EEG and HRV-Based Assessment of Neurosurgeons Training for Anxiety Regulation and Stress Monitoring

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A neurofeedback (NF) -supported training is proposed to enable neurosurgeons to learn how to regulate their emotions. Electroencephalographic (EEG) signal and heart rate (HR) of 5 neurosurgeons were acquired in 4 sessions while performing NF-based emotion regulation (ER). Subjects tried to counteract anxious and stressful states through NF, that is by decreasing the power in the beta band measured in the midline areas of the scalp. The assessment of the neurofeedback effectiveness was based on the use of Heart Rate Variability (HRV) in combination with EEG. Therefore, EEG signal was exploited in real-time to guide the feedback and also in post processing, together with the HRV, to assess the effectiveness of the whole training. As the EEG signal is concerned, the results showed that the power in the beta band decreased within each session when the ER ability was strengthened, as reported in the literature. On the contrary, the HRV did not exhibit the expected increasing trend within each trial. When considering each the session on the whole, thus computing the HRV on a greater time interval, the HRV during the NF training is typically higher than the HRV computed during the rest and negative baseline phases.

***Index Terms*—Neurofeedkack, EEG, HRV, emotion regulation, surgery**

I. Introduction

The neurosurgeon deals with the surgical treatment of problems related to the Central and Peripheral Nervous System. For this reason, the neurosurgeon should have technical skills (e.g. procedural competence, fine motor skills), and should also maintain the mental attention. In addition, the neurosurgeon should be able to control emotions, such as anxiety or stress. In fact, in the literature there are several studies that show how stress, worry, fear of failure can compromise the performance of an intervention. For example, severe bleeding of the patient can lead to acute stress that can affect the neurosurgeon's bimanual psychomotor performance [1]. The perceived level of anxiety can also lead to a decline in overall performance [2]. Anxiety can be also responsible for the increase of the operator's physiological tremor [3]. Thus, it is important to manage and regulate emotions for the neurosurgeons. Emotional regulation (ER) is the ability to monitor and modulate one's emotional states. There are several ER strategies, in particular Gross [4], [5] defined five ER processes which are: situation selection, situation modification, attentional deployment, cognitive change, and finally the modulation of the emotional response that occurs after the responses have been generated. These processes include cognitive strategies (e.g. cognitive reappraisal or distancing) or behavioral (e.g. running) that induce control of one's emotions. The cognitive reappraisal, in particular, consists in the reevaluation of a given situation to change the type of emotional response. Therefore, with ER and mental training the individual learns to interpret situations in such a way as to bring the possible negative reaction to positive (e.g. focusing on positive and successful mental images, rather than failure). This means that stress can be mediated by cognitive abilities, as was found in [6]. For example, according to Folkman et al. [7] there are two primary approaches to regulate stress: (i) coping, and (ii) cognitive assessment with which the individual develops situational awareness and subsequently generates the ability to cope with this situation [8]. The approach implemented in this study for the regulation of emotions (e.g. anxiety) was neurofeedback (NF) which was found to be a useful technique in cognitive and performance improvement [9], [10]. NF is a biofeedback approach, based on electroencephalogram (EEG) measurement, and provides the user with information about the functioning of his nervous system and neural electrical activity [9], [11]. The subject learns how to influence his neural electrical activity thanks to a visual or auditory representation in real time of this activity, allowing a self-regulation [12]. In fact, there are studies that show the association between emotions and brain activity patterns (e.g. [13]). As expressed in [14], the right hemisphere is associated with the processing of negative emotions, while the left hemisphere processes positive emotions. In addition, negative emotions lead to activation in the right prefrontal cortex and also in the amygdala. In subjects in a state of anxiety, a decrease in beta/delta coherence was detected, and beta activity increased in the central area of the frontal cortex. However, as described in [15], emotional states of anxiety or stress can also be detected by biosignals other than EEG, such as the Electrocardiogram (ECG). In fact, such emotions can induce the physiological response by the Autonomic Nervous System (ANS), leading to changes in sympathetic-parasympathetic activity. This involves, among the various mechanisms that are activated, also an increase in the Heart Rate (HR) and a decrease in the Heart Rate Variability (HRV). Furthermore, there are multiple studies that affirm a relationship between the regulation of emotions and HRV: HRV increases when there is a successful regulation of emotions both through suppression and reappraisal. [16], [17]. In addition, according to the neurovisceral integration model, there is a correlation between vagal tone and, for example, the regulation of emotions: the higher the vagal tone [18], the more successful the subject is in regulating his emotions. For this reason, this study analyzed the Root Mean Square of Successive Differences (RMSSD), an index in the time domain of HRV that reflects vagal tone.

The current study aims to investigate the effectiveness of the NF approach for the regulation of emotions applied to neurosurgeons by combining EEG and HRV. Applications of ER strategies on surgeons found in the literature are reported in Section II. In Section III the information about the participants, the hardware used, the software, the experimental protocol, and the signal processing are described. In Section IV, the results obtained are explained.

II. Background

In the literature, some studies defined strategies that can relieve anxiety and stress in surgeons. In [19] Mental Practice (MP) training (exploiting the concept of mental images) is applied to mitigate the component of anxiety or acute stress in surgeons, and, consequently, avoid a drop in performance. The experiment took a randomized sample of 20 novice surgeons (divided into MP group and control group), who performed 5 laparoscopic cholecystectomy surgeries in virtual reality (VR). Subjects completed the State Trait Anxiety Inventory (STAI) questionnaire to provide a subjective assessment of stress, and heart rate (HR) and cortisol present in saliva were acquired. In addition, they completed the Mental Imagery Questionnaire (MIQ). A descriptive analysis based on a Mann-Whitney test was performed to evaluate the difference between the analyzed stress indices, and on the Spearman rho correlations to analyze the relationship between images and stress for each session. A decrease in the response to both neuroendocrine and cardiovascular stress was found. In [20], a stress management program for surgical residents is presented. 137 surgeons were examined over 5 years. Only 65 subjects (the intervention group) were trained in focus, visualization, self-awareness, to learn how to deal with stress in a surgical simulation in virtual reality. All subjects then had to complete a simulation, which consisted in defining the diagnosis and management of a lethal problem for the patient. Physiological (HR and salivary cortisol) and subjective (STAI and the Stress Scale Survey) indices were acquired to measure anxiety. Time to diagnosis and technical accuracy were assessed using the Objective Structured Assessment of Technical Skill (OSATS) Procedural Checklist. From the Fisher's exact test, there were no differences in physiological anxiety indices between the intervention and control groups. Instead, the intervention group provided an accurate diagnosis with a faster time. In [21], a study for stress management associated with surgical performance is conducted through 3 training sessions. Two groups were examined: an experimental one consisting of 11 subjects and a control group of 15 subjects, both subjected to simulation with the objective and subjective measure of stress, also in this case. The Wilcoxon ranks sum test and the independent t-test were employed to evaluate differences between groups. A performance score was obtained in the experimental group 5% higher than in the control group. However, even in this study, no difference was reported between the two anxiety groups in either STAI or HR. In cite [22], a new mode of stress management is introduced, namely the Stress Management Training (SMT). The number of surgeons analyzed was 16, divided into intervention group and control group. The intervention group performed training based on coping strategies, mental and relaxation strategies. Performance during simulations that were evaluated by experts, stress through STAI, HRV and salivary cortisol, evaluation by observers were measured. Qualitative analysis achieved improvements in decision-making and technical capabilities, while a t-test was conducted to evaluate within-subject changes and a multiple linear regression analysis to evaluate the between-subject effects. The intervention group reported an increase in coping skills and a decrease in stress induced in HRV. Instead, example of training based on NF applied to surgeons is reported in [23]. Two NF EEG protocols are described: Sensory Motor Rhythm-Theta (SMR) consisting of increasing low beta (12–15 Hz) and simultaneously suppressing theta activity (4–7 Hz), and Alpha-Theta (AT) consisting of increasing theta-alpha ratio, for the evaluation of their effectiveness in increasing surgical abilities. 20 ophthalmic microsurgeons were examined. The surgical procedure consisted of an EEG-training of eight 30-minute sessions. Performance was measured in terms of time spent performing the task, and the technique was evaluated by two experienced surgeons. Subjects self-reported Spielberger's State and Trait Anxiety Inventory. During SMR NF, the subject varied bandwidth in real time thanks to visual feedback shown on a computer display. A correlation analysis was chosen to analyze the relationship between the learning indices of each protocol and performance change score. With SMR training there was an improvement in surgical performance compared to the control group. Also, the trait-anxiety decreased. With AT training, the increase in theta-alpha ratio was positively correlated with improvements in overall technique. Our study, unlike those found in the literature, tested the NF technique on neurosurgeons, evaluating the effectiveness of training with both EEG and HRV features. Therefore, while the works found focused on the effectiveness of other ER techniques by testing mainly HR, or on the effectiveness of NF tested with EEG features alone, in our case HRV was employed in addition to EEG.

III. Materials and Methods

A. Participants

5 participants (age 29.2 ± 1.8; 3 males and 2 females) were involved in the experimental activities. All subjects were postgraduate neurosurgery students from different European countries. Subjects had never participated in experiments involving EEG-based emotion regulation. The participants were instructed on the purpose of the experiment and informed on the benefits and the risks of the experimental procedure. Ethical approval was provided by the University of Naples ”Federico II”. Prior informed consent to participate was signed by all the subjects.

B. Hardware

EEG data were acquired with the *ab medica Helmate* [24]. The Helmate (see Fig.1a) is equipped with 10 dry conductive-rubber electrodes [25], coated with Ag/AgCl (see Fig.1b). The channels are placed in accord with the 10/20 International Positioning System (Fp1, Fp2, Fz, Cz, C3, C4, O1, and O2), with AFz the reference and Fpz the ground. The Helmate presents the ADS1298 analog front-end of Texas Instruments, that is a 8-channel, 24-bit, $\Delta\Sigma$ analog to digital converter (ADC). The sampling rate at which the EEG signals are acquired is 512 Sps, moreover, the signals are filtered and amplified with a nominal pass-band from $[0.2, 70]$ Hz. The data is transmitted thanks to the Bluetooth connection, is displayed in real time with the Helm8 software manager, which also allows the user to check the contact impedance between the scalp and the electrodes and perform a non-complex pre-processing of the signals.

(a) EEG cap (b) Dry electrodes

Fig. 1: EEG acquisition system.

The heart rate measurement was performed with the chest strap *Polar H10* [26] at the sampling frequency of 1 Sps. Polar H10 is characterized by an internal memory and it uses Bluetooth and ANT+TM for data transfer. In addition, it can be synchronized to any app for reading HR data. The figure Fig. 2 shows the Polar H10 sensor.

C. Software

A 2D-NF system was developed and IAPS images [27] with negative valence and high arousal were used to stimulate emotional states of anxiety. The application used (see Fig. 3) was developed as game engine with Unity (version 2019.4.4f1,

Fig. 2: Polar H10

Personal 64 bit for Microsoft Windows) [28]. The feedback action was implemented by showing on screen a colour bar on the right hand side and a frame placed around the images, which changed color while adjusting the emotions [29]. The colours ranged from blue to yellow, according to the colour scale that was proposed by [30] (see Fig. 4). Blue and yellow represented a low and high control of the emotional state experienced, respectively, depending on registered cortical activation. Based on the level adjustment of the EEG feature, the height level of the colour bar was updated every 1-s.

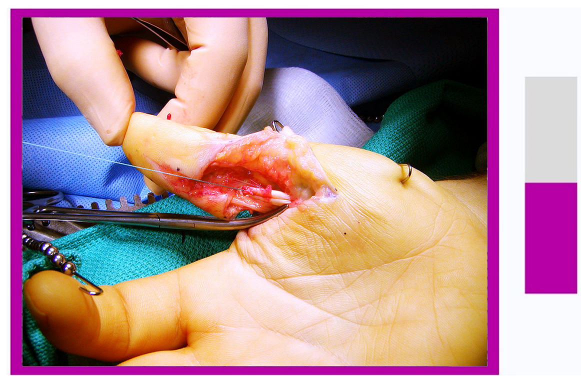

Fig. 3: 2D feedback

Fig. 4: colour scale

Simulink was employed for the EEG signal acquisition, transmission, and online processing. Unity sent Simulink start and end messages for each task via UDP protocol and Simulink returned the values of the reference feature (high-beta power computed over the Fz electrode) in order to update the visual feedback in real time.

D. Protocol

Participants performed 4 NF sessions on two consecutive days, in particular one session in the morning and one in the afternoon. Each session included four phases: the resting phase with open eyes of the duration of 90 s. Next, the registration phase of the task-related baseline [31] which consisted of 5 s fixation cross (to focus the subject’s gaze in the center of the screen) and 5 s visualization of the image, for a total of 21 random images. These first two phases represented the calibration phase. Starting from the average values of high-beta powers measured in the resting phase and during the baseline phase, the high and low limits of the colour scale were defined respectively. At this point, the NF training started, and during the visualization of the images the user was provided with a visual feedback depending on the high-beta power obtained on the Fz electrode. At this step, 21 images were shown, of which 14 with NF, for 20 s, and preceded by a fixation cross of 10 s. At the beginning of each task the user was informed how to perform the task. Finally, the last phase consisted of the transfer run, during which the subject had to complete the task but without NF. The experimental protocol is reported in Fig.5.

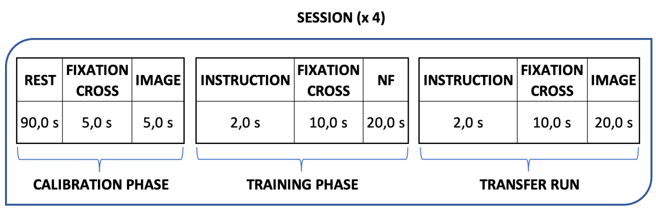

Fig. 5: Experimental protocol

E. Signal processing

Data were first filtered between 20 Hz and 34 Hz by using a bandpass filter, and then 2-s epochs overlapping of 1-s were extracted. The power values in the considered EEG band were extracted in each epoch through the Fast Fourier transform (FFT). The HR signal was converted into RR intervals according to the reciprocity relationship of the two. Next, the HRV in terms of RMSSD for each image was obtained.

Given the aim of this study, the trends of the average beta band power and the RMSSD, as the images progress, were analyzed for each session. Starting from the hypothesis according to which the subject, having to learn a strategy useful for the regulation of emotions, performs better as the number of images proposed to him increases. In this context, one would therefore expect a decrease in the average beta band power and an increase in the RMSSD, as reported in the literature, as the images progress. For this reason, the average of the two parameters was calculated on an incremental number of images.

In addition, RMSSD values were compared in the rest, negative baseline and training phase, considering an entire session for the subject.

IV. Results

Regarding the EEG, at least two sessions per subject were considered for the analysis because less corrupted by artifacts (electrical equipment in close proximity to the EEG device). During one session, the mean beta band power measured in Fz decreased when the averaged trials increased (see Fig. 6), for the most of subjects and the most of sessions. The same trend was shown by the average of the RMSSD; it decreased as more trial were considered (see Fig.7). However, from the literature, it was expected to increase at the strengthening of the emotion regulation abilities. The HRV trend can be explained by referring to the ultra-short temporal window [32] considered for the HRV analysis (i.e., 20 s). The time window exploited for the HR processing could be not sufficient to detect changes in HR caused by the response of the Autonomic Nervous System.

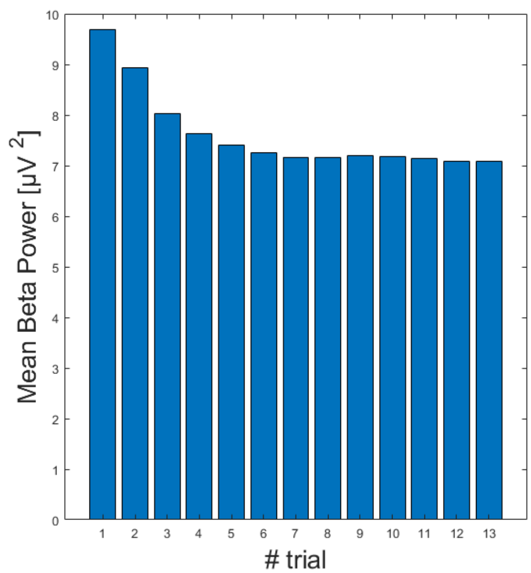

Fig. 6: Average of power in beta band from Fz among the # of trials and the previous ones.

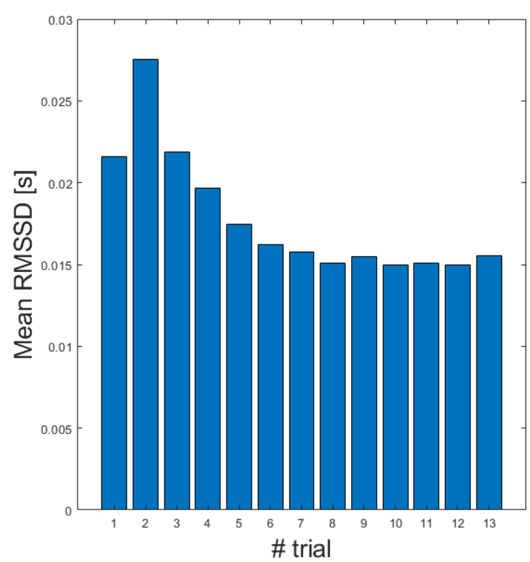

Fig. 7: Average of RMSSD among the # of trials and the previous ones.

Taking into account the last observation, the changes in HRV were evaluated considering wider time intervals. The

HRV measured during the (i) rest phase, (ii) the negative baseline, and the (iii) NF phases considered as a whole were compared for each session. The results showed that a higher HRV is exhibited during the NF phase in most of sessions for all the participants. Therefore, when considering the whole experimental session, the HRV showed the expected trend. Results for all the 4 sessions of a subject are shown in Fig. 8.

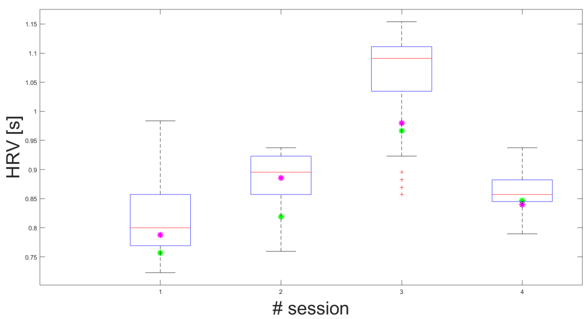

Fig. 8: Box plot of the RMSSD during the NF phase. Averages of RMSSD over the rest and the negative baseline are reported by coloured dots magenta and green, respectively. For each session, the median value of the box plot is greater than the mean RMSSD values of the rest and the negative baseline.

V. Discussion

In this study, the effectiveness of the NF training technique on neurosurgeons was confirmed by exploiting HRV. Specifically, considering the entire training session, the HRV measured during the NF phase is above the negative baseline in most sessions for all participants. Therefore, HRV can be successfully employed together with psychometric tools to evaluate the effectiveness of NF training. In contrast, it cannot be used in conjunction with EEG to guide real-time feedback because of its high latencies. Improvements in the study may be (i) neuromodulation of other scalp areas involved in emotional processes other than the frontal midline, (ii) enlarging the experimental sample, (iii) increasing the number of sessions and thus the overall duration of training to assess its effectiveness, and (iv) recording ECG signal instead of HR to extract HRV.

VI. Conclusions

In this study, NF was proposed to neurosurgeons to improve their emotion regulation abilities. EEG and HR were the signals acquired during NF. Specifically, the NF consisted of decreasing the mean beta power in the midline areas of the scalp by the colour change of a colour bar shown to the user to adjust emotions. Average beta band power and RMSSD were the analysed features, respectively, for NF effectiveness assessment. In particular, both features were averaged on an increasing number of trials. A decrease in the EEG feature was achieved in most cases, as expected by the scientific literature. On the contrary, the HRV feature did not increase during the trials. The HRV related to the NF training was generally higher than the HRV computed during the rest and negative baseline phases when the session was considered as a whole and thus the HRV was computed on a greater time interval. Compared with other studies in the literature, this work examined both EEG and HRV features during NF with the aim of evaluating the effectiveness. A future development of the study will be to increase the length of the regulation trial in order to calculate the RMSSD on a greater time interval, as an increase in HRV feature was obtained only by considering the whole session, thus a longer period of time. Another future consideration is to assess the participants' perceived emotional state through psychometric instruments.

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