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Effects of assisted training with *neurofeedback* on EEG measures, executive function and mood in a healthy sample

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Título: Efectos del entrenamiento asistido con *neurofeedback* sobre el EEG, los procesos de función ejecutiva y el estado de ánimo en una muestra de población normal.

Resumen: El entrenamiento en *neurofeedback* (NF) consiste en enseñar a los individuos a modificar, regular y potenciar su patrón de actividad cerebral. El objetivo de nuestra investigación fue evaluar el efecto del entrenamiento sobre los procesos cognitivos de función ejecutiva y sobre el estado de ánimo en una muestra de población normal. Se seleccionó una muestra de 30 mujeres estudiantes universitarias, asignadas a tres grupos: HD: hemisferio derecho (n = 10), HI: hemisferio izquierdo (n = 10) y control (n = 10). Se entrenó durante una sola sesión el predominio del patrón beta y la inhibición del patrón theta y se realizó una evaluación pre y post-entrenamiento de la función ejecutiva (*Iowa Gambling Test)* y del estado de ánimo mediante autoinforme. Se encontró que el entrenamiento en NF produjo cambios positivos significativos en el rendimiento ejecutivo en el grupo HD. En relación con el EEG, se encontró una tendencia al cambio tras el entrenamiento de ondas beta. Se encontraron correlaciones significativas entre el rendimiento ejecutivo, el estado de ánimo negativo, y la banda de frecuencia theta. Se concluye que el protocolo resulta efectivo para potenciar aspectos de la función ejecutiva y que la disminución de ondas theta parece favorecer la disminución del estado de ánimo negativo.

Palabras clave: *Neurofeedback*; EEG; función ejecutiva; *Iowa Gambling Test*; estado de ánimo; PANAS; POMS; ritmo theta; ritmo Beta.

Abstract: The training in *neurofeedback* (NF) consists of teaching individuals to modify, adjust and enhance their brain activity pattern. The aim of our research was to evaluate the effect of training on cognitive processes, specifically executive function, and mood in a non-clinical sample. A sample of 30 female college students were assigned to three groups: RH: right hemisphere (n = 10), LH: left hemisphere (n = 10) and control (n = 10). The dominance pattern of beta and the inhibition of the theta pattern were trained in a single session. Measures of executive function (*Iowa Gambling Test*) and questionnaires of mood were taken pre and post training. We found that NF training produced significant positive changes in executive performance in the RH group. In the EEG a tendency to improve beta rhythm after the training emerged too. Additionally, significant correlations were found between executive performance and negative mood in relation to theta frequency band. We conclude that the protocol seems effective to enhance some aspects of executive function as well as to decrease theta power improves the negative mood.

Key words: *Neurofeedback*; EEG; executive function; *Iowa Gambling Test*; mood; PANAS; POMS; theta rhythm; beta rhythm.

Introduction

The training in *neurofeedback* (NF) consists of enhancing favorable activation states through the non-invasive stimulation of the thalamus-cortical loop. It is designed to teach the individual to modify and to exert self-regulation on the different components of its pattern of cortical electrical activity: amplitude, frequency or consistency. The subject learns to identify the states of activation that assume an advantage and to produce them voluntarily through the maintenance of his conscious attention at a stimulus either visual, auditory or both (Vernon, 2005). According to Holtmann, Steiner, Hohmann, Poustka, & Banaschewski (2011) the self-regulation of cortical activity is achieved through a process of operative learning using the real-time representation of the electroencephalographic parameters.

The use of NF is justified given the two-way relationship between the patterns of cortical activity and states or specific aspects of the behavior (Vernon, 2005). Therefore, if it is able to modify pharmacological, behavioral or electrophysiologically the cortical activation pattern, it will be observed effects on the physiology, cognition and mood. Well, there are associations between components of specific frequencies of the EEG and the different aspects of the cognitive and affective processing. In relation to the executive function as a process of interest, Boynton (2001) and Angelakis, Stathopoulou, Frymiare, Green, Business Location & Kounios (2007) show that the predominance of one of the neurophysiological patterns, the alpha band, it is associated with increased cognitive effectiveness, including executive function (mental flexibility, fluidity, inhibition) and the attention. Another associated pattern is the beta band, in particular beta 1 or SMR (12-15Hz) and beta 2 (15-21Hz), which has proven to be predominant in the anterior cingulate cortex, temporal cortex and sensorimotor cortex during tasks that require executive functions (Bockova, Chladek, Jurak, Halamek, & Rektor, 2007). In disorders such as attention deficit hyperactivity disorder (ADHD), where predominate alterations of the executive function, the increase of SMR rhythm (12-15 Hz) and the inhibition of theta (4-7 Hz) improve the executive functioning, especially the attentional deficit and the inhibitory control (Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003; Lubar, 1991; Monastra, Monastra, & George, 2002; Rossiter & LaVaque, 1995). Monastra, Lubar & Linden (2001) claim that the subjects with ADHD tend to have excessive activity of slow theta waves (4-7 Hz) in relation to the activity of fast beta waves (13-21Hz) in the central locations of the midline (CZ) and frontal (FZ, F1, F2) of the cerebral cortex. So it has been evident that protocols of NF that reduce theta and reward beta achieve an improvement in the activation of the Anterior Cingulate cortex (CCA), important region for its contribution to cognitive control and executive function

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processes (Bush, Luu, & Posner, 2000; Kouijzer, de Moor, Gerrits, Congedo, & van Schie, 2009). In relation to mood, there is not enough evidence about the effect of the NF about it on healthy subjects. However, studies on associated pathological conditions, such as depression, reveal that the training of SMR (12-15 Hz) rhythm can be effective in the modification of the negative affection. According to Pavlenco, Chernyi & Goubkina (2009) training on the SMR rhythm promotes an increase in the activity of the dopaminergic system (DA) in the ventral tegmentum. Since this system has been associated with the facilitation of positive emotions and the maintenance of the conduct by approximation, to promote an optimal SMR rate (or amplitude) could be considered a promoter for positive affection and emotional stability, as evidenced by Wu, Ding & Zhou (2004) in studies on the prevalence of the SMR band in the depression. In this line, Hammond (2005) propose that the NF protocol more favorable for the depression treatment involves inhibition of slow waves (low theta and alpha) and fast beta waves reinforcement (15-18 Hz). Additionally, it would be appropriate to implement some sessions of SMR neurofeedback (12-15 Hz) in the left hemisphere because of their association with positive emotions (Davidson, 1998; Henriques & Davidson, 1991).

Bearing in mind the precedents, this study has been interested in evaluating the effects of training on NF on executive function and mood in healthy individuals, applying a protocol aimed at inhibition of slow-waves and the reinforcement of fast waves, on the executive function and mood in healthy individuals. The hypothesis from which we start is that the training is effective for improving both aspects, the indices that evaluate the executive function improve and that the self-report questionnaires indicate that the subject experiences a state of mind more favorable (increasing the positive mood and decreasing the negative) after the training.

Method

Participants

The final sample was conformed by 30 healthy women college students with ages between 18 and 31 years (mean 23.4; SD 3.2), selected under the following exclusion criteria: history of medical illness or hormonal changes, have history of psychoactive substance abuse, have diagnosed psychiatric illnesses, having abnormal hearing or visual alterations, and have knowledge or experience with the use of the technique of NF. For hearing verification were taken tonal measures by an audiometer and verified right manual preference (Oldfield, 1971). Finally, 20 were randomly assigned to the neurofeedback group training, 10 of them to the training group right hemisphere (RH), and 10 to the training group left hemisphere (LH). The remaining 10 were assigned to the control group. The three groups did not differ significantly in terms of age or educational level. With regard the menstrual cycle, it was controlled that women did not have the menstruation period during the pass of the experiment (in all groups), although it was not counterbalanced the variable over the pre or postmenstrual period.

Devices and instruments

- *Neurofeedback* Equipment: it was used a *Biograph Infinity Software*, the system comes with *EEG Suite* responsible for processing, filtering, and represent the pattern of brain activity and changing amplitude of the frequency bands. To carrying the signal to the computer was used a *Pro Comp 2 Infinity hardware* system. The connection of the electrodes was single pole type, through which the potential field was recorded with an active electrode in the central region CZ and it was manipulated the placement of the reference electrode: the RH group was placed in the ear´s right lobe and the LH group was placed in the left lobe. To attach the electrodes, abrasive gel and conductive paste were used. It was selected a standardized protocol for reinforcement of the beta frequency band in a range of 13 - 21 Hz and inhibition of the theta frequency band in a range of 4 - 7 hz with threshold standardized. The screen of *feedback* is based on a dynamic image (visual stimulation) and a music CD (auditory stimulation). The protocol was designed following the recommendations of Gruzelier, Egner, and Vernon (2006).
- *Iowa Gambling Task*: instrument in virtual version built by Bechara, Damasio & Damasio (2000) validated for the measurement of the decision-making process and postponement as elements of the executive function (Damasio, 1996). Consists of a set of cards from 4 different decks which purpose is to maximize the amount of seed money. To achieve this, the person must choose cards from the decks 3 and 4 since they offer less immediate gain but less long-term loss. However, if the person chooses the cards 1 and 2, he will win in the short term more money but he will lose more than he has. (Bechara et al, 2000).
- *Profile of Mood States* (POMS; McNair, Lorr, & Droppleman, 1971): used to estimate the mood or negative emotions of the subject. It was implemented a brief Spanish translation developed by Balaguer, Fuentes, Melia, García-Merita and Perez-Recio (1993), which consists of 12 items extracted from the original version. The short version offers a score of general negative emotions, where a higher score, the greater level of negative emotions experienced subjectively by the person.
- *Positive and Negative Affect Schedule* (PANAS, Watson, Clark, & Tellegen, 1988): used to carry out the assessment of mood, distinguishing between positive (PA) and negative (PN). Specifically, it consists of 20 items, of which 10 refer to positive emotions, while the rest to negative emotions. The subject must give score the items on a *Likert* scale of 1 to 5 (1 being nothing and 5 much). In this way, the total scores in each category vary from 10 to 50.

Procedure

At a first moment the participants were informed by telephone of the basic characteristics of the study and the expected duration of the session. At the beginning of the session it was completed the medical history questionnaire and manual preference, what would determinate the person´s participation in the study and, therefore, to give their informed consent. The dependent measures carried out previous to the training with neurofeedback: POMS and PANAS self-report questionnaires and the administration of computerized version of the *Iowa Gambling Test.* A prior measure of EEG for 4 minutes was taken, with open eyes and in a relax state. After this baseline the training online started with a real-time feedback, where the subject was instructed to learn to control their brain activity. All subjects heard the same instructions: "for 30 minutes, you should see an image on the screen and hear music, both are dynamic and will remain so depending on your state, your task is to stay focused on music and the image to continue moving, so you should only keep concentrated on it and as relaxed as possible, during the training, it is important not to move and talk". The contingency of learning was the interruption of the movement and music. After 30 minutes, the subject was informed that the training was over and stopped the feedback program. Finally, an immediate measurement of 4 minutes of the EEG post-training was execute, electrodes were removed of the scalp and the post-test measures were implemented (complete POMS and PANAS questionnaires and the administration of the *Iowa* test again).

Data Analyses

For the statistical analysis of the relative spectral EEG changes, the average values of amplitude of three frequency bands were used: theta, high alpha and standard beta. To execute the analysis of the changes in the executive function and mood, the direct scores of the Iowa, PANAS and POMS tests were used, respectively. Scores of different dependent variables were previously subjected to test of normality through analysis with evidence not parametric (*Kolmogorov Smirnov* for a sample) to be confirmed in all cases (K-S >. 05). For the analysis of the differences pre-and post-treatment inter-group, it was used a model of ANOVA with repeated measures 2 X 3 and used T-tests for samples related post-hoc in order to contrast the means. It was added the Cohen's index as proof of the size of the effect. Finally bivariate correlations were performed to establish possible relationships between variables EEG and IOWA, EEG and POMS and EEG and PANAS, choosing the Spearman Rho due to the reduced n of the respective groups. All analyses were performed using SPSS software. The data are presented in means and standard deviations.

Results

Effects on Executive Function

There were no significant changes in the main effect (F (1,27) = 2.18 ; p =.15), but we found a significant interaction between treatment group and the group variable, with significant differences before and after the treatment depending on the group (F (2, 27) = 3.68 ; p <.03) for the scores of the *Iowa Gambling Task*. Conducted post-hoc analysis through T-tests for related samples, finding that the control group did not exhibit significant differences in their performance in the *Iowa* after training (p = .12). Likewise, in the case of group LH, no significant differences were observed with the training in NF (p = .31), while a decrease in the performance was observed, this is not significant. Finally the group RH it shows significant statistical changes post-training (t = -2,519, p < .01; effect size according to Cohen's d index = .92). In Figure 1 you can see the significant increase of the mean in the gain obtained in the *Iowa Gambling Test* to the group RH.

Effects on mood

Significant differences were found in Positive mood measured through the PANAS between the pre and post-training conditions, showing a significant main effect (F (1,27) = 27.724; p <.001) without interactions between the groups. In Figure 2 it can see a significant drop in the mean scores of positive PANAS in a similar way for the three groups. While there were no significant differences between the groups, it should be noted that the Cohen's index was higher in group RH (d = 1.25) compared to the LH (d = .78) or control (d = .55). No significant differences were found between the scores of the negative PANAS or in the scores of the POMS.

Effects on the EEG

There were no significant changes in the theta band (F (2,27) = 1.005 ; p = .37), but a tendency to the significance in the standard beta band was found (F (2,27) = 2.608 ; p =.09). It was explored this last with post hoc tests to find that, although there was no statistically significant changes in any group, it was highlighted a greater increase in the means in the RH group (Cohen's d index = .21) with respect to the LH (Cohen's d index = .08), and at the same time noting that the control group presented a non-significant decrease with training (Cohen's d index = .30). Figure 3 represent these changes in the means for the three groups.

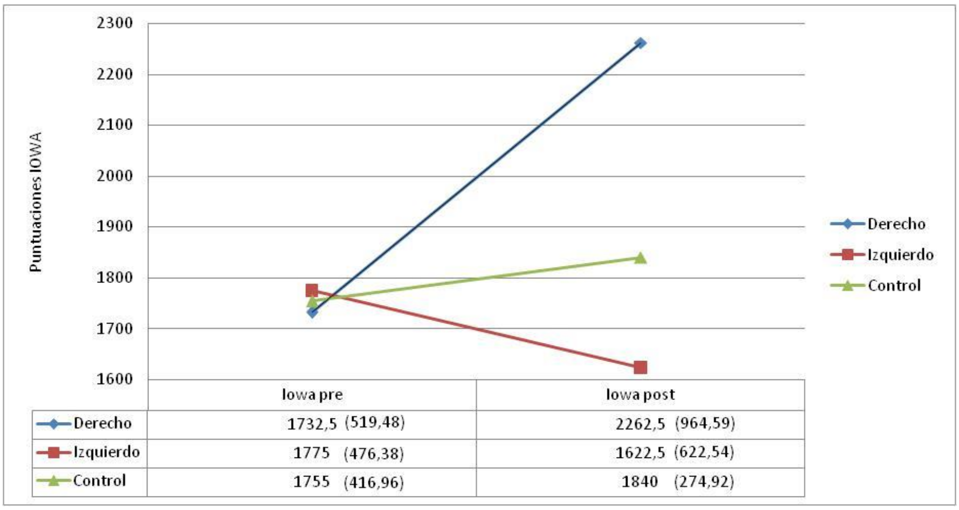

Figure 1. Difference of means (and standard deviation), between pre and post-training performance on the *Iowa Gambling Test* for each study group.

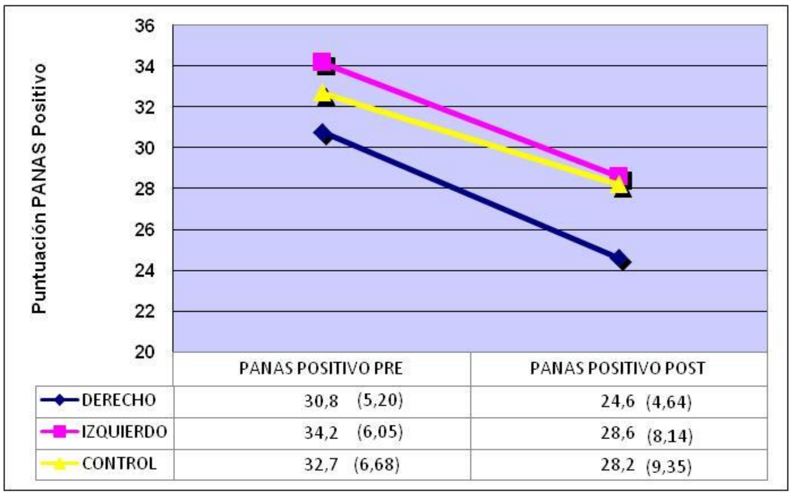

Figure 2. Main effect of training in NF on the Positive Affect in the three conditions of study (means and standard deviations).

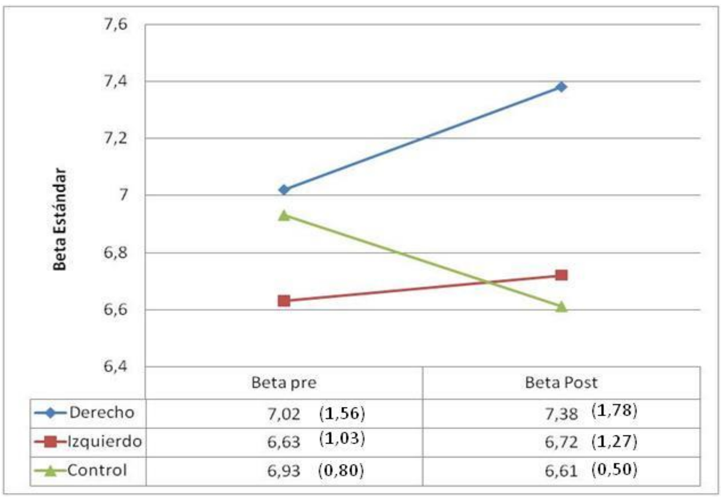

Figure 3. Differences of post-treatment changes in standard Beta band (13-21hz) between groups (means and standard deviations).

Relationship between changes in the EEG and the executive function post-training

It was identified a negative correlation toward the significance between the theta frequency band and the performance in the *Iowa Gambling Task* in the RH group (*Spearman's Rho* = -.57; *p* = .08). No significant correlations were identified nor in the LH group or the control group at the level of post-training.

Relationship between changes in the EEG and the positive and negative affect

Significant correlations were obtained for the group RH. Both negative PANAS scores as the POMS were positively correlated with the theta rhythm (negative PANAS, *Rho* = .69; *p* < .02 and POMS, *Rho* = .65; *p* < .04). In addition, the scores obtained on the POMS showed a significant positive correlation with the low alpha band (*Rho* = .67; *p* <.03). No correlations were found between the EEG variables and affection nor for the LH or to the control group.

Discussion

In relation to the effects on executive function, the results obtained support the effectiveness of the training in *neurofeedback* to enhance specific cognitive abilities from the first session. Significant changes in performance in the task of the *Iowa Gambling Task* compared with the control group and the group LH, support the evidence from previous studies (Boynton, 2001; Doppelmayr, Klimesch, Stadler Polhuber, & Heine, 2002; Egner & Gruzelier, 2004; Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998; Vernon, Egner, Cooper, Compton, Neilands, Sheri, & Gruzelier, 2004) to enhance some of the elements of executive function like decision-making and delaying gratification, aspects that would include supramodal functions as flexibility, fluidity and inhibitory control (Bockova et al., 2007; Boynton, 2001; Lubar, 1991). Hanslmayer, Sauseng, Doppelmayr, Schabus and Klimesch (2005) observed in a sample of 18 healthy students the effectiveness of the training in a single session on the optimization of the cognitive performance in a mental rotation task. Our findings provide similar evidence when looking favorable effects in short time, supporting the use of the technique in the field of cognitive enhancement, and becoming an alternative to clinical populations where intervention techniques tend to be long and can lead to a low adhesion in long-term run.

In relation to the effects on mood, we found a significant decrease in the positive mood measured by the PANAS without differences between the study groups after training in NF. This may be due in part to the perception slightly "disturbing" of the technique, because the participant (both in the experimental groups as in the control without NF) should be kept 30 minutes observing a moving monotone image that is interrupted at intervals of time, which could generate some kind of physical discomfort or emotional; This effect must be measured in future research. Johnston, Boehm, Healy, Goebel, & Linden (2010) found that participants had gained self-regulation of the emotional net (amygdala and insula) through a brief training with NF, evaluated in real time through functional magnetic resonance imaging (fMRI). The subjective changes in mood were measured with the POMS and PANAS, noting a disturbance of the same that the authors explained as a possible dissonance between the effects on the own self-neural regulation and the strategies used by the participants to achieve it. Alternatively, a tentative explanation for the decrease of the positive affect in the PANAS could be that the items that form the scale (excited, awake, decided to…) describe a good state of mind but enabled and, so, the training in NF would have the effect to calm and soothe the subject. Therefore, the decrease of the positive PANAS would reflect relaxation and low activity although not necessarily a mood "less positive"; the absence of changes in the negative PANAS scale could confirm this explanatory hypothesis.

In relation to the effects of the NF on the EEG, the inhibition of theta waves (4-7 Hz) and the reinforcement of beta waves (13-21hz), has proved to be effective in studies that relate the NF training and executive function processes either clinical or healthy subjects (Fuchs et al., 2003; Monastra et al., 2001; Monastra et at., 2002; Rossiter & LaVaque, 1995). Although the findings in our study did not show significant changes in the amplitude of any frequency bands, they show a tendency to the modification regarding the increasing of beta, which makes relevant the magnitude of the change, being observed that especially the RH group changes in the expected direction (Cohen's *d* index = .21), contrary to the control group that changes in the opposite direction. The Beta findings are consistent with previous studies as the Rasey, Lubar, McIntyre, Zoffuto and Abbott (1996), who trained college students to increase it, obtaining positive results in the modification of their EEG and improving their performance in a *Go-no-go* inhibition task. Likewise, several investigations (Egner & Gruzelier, 2004; Vernon, Egner, Cooper, Compton, Neilends, Sheri, & Gruzelier, 2003) focused on increasing cognitive performance in healthy people as well as studies with clinical population with executive dysfunction (Mann, Lubar, Zimmerman, Miller & Muenchen, 1992; Monastra et al., 2001), show evidence for the empowerment of the pattern 12-15 hz, corresponding to a part of the spectrum of the Beta band (13-21hz). Regarding the theta band (4-7 Hz), it is normally associated with states of drowsiness, reverie, distraction, inattention and brain damage (Duffy, Iyer, & Surwillo, 1989). That is perhaps the reason why studies related to executive function in clinical population show an abnormal pattern of this band that is presented in disorders such as ADHD, autism and cognitive impairment (Becerra et al., 2012; Kouijzer et al., 2009; Lubar et al., 1995). This studies leads to significant changes in the theta wave, which are more likely to be modified in clinical population with abnormal basal activity of theta, and there would be no significant changes in healthy subjects.

Vernon et al. (2003) evidence what it was mentioned previously in a study with two groups of healthy students, one in which SMR waves (12-15 Hz) are trained and another study that trained the theta band. It was found that only the group trained to increase SMR waves obtained changes on EEG, as well as in performance, while those who were trained to modify theta did not obtain changes in EEG nor in cognitive performance. Anyway, in this study, although we did not find a change pre-post that was statistically significant, it was found a negative correlation between theta and the *Iowa,* indicating a negative interference but not pathological on executive performance, so their suppression by the technique of NF could be favorable. Supporting this idea, the theta band showed positive correlations with the scores of the negative PANAS and the POMS in the Group RH, suggesting that its increase promotes a negative mood and validating the findings of some studies (Davidson, 1998; Henriques & Davidson, 1991) in which qualifies the predominance of this band as inappropriate for states of relaxation and optimal performance. On the other hand, and applicable both to beta as to theta, remember that it is possible that cognitive changes can be observed from the first session, but the physiological changes and neuronal trace that accompanies them and makes them consolidated are perhaps only achievable after a repeated training, as it might be expected in any kind of learning or training.

Finally, in this study it was applied an adapted design from routine clinical practice, but it raised the possibility of identifying possible asymmetries inter-hemispherical in the administration of the NF training, since there are no studies that approach this matter and most clinical protocols apply the training in RH without specifying a theoretical justification. Here most significant and non-significant changes of relevance were actually in the RH and not in the LH. It is not clear in the literature since these asymmetries have not been explored. However a related appearance may have to do with the hypothesis of the asymmetrical *arousal* between hemispheres, arousal between hemispheres, where RH has been associated with a greater level of *arousal* as reflected in the results of this study. Since fast Beta waves level before the training is higher in the group of RH, it supports the previous conclusion and it allows the suggestion that a protocol to train the *arousal* and promoting executive function processes can have notable effects on the hemisphere of higher cortical activation and responsible for attentional processes. This is relevant if it is taken into account that the NF training is intended to balance the *arousal* and improve the level of alertness, what relies on the voluntary control of attention, functions in which the RH has the main participation (Heilman, Bowers, Valenstein, & Watson, 1986; Posner & Driver, 1992).

In conclusion, this study has demonstrated that a group of women who underwent to a single session of *neurofeedback* training, in order to inhibit slow waves and strengthen fast waves on the right hemisphere, achieved a significant improvement in the executive function and a partial modification of their EEG, increasing the beta amplitude not significantly although reasonable, taking into account that they were subjected to a single session. The mood of the sample varied significantly after training, indicating that the realization of the technique could be disturbing, which should be investigated in future studies.

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