Talpsep, M. Paaver, Mechanisms of mindfulness: The dynamics of affective adaptation during open monitoring, Biol. Psychol. 118 (2016) 94–106, https://doi.org/10.1016/j.biopsycho.2016.05.004.

[57] K. Bluth, P.N.E. Roberson, S.S. Girdler, Adolescent Sex Differences in Response to a Mindfulness Intervention: A Call for Research, J. Child Fam. Stud. 26 (7) (2017) 1900–1914, https://doi.org/10.1007/s10826-017-0696-6.

[58] R. Rojiani, J.F. Santoyo, H. Rahrig, H.D. Roth, W.B. Britton, Women benefit more than men in response to college-based meditation training, Front. Psychol. 8 (2017) 1–11, https://doi.org/10.3389/fpsyg.2017.00551.

[59] D. Katz, B. Toner, A Systematic Review of Gender Differences in the Effectiveness of Mindfulness-Based Treatments for Substance Use Disorders, Mindfulness (N Y) 4 (2013) 318–331, https://doi.org/10.1007/s12671-012-0132-3.