Neurofeedback Training Intensity: impact on EEG self-regulation

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Abstract

Neurofeedback has proved to be useful in many instances. In fact, this technique is often used to address both medical issues and needs regarding performance improvement. Despite the wide range of applications, no consensus has been reached about the ideal training intensity.

In this work, a practical experiment was conducted aiming to compare the effects of intensive and sparse training modalities of enhancement of the individual upper alpha band, for working memory improvement, in 19 healthy subjects. Furthermore, a thorough analysis of intensity parameters, using also previously collected data, was performed, attempting to predict training performance based on intensity. Considering only the learners, the intensive modality proved to be significantly more effective in increasing the target frequency, both across sessions and within. However, no significant differences were found regarding cognitive improvements. Regarding intensity parameters, there was also no evidence of a significant influence, despite the suggestion that an accumulated measure of intensity and the variation of the time at which sessions are performed should be further investigated.

Therefore, based on these findings, it is proposed that training intensity might influence EEG self-regulation, but cannot by itself explain training results, and further investigation is needed to establish reliable conclusions. A larger sample and stricter training schedules, as well as a more refined model construction, based in data science techniques, could provide a better insight on this topic.

Keywords: Neurofeedback, Training intensity, Individual upper alpha band, Working memory, EEG.

1 Introduction

1.1 Context

Neurofeedback (NF) relies on the voluntary modulation of brain activity: brain signals are extracted and evaluated in real time, and presented back to the individual in the form of an auditory or visual feedback [1]. Therefore, it reveals a great potential to treat cases in which complementary or alternative therapies are needed due to lack of success using medication or even negative side effects [2, 3].

The first NF experiments were held concurrently by independent researchers [4]. In the 1960's, Joe Kamiya found out evidence of human ability to control brain patterns [5]. Later, Barry Sterman published the results of his experiment with cats that were trained to control their Sensory Motor Rhythm (SMR) (12-15 Hz). The cats learned how to increase SMR in response to a conditioning stimulus [6, 5] and, working in an unrelated experiment, Sterman accidentally found that the cats that had been previously trained were more resistant to seizures [7]. A medical application had been found, and in later work, the operant conditioning of Electroencephalography (EEG) rhythms was applied in humans, for the purpose of mitigating epilepsy [8, 7]. In recent years, research has spread to non-medical fields and newer protocols have been applied [4]. NF has been used to treat Attention-deficit/Hyperactivity disorder (ADHD), mostly with training of Slow Cortical Potentials (SCP) [9, 10, 11, 12, 13] and theta/beta training [14, 15, 11, 16, 17]; depression, usually addressing alpha asymmetry [18, 19, 20]; schizophrenia [21, 22, 23]; epilepsy, mainly with regulation of SCP [24, 25, 26, 27] and uptraining of SMR [28, 27, 29]; pain [30, 31, 32, 33, 34]. Additionally, applications extend to artistic performance [35, 36, 37, 38], sports [39, 40, 41, 42], and cognitive performance [43, 44], within which effects in memory have been studied [45, 46, 47, 48]. Notwithstanding, there are few well-designed and controlled studies and usually they do not follow standard rules, so further research is needed in order to undoubtedly demonstrate effectiveness [49]. Moreover, some aspects of NF methodology, such as protocols, number of bands, feedback modality, number of electrodes and training intensity are not standardized [50].

The present study focuses on the last one: training intensity, which comprehends factors such as the number of sessions, the duration of the subdivisions inside one session and the spread of the training over time. As there are many possible combinations, there is the need to understand if some of them might benefit training more than others and which information should be used when making such decision. In this work, an experiment was performed with healthy subjects, to test if there are differences between employing a short intensive training or a sparse and lighter one when attempting to increase the upper alpha band in order to produce working memory improvements.

1.2 Motivation

For the same application, very different training intensity parameters have been used. For instance, for schizophrenia, one protocol consisting in a total of 13.5 hours within four consecutive days [23] and another one composed of a total of 130 sessions of 1 hour twice per week, during 18 months [51] revealed positive results at the electrophysilogical and behavioural levels. Although this example needs a proper context, it illustrates that in some cases much time and resources could be saved, as results could probably be achieved in a more efficient way, increasing also the motivation of the subjects.

Furthermore, several authors attribute poor or unexpected results to insufficient training time [52, 53, 54]. Moreover, when making a distinction between learners and non-learners, it might even be the case that some individuals considered as non-learners, i.e. that do not respond to the protocol as expected, simply needed more sessions for an effect to be visible [20]. Therefore, a deeper knowledge of training intensity would also allow for a more reliable evaluation of the results, dissipating the doubts about the impact of choices regarding this matter.

1.3 Objectives

The present work primarily seeks to investigate the influence of training intensity in NF performance, doing so by searching for a pattern that relates intensity and electrophysiological changes at the cortical level. For this purpose, two distinct paths were taken. On one hand, a protocol-specific experiment which aimed to find out if there are differences between intensive and sparse training in the case of a specific protocol and explain variations in performance that are not intensity-related. On the other hand, intensity parameters were analysed seeking to understand how training performance varies with intensity parameters and predict the progression along training. The ultimate target is to combine this information, in order to gain a deeper understanding of the mechanisms through which NF operates and how training intensity can be set in order to optimize learning.

1.4 Structure Outline

This extended abstract is divided in five sections. First, an introduction has been depicted in the present section, providing the context, motivation and objectives for this work. Second, the methods employed in order to achieve the proposed goals are substantiated. Third, the more relevant obtained results are shown. Fourth, a detailed discussion on the remarks and limitations of the results and procedure is given. Fifth, and ultimately, the conclusions, including the contributions of the present study to this field and a proposal for future work, are presented.

2 Methods

2.1 Protocol-specific experiment

2.1.1 Participants

Nineteen healthy subjects participated in this study. Participants were allocated to two different groups: INTENSIVE (9 subjects) and SPARSE (10 subjects). It was not possible to assign participants to their group in a random way. Since the training hour load differs significantly between groups, time constraints had to be taken into account and thus the choice was made according to the participants' requirements. There was one drop-out in the SPARSE group after 4 sessions, due to incompatibilities with personal schedule. For the final sample, the INTENSIVE group consisted in 2 males and 7 females (aged 23.44 ± 2.41, range: 22-30) while the SPARSE group consisted in 6 males and 3 females (aged 27.67 ± 9.81, range: 22-46). No significant difference was found between groups regarding age.

An informed consent was provided to all participants describing the project, objectives, protocol, possible side effects and exclusion criteria. The aim of the experiment and experimental procedure were also verbally explained briefly. All subjects accepted and signed the informed consent. Participants were all volunteers and no monetary award was given for their cooperation in this study.

2.1.2 Equipment and Signal Acquisition

The acquisitions were carried out using *Somnium* software, in a room provided by the Evolutionary Systems and Biomedical Engineering Lab (LaSEEB), a research lab of Institute for Systems and Robotics (ISR), at Instituto Superior Técnico (IST) facilities. Electrodes were placed according to the International 10-20 System, using the left and right mastoids as references for common mode rejection and the middle of the forehead as ground. Relevant signal was recorded, with a sampling frequency of 256 Hz, from 20 electrodes: Fz, Fp1, F7, F3, T3, C3, T5, P3, O1, Cz, Pz, Oz, Fp2, F8, F4, T4, C4, T6, P4 and O2, and amplified by the EEG amplifier Vertex 823 (produced by Meditron Electromedicina Ltda, São Paulo, Brazil), with an analogical band-pass filter between 0.1 and 70 Hz. The impedance was measured during this process, guaranteeing that all electrodes had an impedance below 10 $k\Omega$.

2.1.3 Design

The differences between INTENSIVE and SPARSE groups rely on training intensity. INTENSIVE group performed 4 sessions, of approximately 2 hours each, in 4 consecutive days while SPARSE group performed 15 sessions, around 1h30 each, spread along approximately 8 weeks, with 2-4 sessions per week. A follow-up assessment was carried for each participant, one month after they completed the training. Both groups were submitted to NF training (upregulation of Upper Alpha (UA) with feedback), transfer training (upregulation of UA without feedback) and cognitive tests (tests to assess working memory performance). Resting baselines were preceded by a 2-minute relaxed state and assessed both for Eyes Open (EO) and Eyes Closed (EC), with recording of two alternating epochs of 1 minute for each, at the beginning and at the end of each session. A questionnaire to assess general health state, the SF-36 Questionnaire, was answered in the first session, before training and in a follow-up assessment. In every session, participants were also asked to fill a questionnaire in which they rated several parameters referring to their mental state.

Participants in the INTENSIVE group underwent sessions with 5 sets of 3 blocks each. Blocks were composed by 5 trials of 30 seconds, with 5 seconds of interval between them. Transfer trials were introduced from session 2 to 4, during which no feedback was provided. A transfer trial for adaptation, with a duration of 30 seconds, was introduced at the end of the 3rd set of blocks in the 2nd session. The following transfer periods consisted in two trials of 30 seconds and were performed after the 5th set of the 2nd session, after the 3rd and 4th sets of the 3rd session and after the 3rd and 4th sets of the 4th session. Total NF time in each session was 37.5 minutes (transfer trials and intervals are not taken into account). Cognitive tests were performed after the pre-training baselines in the first session and after the post-training baselines in the last session. Follow-up assessment was similar to the first training session, with the exception that the training period consisted in a single training block, followed by a 30-second transfer trial.

Participants in the SPARSE group underwent sessions with a single set of 5 blocks. Each block consisted in 5 trials of 60 seconds each, with 5 seconds of interval between them. Transfer training was introduced only in the 11th session and lasted until the last session. In every session, after the 5th NF training block, a transfer block was performed, with 2 transfer trials of 1 minute separated by 5 seconds of interval. Cognitive tests were performed after the pre-training baselines in the first session and after the post-training baselines in the 5th, 10th and 15th sessions. As in the INTENSIVE group, the follow-up assessment also resembled the first session, differing only in the existence of a single training block which was followed by a 1-minute transfer trial.

2.1.4 Protocol

Although the main focus of the present work is the study of training intensity effects, it also aims to evaluate the outcomes of distinct training intensity modalities regarding the enhancement of working memory. For that purpose, training consisted in the enhancement of the individual upper alpha band at Fz, as both the upper alpha band and the prefrontal area are associated with memory functions [55]. The evidence of a link between increased upper alpha band activity and good working memory performance [56, 45, 47] lead to the decision of training individuals to increase the activity in this band. The use of the Individual Alpha Band (IAB) was based on [56] that invokes a large variability of the boundaries of this band among subjects to justify the need of a personalized definition.

Individual Upper Alpha Measurement The first baseline measurements were used to define the IAB of each individual. The power spectrum density is estimated using the Welch's method [57], with an overlap of 10% and a segment length of 5 seconds, in *Somnium*. The crossings between both spectra provide the frequency boundaries Lower Transition Frequency (LTF) and Higher Transition Frequency (HTF). The UA band is defined as the frequency range between the individual peak alpha frequency, which was used as Individual Alpha Frequency (IAF), and the HTF.

2.1.5 Neurofeedback Training

The EEG training platform integrated in the *Somnium* software, described in more detail in [58], was used to perform NF training.

Feedback

The feedback is established according to the achievement of two goals and makes use of two three-dimensional objects against a grey background, a sphere and a cube that change according to previously defined settings reacting to subject's EEG in real-time. *Goal 1* depends on the relation between the

EEG measurement that is being evaluated and a predefined threshold value. In this case, since the interest is to enhance the upper alpha band, it is considered that *Goal 1* is achieved every time that the relative amplitude of this band is above the threshold, which makes the sphere change from white to purple and increase in size and number of sides. Using X(k) to denote the frequency amplitude spectrum computed using the fast Fourier Transform with a sliding window of 2 seconds and shifts every 0.125 seconds, the relative amplitude as presented in [59] is given by:

$$Relative\ Amplitude = \frac{Band\ Amplitude}{EEG\ Amplitude}$$

In this case, for the upper alpha relative amplitude:

$$UA\ Relative\ Amplitude = \frac{\frac{\sum_{k=IAF/\Delta f}^{HTF/\Delta f} X(k)}{HTF - IAF}}{\frac{\sum_{k=0.5/\Delta f}^{30/\Delta f} X(k)}{30 - 0.5}}$$

The frequency resolution is represented by Δf. All subjects started with a threshold value of 1, which was adjusted according to individual performance evaluated by the total amount of time during which *Goal 1* was reached. If the percentage of time during which the feedback parameter was above threshold exceeded 60%, threshold was increased by 0.1. If this percentage was lower than 20%, the threshold was decreased by 0.1. The aim was to maximize the effect of the feedback.

Training

Participants were informed about the existence of the two goals during NF training and told to focus primarily on the sphere, trying to make it purple, and as round and big as possible. They should use a single mental strategy per block, so that the effects of that strategy could be isolated in order to rate its effectiveness. During the first blocks participants were encouraged to try different strategies in order to understand which ones produced better results and then repeat them afterwards. In the INTENSIVE group, between the sets of blocks there was a larger break that also served to check the average time spent above threshold and reset the NF threshold when necessary. In the SPARSE group, threshold resetting only occurred at the end of each session.

Transfer training was performed to assess the ability to control cortical activity without feedback.

2.1.6 Measures

Working-Memory Performance So that the effects of NF training in working memory performance could be analysed, allowing also a comparison between the two training intensity modalities, several cognitive tests were carried out: Digit Span (Forward), Digit Span (Backward) and N-Back. During the Digit Span test [60] participants had to recall several sequences, with increasing length in each trial, from 3 to 13. Subjects were asked to introduce the digits in the order by which they appeared, forward digit span, and by the opposite order, reverse digit span. During N-Back test [61] the individuals were required to monitor a series of numbers/letters and identify if the current one was the same that was presented n trials before, with n = 3. Twenty-three trials were performed, which resulted in 20 answers.

Questionnaires This study also aimed to understand the extent to which factors such as concentration, motivation, sleepiness and stress affect training, as they may mask intensity effects. For this purpose, a numerical rating scale was used to evaluate the frequency of the four mentioned states/sensations during training: 1 - never, 2 - rarely, 3 - sometimes, 4 - frequently, 5 - always. Furthermore, the 36-Item Short Form Survey (SF-36) questionnaire was performed to assess different domains of health state and quality of life [62, 63].

2.1.7 Data Pre-processing and Extraction

The pre-processing and extraction of information from the raw EEG was performed using *Somnium* tools. It was necessary to remove some recorded periods which contained artifacts that would mislead the analysis. With the exception of eye movements, the artifact removal was performed manually, for all baseline measurements of each patient.

Baseline registration was done through manual classification of the signal as “Eyes Open” or “Eyes Closed” events, based on indications made during sessions. Artifacts were not classified and thus were not considered in further processing of the signal. NF sessions were automatically marked in the course of the session. Individual reports were copied to from *Somnium* to Excel files and extracted with MATLAB R2015b, with which all the subsequent analysis was performed. Chosen relative amplitudes concern the following frequencies: Individual Theta Band(from 4 Hz to LTF); Individual Lower Alpha Band 1 (from LTF to LTF+(IAF-LTF)/2); Individual Lower Alpha Band 2 (from LTF+(IAF-LTF)/2 to IAF); Individual Upper Alpha Band (from IAF to HTF); SMR (from 12 Hz to 15 Hz); Beta Band (from 16 to 20 Hz) and Beta Band 2 (from 20 to 28 Hz).

2.1.8 Data Treatment

The treatment of the data for this work was performed using the MATLAB software (version R2015b) and the visualization of plots as well as statistical analysis was also accomplished resorting to MATLAB.

Evaluation of Training Performance Since the participants had different baseline amplitude values and the electrode impedance varied from session to session as the only restriction imposed was that values are all under 10 kΩ, amplitude values for each individual session were normalized by the corresponding pre-training baseline with eyes open. In order to evaluate the evolution of the relative amplitude of frequency bands along time, both within session and across sessions, distinct measures were used:

- Within Session
  - W1: this measure is based on [59] and aims to quantify the mean change within session across all training sessions:

$$W1 = \frac{\sum_{i=1}^{\#sessions} \sum_{j=2}^{\#blocks\ of\ the\ i^{th}\ session} (block\ j - block\ 1\ of\ the\ i^{th}\ session)}{\#sessions \times (\#blocks - 1)}$$

  - W2: is the slope of the linear regression that describes the evolution of the relative amplitude of a certain frequency band along blocks, averaged across sessions. Considering $y = m_i x + b_i$ as the trendline for the i^{th} session:

$$W2 = m_a = \frac{\sum_{i=1}^{\#sessions} m_i}{\#sessions}$$

    in which y corresponds to the relative amplitude, m_i is used to refer the slope, x is the block number and b_i is the y-intercept, which will depend mostly on subject's characteristics.
- Across Sessions
  - A1: only takes into account the initial and final amplitude values, normalized with respect to initial amplitude values. For n sessions, and denoting sessions by S_i, with $(i = 1, ..., n)$:

$$A1 = \frac{Mean(S_{n-1}, S_n) - Mean(S_1, S_2)}{Mean(S_1, S_2)}$$

  - A2: corresponds to the slope of the linear trendline computed for the evolution of frequency amplitude along sessions, therefore taking into account the variations that may occur in between.

The distinction between learners and non-learners relies only on the training performance for the target frequency band, in this case the UA band. A2 measure being positive was chosen as the criteria to classify a participant as learner: 5 learners were identified in the INTENSIVE group and 6 in the SPARSE group.

Evaluation of cognitive effects The results of Digit Span Test (both Forward and Reverse) and the N-Back test(both with numbers and letters) were used to evaluate the effects on cognition, at the working-memory level. For the Digit Span Test, two indicators were chosen "Span" and "Score". Regarding the N-Back Test, the performance was evaluated based on the "Number of Successes". The results obtained at t_0, t_1 and t_{fu} were used to evaluate the effects along time and examine if the training influenced them.

2.1.9 Statistical Analysis

Since this experiment was performed in a small sample (total $N = 18$ participants), and several results are analysed individually for each group ($N = 9$ for each group), the analysis relies mostly on medians, instead of means, and non-parametric tests. Shapiro-Wilk test [64] was used in order to assess if variables under examination came from a normally distributed population. Nonetheless, since in several cases normality was not verified, an option was made to rely only on non-parametric tests, even when no evidence of non-normality was found.

To analyse the median of a group or the difference between two time points within one group, Wilcoxon signed rank test was used [65]. Right-tailed tests were employed when there was a prior hypothesis of an increase, as it was the case for the UA amplitude within and across sessions as well as (post−pre) baseline measurements. For the validation of the use of individual alpha band, the boundaries IAF and HTF were not compared with zero, but with standard values.

In order to make comparisons between groups, the Wilcoxon rank sum test was used, usually to test if the medians considering all the participants of each group differed significantly [66].

To assess correlation between variables, two different coefficients were used, depending on the purpose: Spearman's rank correlation coefficient to evaluate monotonic relation between two variables [67] and and Pearson's correlation coefficient to test for linear relationships [67]. Spearman's rank correlation was used in cases for which a linear relationship was not predicted and outliers were likely to be present.

A significance level of 5% was considered.

2.2 Intensity Parameters

In order to establish a relationship between intensity parameters and EEG-self regulation using a larger sample, data collected for two other studies was grouped with data of INTENSIVE and SPARSE groups

2.2.1 Data

The two included groups of data were previously and independently acquired by two different people, Cristiana Alves and Christophe Domingos. From the data collected by Cristiana Alves, a group of 9 healthy individuals, who received IAB uptraining at Cz, was considered. They were submitted to 15 sessions, each one composed of 5 blocks with 5 trials of 60 seconds (5 seconds of interval between them).

Using the data collected by Christophe Domingos, who also performed a training to increase IAB at Cz, one group of 15 healthy athletes was considered. Data referred to 12 sessions, each one composed of 1 block with 25 trials of 60 seconds (10 seconds of interval between them)

Although these two protocols do not target the same frequency and electrode site as the present study, one may consider that there is enough proximity between UA band and the whole alpha band as well as between Fz and Cz so that data can be grouped.

2.2.2 Intensity Measure

An intensity measure, which refers to a single session, was established seeking to understand if there was a direct relationship between the intensity of a certain session and the changes obtained for the target frequency in that session. It takes into account both the current training load (numerator) and the interval between current and past session (denominator). IM denotes the intensity measure and S_i denotes the i^{th} session ($i = 2, ..., n$), for n sessions:

$$IM_i = \frac{(\#\ trials \times trial\ duration) - (\#\ trial\ intervals \times trial\ intervals\ duration)}{duration\ of\ interval\ between\ S_{i-1}\ and\ S_i}$$

Correlation between successive intensity values and relative amplitude values along sessions was computed for each study.

2.2.3 Model

A linear model was established using intensity parameters as predictors and the measures established for the training performance as response variables.

Intensity Parameters All intensity parameters were computed from the data regarding date and time of each session, taking into account session parameters such as number of trials, trial duration, trial interval duration and total number of sessions.

At the end, nine parameters were defined: 6 parameters mostly related to intervals between sessions and session duration and 3 parameters focused on session time schedule:

Evaluation of Training Performance The same measures that were used to evaluate the evolution of the target frequency across sessions for the experiment, A1 and A2, were employed in this section to calculate the response variables related to training performance. The only difference is that in this section the values of relative amplitude are not normalized by the EO pre-baseline of the respective session, as they are in all the other results that refer to the present experiment, since only the values obtained during NF were collected from these external studies.

Variable selection Despite the fact that 9 intensity parameters were computed, as previously mentioned they were all derived from two variables only, date and time. Therefore, as some parameters may provide redundant or even useless information, there is the need to select the more meaningful ones. In order to do so, a stepwise procedure was used to build the model, through the function *stepwiselm* available in MATLAB. This method was applied both when considering all participants and only the learners.

Model Evaluation The model obtained was evaluated based on the estimates for the weights and p-values for the intensity parameters considered relevant, as well as the residuals obtained by subtracting the predicted values to the observed values. These residuals were standardized, *i.e.*, divided by their estimated standard deviation.

3 Results

3.1 Protocol-specific experiment

3.1.1 Individual Alpha Band

Concerning only the IAB at t_0, in order to check if there were significant differences between groups for each of these values, the Wilcoxon rank-sum test was applied. The results indicate that the null hypothesis cannot be rejected for LTF ($U = 39,\ p = 0.914$) and IAF ($U = 30,\ p = 0.372$) at a 5% significance level, as both p-values were larger than 0.05. However, the difference for HTF values ($U = 17.5,\ p = 0.041$) was considered significant, as the hypothesis of equal medians was rejected. Notwithstanding, at t_1, no p-values under 0.05 were obtained. The smaller U value indicates that, in an ordered arrangement of values from INTENSIVE and SPARSE groups, there were fewer occurrences of SPARSE values preceding INTENSIVE ones. In order to assess the effect of training on the intra-variability of individual alpha band, the Wilcoxon signed-rank test was performed to test if the median of the change (t_1 - t_0) was different from zero, for each group individually. This test was chosen because repeated measures were performed on the same sample. In the INTENSIVE group: LTF

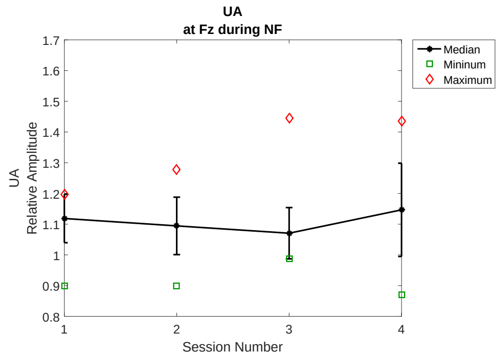

Figure 1: Evolution across sessions for the INTENSIVE group during neurofeedback at Fz. Normalized UA relative amplitude and error bars show median absolute deviation

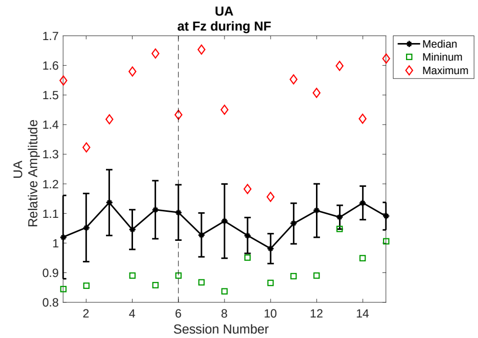

Figure 2: Evolution across sessions for the SPARSE group during neurofeedback at Fz. Normalized UA relative amplitude. The dashed line marks the time point in which both groups had performed training during the same amount of time and error bars show median absolute deviation

($W = 19,\ p = 0.453$), IAF ($W = 10.5,\ p = 0.625$) and HTF ($W = 24.5,\ p = 0.840$). In the SPARSE group: LTF ($W = 36,\ p = 0.1289$), IAF ($W = 33,\ p = 0.242$) and HTF ($W = 33,\ p = 0.039$). There was only evidence of a statistically significant difference between HTF measured at t_0 and t_1 in the SPARSE group. One common fixed reference range for the upper alpha band is from 10 to 12 Hz [68]. Thus, Wilcoxon signed rank test was performed to assess if the IAF and HTF of both groups as a whole differed significantly from 10 and 12 Hz, respectively. IAF was not considered significantly different from 10 Hz ($W = 128,\ p = 0.064$) while for HTF the difference from 12 Hz was considered significant ($W = 140,\ p = 0.003$). After training, at t_1, both were considered significantly different from the respective fixed values: IAF ($W = 133,\ p = 0.040$) and HTF ($W = 135,\ p = 0.006$).

3.1.2 Training

The analysis of neurofeedback training results focuses on the changes that occur both along the time course of the training experiment and within each session. The evolution of the relative amplitude of UA was examined to assess trainability while changes regarding other frequency bands are shown so that independence may be studied, as suggested by [44].

Across Sessions Recurring only to visual analysis of Figures 1 and 2, there is no apparent increasing tendency of the median UA relative amplitude across sessions, for any of the groups. However, for the INTENSIVE group, the maximum value increased along sessions, similarly to what happened along sessions 2-5 of the SPARSE group.

When comparing the two groups regarding the medians of A1 and A2 measures for all frequency bands, no significant differences were found.

Since the groups were not submitted to the same neurofeedback time, this scenario was hypothetically analysed, through a comparison of measures computed considering only 6 sessions for the SPARSE group, the equivalent to INTENSIVE total training time. Like it was obtained when considering the whole training, there is not enough evidence to say that the medians of the measures are significantly different from zero, for any of the bands. However, between groups, there are significant differences regarding the SMR.

When considering only the learners, for both groups, there is evidence that the medians of measures are significantly larger than zero concerning the UA band. Moreover, for the SPARSE group, the median of A2 for Lower Alpha Band 1 (LA1) and IAB is also considered significantly different from zero. There are also significant differences between groups for UA and SMR concerning A2 measure. In the INTENSIVE group, A2 was lower for UA and higher for SMR than in the SPARSE group.

Within Session Results within session were analysed in a similar way to what was shown for those across sessions. The changes regarding UA band within one representative session, which corresponds to the mean of all sessions, are shown on Figures 3 and 4. While for the INTENSIVE group an increasing trend throughout blocks is visible, this does not occur for the SPARSE group. Moreover, for the INTENSIVE group, although in the first session the median for all participants was lower than for the other sessions during most of the blocks, the final values for all sessions seem to converge to a maximum. For

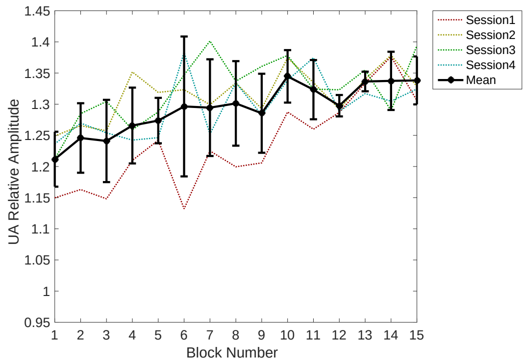

Figure 3: Evolution within session for the INTENSIVE group during neurofeedback at Fz. Normalized UA relative amplitude, the dotted lines represent the median for all participants for a given session and error bars show standard deviation

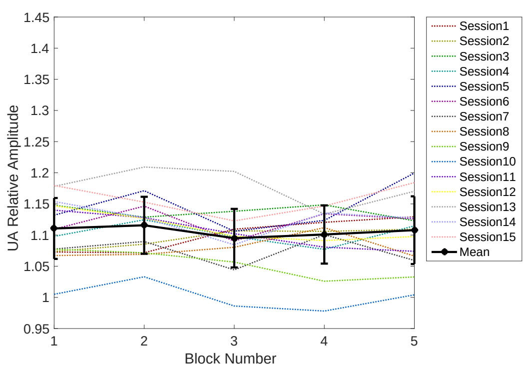

Figure 4: Evolution within session for the SPARSE group during neurofeedback at Fz. Normalized UA relative amplitude, the dotted lines represent the median for all participants for a given session and error bars show standard deviation

the SPARSE group, session 10 stands out, since none of the lowest values for the other sessions was lower than any of the values that correspond to its blocks. Regarding the other frequencies, changes were visible only for the INTENSIVE group, mainly for the other components of IAB, besides UA, both LA1 and Lower Alpha Band 2 (LA2) also show an increasing trend.

Within group, measures regarding changes within sessions are not significantly different from zero for any of the frequency bands of the SPARSE group. However, both W1 and W2 are significantly larger than zero for the UA band and different from zero for LA1, IAB and Beta2. LA2 also has a significant W2. For both W1 and W2 there are significant differences between groups for UA and IAB, at a 5% significance level. Only for W1, significant differences were also found for LA1 and Beta2. Concerning the learners, within session, the only visible effect of training is for the INTENSIVE group, as the median of W1 for UA is significantly larger than zero. W1 for IAB and W2 for UA band have a significantly different median between groups. Both medians are significantly larger for the INTENSIVE group.

Transfer Training The correlation between A2 measure of training performance during neurofeedback training and transfer training was computed. For each participant, only the best transfer trial was chosen, which consisted in the one for which the UA normalized amplitude was the largest. Using the Pearson's correlation coefficient, no significant correlations were found.

3.1.3 Baselines

Using the Wilcoxon signed rank test to evaluate the differences within session, *i.e.* check if the median of (post-baseline − pre-baseline) is larger than zero, no p-values under 0.05 were obtained for any participants, both for EO and EC in the two groups, and therefore there is not enough evidence to conclude about significant effects of training on the baselines within session.

The slope of the trendline across sessions was analysed using a Wilcoxon rank sum test to compare both groups and a Wilcoxon signed rank test to determine if the median slope was significantly larger than zero (right-tailed test) for each group. No p-values under 0.05 were obtained both for EO and EC, either for the between groups or the within group analysis.

The correlation between pre-baseline values of the first session, prior to any neurofeedback training, and A2 measure was computed. No significant correlation was found for EO ($r = 0.157,\ p = 0.534$) or EC ($r = 0.105,\ p = 0.678$).

3.1.4 Cognitive Tests

Medians of change ($t_1 - t_0$) for both groups were not considered significantly different from each other. However, within group there were score changes whose median was considered significantly larger than zero using a one-tailed Wilcoxon signed rank test. The correlation between the performance in cognitive tests and training performance was assessed in order to understand if the results could be seen as training effects. A significant correlation was found between the score change in Digit Span Test (Reverse) and A2 for the INTENSIVE group ($r = 0.740, p = 0.023$)

3.2 Intensity Parameters

Using Spearman's correlation coefficient to test the relationship between the intensity measure and the amplitude of the target frequency along sessions, p-values below 0.05 were obtained only for 5/42 (11.9%) participants. In order to assess if any of the intensity parameters had an individual strong relation with working performance, the Pearson's correlation coefficient and respective p-value were computed for each of them, both for A1 and A2. Based on the p-values, no correlations were considered significantly different from zero.

After performing stepwise linear regression, the number of intensity parameters contributing for the models of A1 and A2 prediction was narrowed. The intensity parameters that achieved higher weights and lower p-values are the chosen ones after this procedure. It was considered that these models were more realistic than those obtained for the learners only, in which a constant model was obtained for A1, and a model relying on only one variable was obtained for A2. Therefore, the final evaluation was performed on those obtained using the whole sample. Intensity parameters "AccIntMeasure" (accumulated intensity measure divided by the number of sessions) and "TimeVariation (standard deviation of the hours at which each session was performed) were the selected values with non-negligible weights, both for A1 and A2. Using the Shapiro-Wilk test for normality, the standardized residuals associated to each of the models were not considered normally distributed.

4 Discussion

Individual Alpha Band The individual alpha band was used in this experiment instead of a fixed ranges of values. Along time, there were no significant changes of the IAF, as in [44] and [45]. The only case of intra-variability occurred for the HTF of the SPARSE group. Although this could have been an effect caused by training, which should be further studied, the difficulties in manually marking the frequencies might have triggered this variation.

Trainability [44] defines trainability as the existence of effects due to training in the target frequency band, which for them was also the upper alpha band. Considering the whole training for all participants, there was no evidence of significant changes in the UA across sessions for any of the groups. Across sessions, none of the training intensity modalities revealed to be effective in producing a growing increase of the UA amplitude. Considering only the first six sessions of the SPARSE group, differences either within or between groups are also not present.

However, making the distinction between learners and non-learners, and thus considering 56% and 67% of the participants of the INTENSIVE and SPARSE groups, respectively, the results point to trainability. The differences between groups indicate that the INTENSIVE group achieved a significantly higher increase of UA amplitude than the SPARSE group. Equivalent results across sessions were also obtained by [44] and [45] for learners (79% and 60%, respectively). Both performed 5 sessions with 5 training blocks of 5 minutes each in five consecutive days. The training load in each session was equivalent to the one for SPARSE group, but the training was done intensively which, combined with the results for this study for learners, suggests that sessions on consecutive days may be more suitable for UA increase.

Within session, for the INTENSIVE, measures were considered significantly larger than zero regarding UA, which means that this group accomplished a good training performance within sessions. The mean for all sessions is constant for the last 3 blocks which suggests that a larger training session would not benefit training. Being true, taking out one set, which would correspond to these last three blocks, could even be advantageous.

For the SPARSE group, however, W1 and W2 were not significantly larger than zero nor there were any visible changes within session for the UA band. Another study, also performing 5 trials with 5 minutes each, found a significant positive tendency for UA (using a metric similar to W2), though only one session was performed [69].

Significant differences were found between groups, with the INTENSIVE group obtaining a better performance within session. The equivalent training time of the one received by the SPARSE group, for a single session, is 10 blocks. Since the increasing trend for the INTENSIVE group starts at the first blocks and differences between groups are already visible if one considers only these 10 blocks, it may be concluded that the disparity is due to block duration and not to the total number of blocks. Therefore it seems that smaller blocks, in this case 30 seconds, might be more suitable for training when compared to larger ones, of 60 seconds. Additionally, larger breaks might also be beneficial, alleviating the burden of a longer session. Nevertheless, in the work of [1] both stroke patients and healthy controls were able to regulate upper alpha activity within session, with each session consisting of 6 feedback runs of 3 minutes.

Although distinguishing between learners and non-learners led to significant results for the two groups (using both A1 and A2), only the learners of the INTENSIVE group show significant changes within session. The median measure W2 is significantly larger than zero for UA, yet the same cannot be verified for W1. Therefore, either there is not a strict relationship between within and across sessions performance, or the criteria that was used gives a poor distinction.

Independence The ability to train the UA band independently of other frequency bands was evaluated only regarding NF training. Considering all the subjects, there were no significant changes across sessions for other frequencies. Concerning the learners, within group, only the SPARSE revealed changes for other frequency ranges besides the UA band across sessions. Therefore, it is considered that independence was accomplished for the INTENSIVE group, across sessions, but not for the SPARSE one. These results are not in line with what was obtained by [44] and [45], for whom independence was accomplished regarding training. However, their conclusions are based in different computations. Between groups, there are no differences concerning the whole training for all individuals, regarding other frequencies.

Analysing the results within session, for the SPARSE group there are no significant effects on other frequencies, either considering the whole group or only the learners. However, contrary to what was verified along sessions, for the INTENSIVE group there are significant changes for LA1, LA2 and IAB and also for Beta2. Hence, it is considered that UA was not trained independently from other frequency bands within session for this group.

Baselines Contrarily to what was obtained by [44] and [45], for the upper alpha band, the effects of training do not show up on the baselines along time, neither for EO nor for EC.

Cognitive Tests No significant differences were found between groups either for the Digit Span or the N-Back test, as no differences on the measures of training performance across sessions had been found also. However, there were significant effects within each group. Therefore, training may have caused improvements but training intensity might have not influenced the results directly.

5 Intensity Parameters

No significant correlation was found between the intensity measure and amplitude across training. Therefore, it is considered that either this measure does not appropriately evaluate impact of training intensity on training or that such influence is not expressed as directly as expected.

The effect of each intensity parameter was analysed regarding both measures of training performance yet none of the parameters showed a significant linear correlation with them. Moreover, during the exploratory analysis of this data, no clear patterns were found.

Distinct linear models were built using each training performance measure as a response variable, considering all intensity parameters as predictors. For both measures, "AccIntensityMeasure" and "TimeVariation" were considered relevant, being the ones with highest weights.

For an appropriate model, the characteristics of the residuals should comply with the assumptions. In this case, relying on linear regression assumptions, residuals should follow a normal distribution with zero mean and standard deviation equal to one. The residuals obtained with each of the final models were not considered normally distributed. The models were not considered reliable predictors of training performance.

6 Conclusion

In the present study, an experiment of NF training for the increase of the activity in the UA band was performed, using two different training intensity modalities. Furthermore, a model for prediction of performance based on training intensity was tested. Concerning the first goal of this study, it is considered that differences were found between groups, though it was not possible to establish a correspondence between not intensity-related variables and training performance and further investigation is need to establish if one modality outperforms the other. Taking into account that nor the intensity measure nor the final models were good predictors of training results, the second goal of this work was not met, although it is considered that the variables with strongest weight in the final model should be further studied.

It is considered that the present work introduces new findings in the field, as no other studies were found in which two groups with different training intensity modalities were compared or intensity parameters were exhaustively studied. Future work regarding the data collected from the experiment should include a topographical study. Concerning the prediction, collecting a larger sample would help in finding better models, as well as including other variables and investigating different methods of variable selection. Finally, the literature could be reviewed using a meta-analysis methodology such that useful information on this subject could be found using data science techniques, after establishing intensity indices and defining an intensity nomenclature.

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