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Mindfulness-based Emotional Acceptance in Combination with Neurofeedback for Improving Emotion Self-Regulation: a Pilot Study.

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A feasibility of Mindfulness-based *emotional acceptance* in combination with neurofeedback for improving *emotion self-regulation* is presented. The study was performed using a low-cost wearable system designed to perform electroencephalography (EEG) outside the clinical setting. The focused EEG feature is the beta-band Power Spectral Density along the midline (FCz-CPz electrodes). Four subjects new to the practice of mindfulness were involved in the experiments. A comparison between two neurofeedback conditions (in a within-subject design) is performed: a) cognitive reappraisal task; b) emotional acceptance task. In both cases the expected decrement of PSD in high-beta band linked to the neurofeedback training was found. Emotional acceptance in combination with neurofeedback emerged as a promising emotional regulation strategy.

I. Introduction

Emotion regulation encompasses a series of processes by which a subject consciously or unconsciously modulates the trajectory of his/her emotional state in order to respond to specific demands. Deficits in emotion regulation appear to be linked to a whole range of psychopathological conditions (such as depression [1], addiction [2], borderline personality disorder [3]) and their study is well advanced in the literature with the aim of treating a wide range of mental disorders [4], [5], [6]. Among the various strategies the one based on cognitive reappraisal has received particular interest [7], [8]. This strategy involves an explicit alteration of the meaning (in terms of evaluation) of a given emotional stimulus, aimed at varying its emotional impact on the subject.

Considered as the process of 'paying attention in a particular way: on purpose, in the present moment and without judgement', mindfulness has recently been identified as a potentially effective emotion regulation strategy [9]. Mindfulness itself emphasises the full acceptance of all emotional experiences, the act of allowing, with a non-judgmental attitude, the present experience (emotional acceptance) [8]. Acceptance is positioned as a particular regulation strategy that focuses on the emotional response, which confronts the experience of emotion without any attempt at control or suppression [10]. Neurofeedback is a widely used tool for emotion regulation and has become the subject of extensive study in recent years [11]. EEG-based brain-computer interfaces (BCIs) allow the measurement and decoding of emotional states in real time and support individuals to regulate their emotions. There are several applications of neurofeedback in the clinical field for the treatment of various disorders, including ADHD [12], sleep disorders [13] and self-regulation of emotional behaviour [14]. Neurofeedback applied for emotional regulation purposes has numerous successful examples in the literature, and has been exploited for the treatment of various psychopathologies (ie. schizophrenia [15], anxiety [16], [11] and depression [17]) and for stress reduction [18]). Also in Mindfulness scenarios, neurofeedback interventions have proven effective in supporting practice in real-time adaptive experiences [19], [20].

Generally, most EEG-based neurofeedback methods in the field of emotional regulation work by regulating the frequency of brain activity in specific regions of the scalp. In [15] frontal delta asymmetry is used in order to rebalance the hemispheres: the authors jointly use functional near-infrared spectroscopy and EEG to perform emotional neuroregulation on a group of 18 subjects with schizophrenia. Frontal alpha power and frontal alpha asymmetry were used in [18] for stress treatment, in [11] for anxiety reduction, and in [21] to evaluate the impact of neurofeedback on mood regulation. In [22] high-beta band asymmetry is successfully exploited by achieving significant upregulation on subjects with major depressive disorder, while in [23] frontal beta activity is exploited by neurofeedback training to evaluate long-term effects on a sample of 25 healthy subjects. In [24] neurofeedback is applied on anxious patients, exploiting alpha-, beta- and alpha-theta-band power in the Pz and Fz positions.

In this pilot study, a neurofeedback solution using a real-time EEG-based BCI system to allow users to effectively regulate their emotions is presented. The focus was on beta-band power along the midline (cFz-cPz electrodes). Clinical research shows that an excess of such beta activity is associated with an increase in state anxiety [25]. Specifically, the aim of the study is to perform a comparison between two neurofeedback conditions (in a within-subject design): a) cognitive reappraisal task; b) emotional acceptance task.

In Section 2, the overall neurofeedback system, the experimental campaign for the EEG signal acquisitions, and the EEG data analysis procedures are presented. The EEG data analysis are reported in Section 3. Discussions is illustrated in Section 4, outlining the strengths and major limitations that will guide future developments of the study.

II. Material and Methods

A. Neurofeedback system

The proposed system consisted of a computer application connected to an EEG headset. The application showed on the monitor random sequences of negative stimuli, in accordance with the experimental protocol. The database IAPS [26] was chosen to elicit an emotional response, negative emotions, from participants. IAPS is a standardized database that includes images categorized as pleasant, neutral, or unpleasant. We used images with neutral arousal and negatively polarized on the valence axis; specifically, negative images with a valence score < 4 on the IAPS scale were chosen.

During regulation, a color bar put on the right hand side and a frame placed around the image provided a feedback to the user about his progress. Fig. 1 shows the neurofeedback application. According to the measured value of the EEG feature to regulate, the color bar and the frame change their colors following the color scale suggested by [27] (Fig. 2). The heights of the bars were updated every 1-s. The proposed applications were developed using Unity [28] (version 2019.4.4f1, Personal 64 bit for Microsoft Windows) as game engine.

Fig. 1: Provided visual feedback

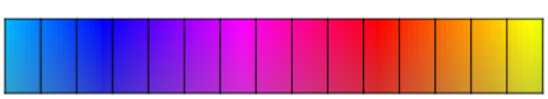

Fig. 2: Color scale

EEG data were acquired with the Flex EEG™from Neuroconcise [29]. The EEG acquisition system is show in Fig.4. Signal were recorded from the threebipolar channels Fc3-Cp3, Fcz-Cpz, and Fc4-Cp4 placed following the 10/20 International Positioning System Fig.5. The bias electrode is located in the Afz position. Electrolyte gel was used to increase conductivity. The signal was wireless transmitted via Bluetooth 2.0 with an adjustable sampling rate (125Hz-250Hz) and ADC resolution (16-24 bits). The EEG data were acquired, transmitted and real time processed with Matlab R2021b. The Flex EEG is equipped with a Matlab script for the parameters setting and with default Simulink model to run the device.

The online processing of the EEG signals was carried out in Simulink environment. A bandpass filter between $[20-34]Hz$ was used for getting the band of interest.

After, $2s$ epochs overlapping of $1s$ were extracted. The Fast Fourier Transform (FFT) algorithm was then applied to the epochs to compute the power values in the considered EEG band. The aim of the neurofeedback training was to decrease the high-beta power in midline locations (Fcz-Cpz) [30]. Each session was made of an initial calibration phase and a training phase. The calibration allowed to adapt the neurofeedback session to the current user and consisted of (a) $2min$ eyes open resting state and (b) a task-related baseline [15]. The mean high-beta powers of the neurofeedback electrodes were computed for both the rest and the baseline. These values were used to fix the upper and lower limits of the color scale, respectively. Also in the training phase, the EEG data were online processed. The high-beta power related to the Fcz-Cpz electrode was used to update the visual feedback provided to the user. Simulink sent to Unity the values of the reference feature computed in the rest and baseline phases, as well as the current values related to the neurofeedback training. These values were employed by unity to set the parameters' application and to update the feedback to the user. Unity also fixed the start and end times of each phase. Simulink and Unity communicated via UDP protocol.

The study was a within-subject trial of four participants (three males and one female, mean age 33.75), healthy, right-handed and with normal or corrected to-normal vision, who took part in this experiment after having signed an informed consent, in order to carry out a preliminary validation. All subjects were not familiar with emotion-related BCI experiments. A local ethics committee approved the experimental protocol and the entire experiment was conducted at the Augmented Reality for Health Monitoring Laboratory (ARHeMLab, University of Naples Federico II) in Italy, in compliance with legal requirements and in accordance to the declaration of Helsinki.

B. Procedure

The participants completed six neurofeedback sessions. Before starting the experiments, information and instructions about the activity were provided to the subjects. More in details, in three sessions, participants were instructed to make use of neurofeedback in conjunction with a regulation strategy based on Cognitive Reappraisal, for which a script with

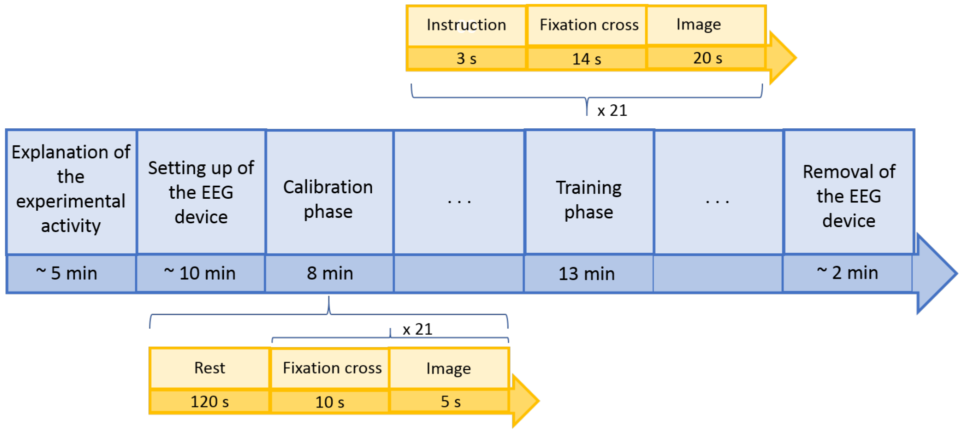

Fig. 3: Experimental protocol

Fig. 4: EEG acquisition system

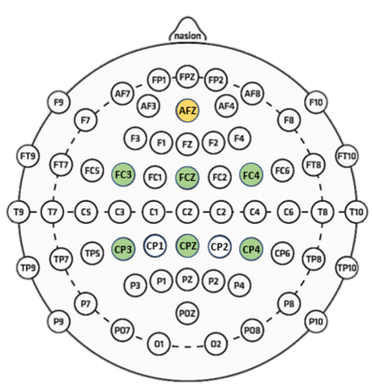

Fig. 5: Electrodes placement of the EEG acquisition system

instructions to follow was given, possibly providing clarification to possible doubts or misgivings; in the remaining three sessions, the regulation strategy given was the Emotional Acceptance one (scripts for both strategies are presented in Fig. 6).

Each subject participated to all sessions and they were randomly separated into two different groups: subjects referred to as SO1 and SO2 (2 males, mean age 34.5) started with the Cognitive Reappraisal strategy condition in their first three sessions, followed by the Emotional Acceptance strategy condition; subjects referred to as SO3 and SO4 (one male and one female, mean age 27.5) received a reversed treatment, starting with the EA strategy condition and then switching to the CR strategy condition in their last three sessions. In addition, each session provides the user with different IAPS images in the various phases of the experiment; the sequence was randomised in order to avoid multiple participants viewing the same images in the same phase of the experiment. All the sessions were carried out at the Arhemlab laboratory of the University of Naples Federico II. To avoid disturbing elements, the activity was conducted in a dark and soundproofed environment. Participants were asked to sit on a comfortable chair and positioned approximately 70 cm away from a monitor (16" size). The researchers installed the EEG device, filled the electrodes with conductive gel and performed a visual check on the signal quality. Participants were also instructed to limit body movements during the experiments.

An ad-hoc experimental protocol was realized for the purpose of the study following [31], [32]. The aim of the experiment was to decrease the high-beta power value registered in Fcz-Cpz position with respect to the baseline while watching negative images. The color bar and the frame provide to the subject real time information about the progress and the achievement.

Each neurofeedback session was divided in two phases: an initial calibration phase and a neurofeedback training phase. The calibration phase was made of (a) 120-s of opened-eyes resting state and (b) of a negative baseline consisting of the projection of 21 images, each lasting 5-s and preceded by 10-s fixation cross. During the calibration phase, the subjects had to relax himself and after, to passively watch at the projected images.

The training phase consisted of 22 trials organized in 14 regulation trials, 7 only vision trials and a final transfer run trial. During the regulation trials, subjects were required to adjust their emotions according to the provided visual feedback. During the only vision trials, subjects were required to passively watch at the projected images. During the final transfer run, the subjects were asked to regulate their emotion but without the feedback. Regulation trials and only vision trials were presented in a random order to participants. Regulation trials were preceded by 3-s instruction about the following

Strategy	Instructions
Cognitive Reappraisal	"When looking closely at images, try to relate to them as detachedly as possible, with an attitude that is as 'at a distance', objective and unemotional towards them. To favour this way of experiencing the images, you could for example put yourself in the shoes of a professional, e.g. an art critic who, during a selection of photos, focuses on technical aspects of the events shown such as the dynamism of the images and the interweaving of shapes and colours in them. It is very important that you do your best to adopt a neutral attitude towards images. Another example in this respect is that of a doctor's detached attitude when observing different aspects of a patient's condition. In other words, when looking at images, try to consider them objectively and analytically rather than personally or in a way that may be emotionally involving for you. Thus, look carefully at the images, but consider as much as possible what you see in a way that does not arouse any emotion in you".
Emotional Acceptance	"It is very important that, when looking closely at the images, you do your best to accept every emotional response you may experience. Immerse yourself completely in viewing the images, allowing yourself to experience internally and express externally each emotion that arises. Rather than attempting to control your emotions, imagine that each emotion that arises within you is like a cloud passing across the sky - a natural phenomenon that comes and goes without any attempt to influence it. Let the emotions flow freely through the space of your experience in the present moment, being aware of how these emotions influence thoughts and reactions. Therefore, limit yourself to fully observing the different aspects of what you experience in response to the images presented, rather than judging whether a particular emotion experienced is 'good' or 'bad', 'wanted' or 'unwanted'. Should you observe that you are beginning to make a judgement or control of an emotional reaction you have experienced, quietly limit your noticing by returning your focus to observing and accepting any reaction to the images presented".

Fig. 6: Instruction scripts for the two emotion regulation strategies: Cognitive Reappraisal and Emotional Acceptance.

Fig. 7: Neurofeedback phase during the experiment.

task and 14-s fixation cross. The image projection lasted 20 s. In Fig. 3, the overall experimental procedure is reported.

During the regulation phase, subjects had to adjust the felt emotion following the provided visual feedback. Specifically, the aim was to down regulate the activation of the region of interest guided by the visual feedback. Subjects were instructed to turn both the color of the frame and the color of the progress bar to yellow and to keep that level as much as possible.

The Italian version of the System Usability Scale (SUS) [33], was employed to evaluate the usability of the proposed neurofeedback system.

III. Results

EEG tracks were processed based on epochs of 2 s. The high-beta (20.5–28 Hz) power spectral density (PSD) was calculated from the signal acquired over FCz and Cpz positions (according to the *International 10/20 System*). Moreover, the median values of PSD among the epochs was computed for (i) the calibration fase (a), namely resting state (MRS) and (ii) for the calibration fase (b), namely baseline, (MB). In Fig. 8 the box plots of the PSD for the training epochs of the four subjects are showed. In the box plots MRS (pink) and MB (green) are reported to compare the PSD trend between calibration and training phase. For all the subject, a decrement of PSD median can be appreciated during the training with respect to the calibration phase, with the exception of the first session for subject 1 and 3. Subject 2 exhibited low variability between calibration and training phases for all the sessions. The higher variability was found in subject 3.
Data of SUS scores (2D versus VR) were analyzed via the Wilcoxon signed-rank test. The SUS results indicated that the usability of system is marginal acceptable (M=63.75; SD=14.22).

IV. Discussion

The expected decrement of PSD in high-beta band linked to the neurofeedback training [11] was found for three subjects. The different trend exhibited from two subjects in their first session can be related to a *warm-up* for inexpert neurofeedback users. The fourth subject, namely subject 2, can be excluded from the analysis for sensitivity issues. Likely confirming this, subject 2 was the only one who stated that the stimuli offered were particularly unevocative. He explicitly affirmed: ”*I find that the images are stylistically and thematically very outdated; moreover, they refer to a world (that of American culture and imaginary) that I find very distant from our own*”. Despite the small size of the experimental sample, it is interesting to highlight that the greatest variability of the PSD was exhibited by the only woman included in the study. As emerged from SUS results all the participants found almost usable the neurofeedback training. With regard to the strategies proposed for emotional regulation, subjects generally found more difficult to implement the Emotional Acceptance strategy than the Cognitive Reappraisal strategy. None of the participants, indeed, had previous experience as mindfulness practitioner. Nonetheless, according to a visual inspection of the boxplots, in both cases the trend of PSD seems to be similar. Therefore, Emotional acceptance in combination with neurofeedback emerged as a promising emotional regulation strategy. Better result can be obtained if neurofeedback will be preceded by appropriate mindfulness training. Future work can deep the effectiveness of on larger experimental sample.

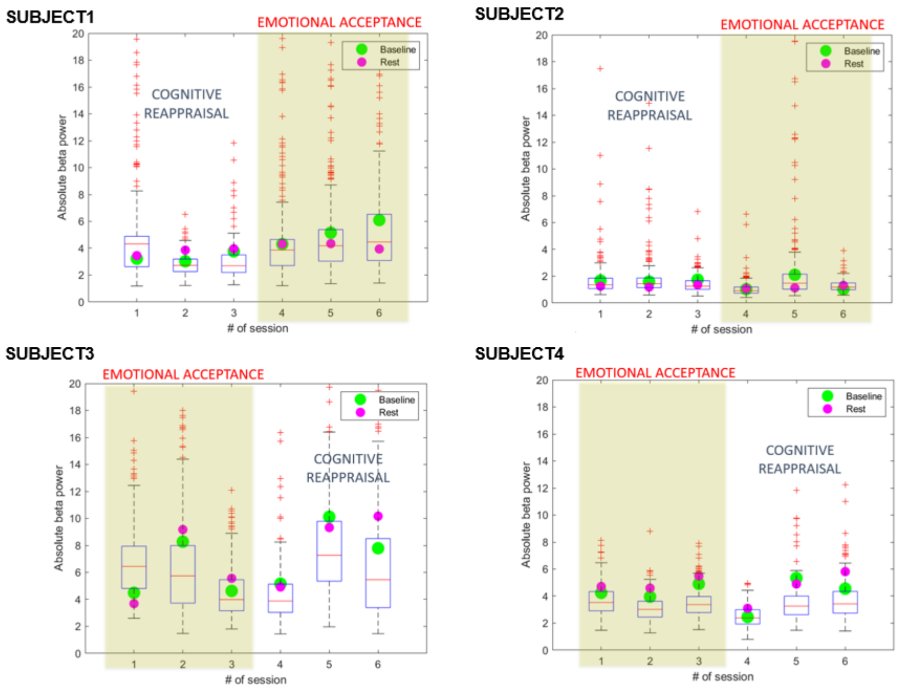

Fig. 8: Boxplot of high-beta power from midline locations (FCz-Cpz) computed during the Neurofeedback training for the six sessions (Emotional Acceptance and Cognitive Reappraisal sections are highlighted). The resting-state and the baseline values are also reported.

The observed modulation of high-Beta PSD is inferentially assumed to be linked to the emotional state. A limitation of this study is the absence of a subjective report from the participants on their mood state (ie. Self Assessent Manikin, Positive and Negative Affect Schedule, etc.). Future developments could consider the use of these psychometric tools in order to better investigate a possible correlation between the EEG features considered and the regulation of specific emotional states.

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