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Effects of Combined SMR Neurofeedback and Music Listening on Executive Function and Emotional Regulation in Hispanic/Latino Polydrug Users

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Abstract

Background. Substance use disorders (SUD) are a significant health problem affecting executive function. Neurofeedback training (NFB) allows subjects to voluntarily modulate brain activity, aiming to modify cognitive processes. Studies measuring neuropsychological processes and music have found significant changes in attention, memory, and speech, supporting the notion that music enhances brain functioning. In this study, we measured cognitive processes (decision-making and attention) and emotional regulation aspects in a sample of Puerto Ricans with SUD, before and after participating in NFB-assisted training sessions with or without music. **Method.** Forty-six residency program patients were assigned to NFB, NFB+Music, or a control group. NFB protocol included reinforcement training of low beta sensorimotor rhythm (SMR) and theta and high beta inhibition at Cz. **Results.** Data suggest favorable changes in decision-making, attention, inhibitory control, and emotional regulation in the NFB groups. No differences were found in behavioral, self-reported, and EEG data between NFB and NFB+Music. Statistically significant changes on SMR amplitude were observed in both experimental groups. Self-reports underpin participants' relaxation states during NFB sessions. **Discussion.** NFB training with and without music effectively optimizes executive function; however, NFB+Music seems to have a precise effect on emotion regulation, particularly in emotion expression.

Keywords: substance use disorder; EEG-neurofeedback; sensorimotor rhythm; SMR; music

Citation: Castillo-Reyes, I. J., & Cruz-Bermúdez N. D. (2023). Effects of combined SMR neurofeedback and music listening on executive function and emotional regulation in Hispanic/Latino polydrug users. *NeuroRegulation, 10*(2), 62–77. https://doi.org/10.15540/nr.10.2.62

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Introduction

According to the U.S. Substance Abuse and Mental Health Services Administration, substance use disorders (SUD) are one of the most significant health and social problems, affecting 20.4 million people (SAMSHA, 2019). Particularly in Puerto Rico, one-fifth of the population is between 15 and 74 years old, with 9.2% suffering from an SUD (Administración de Servicios de Salud Mental y Contra la Adicción, 2009). It is known that impaired cognitive executive functions such as decision-making, working memory, attention, and inhibitory mechanisms are primary traits of SUD (Kozak et al., 2019; Noël et al., 2013). Neuroimaging studies have highlighted the dysfunctions of brain regions underlying these cognitive mechanisms in SUD (Li, Lu, et al., 2010; Noël et al., 2013). Dysregulation in motivational and affective circuits involving prefrontal cortices, amygdala, somatosensory cortex, and anterior cingulate cortex leads to impulsive behavior, poor evaluation of long-term consequences, and therefore to the occurrences of inadaptive behaviors (Bechara, 2005; Goldstein & Volkow, 2011; Koob & Volkow, 2016). These brain areas are associated not only with top-down processing (cognitive and behavioral monitoring) but with bottom-up (interoceptive) processing as well (Verdejo-Garcia et al., 2012).

Current SUD research suggests that approaches involving cognitive function strengthening might be appropriate for individuals or patients with high impulsivity levels, deficient decision-making skills, and poor executive functioning (Verdejo-Garcia, Garcia-Fernandez, et al., 2019). Moreover, the National Institute on Drug Abuse (NIDA) has supported the use of complementary strategies such as neurofeedback (NFB) to strengthen brain regions involved in executive function and inhibitory control in patients with addictive disorders (National Institute on Drug Abuse, 2010; Noël et al., 2013).

NFB training is a neuromodulation model in which individuals have access (through a brain–computer interface) to information about their neurological phenomena and are encouraged to self-regulate it through a basic principle of operant conditioning as well as through an experiential mental, perceptual, or conscious activity. In an electroencephalogram (EEG) NF setup, the individual receives real-time visual and/or audio information about their brain activity after achieving a certain state of neurological regulation. It can be used to uptrain or downtrain a rhythm or amplitude of a specific frequency or to normalize electrophysiological brain activity giving feedback according to how deviated the brain activity is from a normative database. During NFB training, not only are neuronal circuit ensembles modified but also the conscious psychophysiological activity involved with them.

SMR Training on SUD Population

Sensorimotor rhythm (SMR) NFB training (12–15 Hz, or low beta) has shown effectiveness in counteracting cognitive and behavioral impairment associated with SUD (Sokhadze et al., 2014). SMR training was one of the first protocols used in the NFB field and tested within the animal model. Sterman et al. (1970) demonstrated that increasing the amplitudes at this frequency range made cats more resistant to the effects of a convulsive substance. Sterman (2010) also applied this protocol on human models showing significant reduction of seizures after SMR conditioning. Later on, Lubar and Lubar (1984) applied this protocol (SMR uptraining including theta down training) to children with attention-deficit disorders with hyperactivity, showing remarkable results on motor control and school performance. It is believed that SMR training produces greater integration of information in the cortex as it targets inhibitory mechanisms of thalami-cortical circuitry (Kaiser, 2008). This circuit regulates bottom-up mechanisms that reduce the interference of somatosensory information, enabling the cortex to process the information more effectively while relaxing the motor interferences (Gruzelier & Egner, 2005; Kober et al., 2015).

In the 2000s, SMR training protocol was added to the popularized Peniston and Kulkosky alpha-theta training protocol in a sample with mixed SUD by Scott et al. (2005). The authors believed that stabilizing attentional variables through SMR training would produce better outcomes after the alpha-theta training. As is known, ADHD and SUD are common comorbidities (Zulauf et al., 2014). Scott et al. (2005) reported decreasing depressive personality symptoms and anxiety, improvement of attentional variables, refining treatment adherence, and abstinence. Since that study, SMR NF training has been successfully employed on alcohol (Lackner et al., 2016), cocaine (Burkett et al., 2005; Horrell et al., 2010), crystal meth (Rostami & Dehghani-Arani, 2015), opioids (Cannon et al., 2008; Dehghani-Arani et al., 2010, 2013), mixed abusers (Keith et al., 2015), and general SUD with comorbid diagnosis (Fielenbach et al., 2018). These studies have generally reported beneficial changes of SMR NFB as a stand-alone or add-on intervention on cognitive executive functioning (i.e., attention), psychological symptomatology, addiction severity, quality of life, compulsive behavior, drug craving, and relief from withdrawal.

Music Listening on Cognition and Behavior

Appreciation of music, particularly classical music, has been reported to produce an optimization of cognitive performance (Thompson et al., 2005). There are two types of interventions in the field of music therapy: receptive music therapy (RMT) and active music therapy (AMT; Li, Wang, et al., 2015). The RMT involves the listening of music provided by the therapist as a sung song or a musical production. The AMT consists of active participation in the musical creation, whether singing, playing an instrument, or improvising musically with body movements. Playing musical instruments requires the interaction of superior cognitive functions, and continuous practice produces complex changes in motor, auditory, and multimodal skills associated to functional and structural neuroplasticity (Schlaug et al., 2005).

Music stimulates multiple brain regions, particularly the brain stem, inferior colliculus, middle geniculate body, and the primary and secondary auditory cortices (Ragot et al., 2002). Neuroimaging studies show that music modulates metabolic brain activity in the amygdala, nucleus accumbens, hypothalamus, hippocampus, insula, cingulate cortex, and orbitofrontal cortex, all associated with the regulation of emotions (Koelsch, 2014). Music listening as therapy, being a form of nonpharmacological intervention like NFB, positively modifies impulsivity, autonomic responses, memory, mood, and emotional regulation (Panksepp et al., 2012; Rickard et al., 2005). Therefore, the potential of music to produce changes in brain activity has implications for the development of neurological and psychiatric disorders interventions.

Music appreciation produces changes in basic socio-emotional feelings (socially constructed emotions) such as nostalgia, sadness, and tenderness. A series of theoretical studies have explored how music listening facilitates cognitive and affective self-regulation. For example, listening to music can be used to change, maintain, or reinforce affection, mood, and emotion (Chen et al., 2007) to unleash nostalgia and promote emotional regulation (Lonsdale & North, 2011; Van Goethem & Sloboda, 2011), to stimulate cognitive effects (Sloboda et al., 2016), as a meaningful tool for a social group (Maher et al., 2013), or as a tool promoting cognitive reassessment (Saarikallio & Erkkilä, 2007).

Few experimental studies have systematically measured the effect of listening to music on neuropsychological processes, particularly exploring its therapeutic effects in SUD populations. Researchers have found significant effects in executive-type cognitive processes such as sustained and focused attention, working memory, fluency of categorization and fluency of speech (Irish et al., 2006; Maclean et al., 2014; Mammarella et al., 2013; Särkämö et al., 2008; Thompson et al., 2005). Two studies revealed statistically significant results in variables related to mood (Baker et al., 2007; Särkämö et al., 2008). In four of these studies, investigators selected music from the Baroque period, particularly music by Vivaldi (Irish et al., 2006; Lake & Goldstein, 2011; Mammarella et al., 2013; Thompson et al., 2005) and the Jimmy Shand’s Blue Polka piece (Maclean et al., 2014). In another study, authors used popular music (e.g., Foo Fighters, John Lennon, Elvis Presley) and found that music therapy sessions facilitate the experiencing of a moderate to high degree of positive emotions (Baker et al., 2007). The evidence supports the notion that incorporating passive listening of classical music to NFB training might enhance brain functional and cognition.

The primary objective of this study was to explore the effects of SMR NFB on executive functions such as sustained attention and decision-making on an SUD sample. The secondary objective was to test an SMR NFB protocol that included Baroque music listening during the NFB training on a SUD sample. Other outcome variables included were self-reported emotional and attentional regulation.

Methods

This study was authorized by the University of Puerto Rico-Río Piedras’ Institutional Review Board (protocol #145-038) and was conducted in accordance with the Declaration of Helsinki. The study complied with ethical standards for the protection of human participants in research, including an informed consent process.

Study Design

The study design was based on a not blinded, randomized controlled trial with pre and post measurements.

Participants

We recruited 59 adults by availability. Participants were receiving treatment for SUD in residential programs operated by nonprofit organizations in the metropolitan area of San Juan, Puerto Rico. These programs are supervised by the Mental Health and Addiction Services Administration (ASSMCA, in Spanish) of Puerto Rico’s Health Department and provide rehabilitation services from a biopsychosocial perspective to adult men and women, including individual and group therapy based on a cognitive behavioral therapy (CBT) integrative model, occupational therapy, and spirituality (optional). The final sample was composed of 16 men and 27 women (n = 46) between the ages of 21 and 50 years, most of them polydrug users (79%). Participants were randomly assigned to the NFB experimental group (n = 14), NFB+Music experimental group (n = 13), and control group (n = 16, treatment as usual). There were not significant differences ($p > .05$) in group composition (see Table 1 χ^2 analysis). Participants who did not complete the first stage of treatment (detoxification and stabilization) and had a history of brain lesions were excluded. Patients with ongoing medication were included.

Table 1
Sociodemographic

Variables	Group				
	Control (%) (*n* = 16)	NFB (%) (*n* = 14)	NFB+Music (%) (*n* = 13)	χ^2	*p*
Sex				0.537	.76
Men	7 (43.8)	5 (35.7)	4 (30.8)		
Women	9 (56.2)	9 (64.3)	9 (69.3)		
Age				7.79	.78
21–25	3 (18.8)	5 (35.7)	1 (7.7)		
26–30	3 (18.8)	2 (14.3)	3 (23.1)		
31–35	3 (18.8)	2 (14.3)	2 (15.4)		
36–40	2 (12.5)	2 (14.3)	4 (30.8)		
41+	5 (31.2)	3 (21.4)	3 (23.1)		
Medication				1.39	.49
Yes	11 (68.8)	12 (85.7)	9 (69.2)		
No	5 (31.2)	2 (14.3)	4 (30.8)		
Drugs				20.14	.06
Cocaine (only)	4 (25)	0 (0)	0 (0)		
Meds (only)	2 (12.5)	0 (0)	0 (0)		
Marijuana (only)	1 (6.2)	2 (14.3)	0 (0)		
Alcohol and Cocaine	0 (0)	0 (0)	1 (7.7)		
Cocaine and Meds	0 (0)	0 (0)	1 (7.7)		
Meds and Marijuana	1 (6.2)	0 (0)	0 (0)		
Mixed substances (more than 2)	8 (50)	12 (85.7)	11 (84.6)		
Consumption time				8.26	.082
1 year	0 (0)	3 (21.4)	2 (15.4)		
3 years	3 (18.8)	0 (0)	0 (0)		
5 years or more	13 (81.2)	11 (78.6)	11 (84.6)		
Reported psychiatric diagnosis				11.44	.17
Depression	5 (31.2)	8 (57.1)	7 (53.8)		
Bipolar	4 (25)	1 (7.1)	0 (0)		
Anxiety	0 (0)	1 (7.1)	3 (23.1)		
Attention deficit	1 (6.2)	1 (7.1)	0 (0)		
None	6 (37.5)	3 (21.4)	3 (23.1)		

Measurements

NFB Equipment and Protocol. SMR NFB training was provided using a BrainMaster Atlantis II amplifier and BrainAvatar software (version 4.0). We set a 60-Hz notch filter, sampling rate of 256 Hz, and 125 µv artifact threshold within BrainAvatar. Based on the 10–20 system, we used a monopolar electrode montage with an active electrode on Cz for the acquisition of SMR activity, with a reference electrode in the left ear lobe (A1) and a ground site on the right ear lobe (A2). Abrasive gel and conductive paste were used for electrode attachment. The electrode impedance was monitored across all sessions and kept under 5 kΩ. We used a standardized protocol for low beta reinforcement, called “Focus” on BrainAvatar software. The feedback was provided when the criteria of increasing the amplitude of SMR frequency (12–15 Hz), and inhibition of theta frequency (4–7 Hz) and high beta frequency (22–30 Hz) amplitudes were met. The protocol followed a schedule of seven blocks of 4 min in which the participant focused on “thermometers” showing each frequency amplitude. In the first block, the patient focused on inhibiting high beta; in the next two blocks on inhibiting theta, and in the next four blocks on increasing SMR amplitude. Automatic threshold was selected. We used an external monitor and loudspeaker to provide audiovisual feedback and Baroque period music. In the NFB+Music group, the auditory feedback tone was in tune with the music selected in the key of D or G. Mind Media BV Zukor's Air game was the NFB game primarily used.

Iowa Gambling Task (IGT). This computerized cognitive task measures the decision-making process as an element of executive function (Bechara et al., 2000; Damasio, 1996). The task consists of a set of cards from four different decks, with the purpose of maximizing money gain. Participants choose cards from the decks C and D since those two offer less immediate gains, but less long-term losses. By choosing cards of decks A and B, participants win more money in the short term, but eventually lose more (Bechara et al., 2000). This paradigm was executed from an open-source PEBL platform (Mueller, 2013), which is a faithful adaptation to the original test (Bechara et al., 1994). The computerized task was administered in Spanish, with a numerical classification of the groups of letters: A = 1, B = 2, C = 3, D = 4. The contingency with which the reward and penalties appear in this version are identical to those used in the original IGT.

Sustained Attention to Response Task (SART). This Go/No-Go computerized task was used to measure executive function, particularly the ability to inhibit responses to infrequent and unpredictable stimuli during a quick, rhythmic period when frequent stimuli are responded to (Robertson et al., 1997). A modified version was administered in which stimuli (e.g., pictures of clock, book, umbrella) varied across all trials and were randomly presented at a 1.15-s rate. The task included 225 trials (each stimulus appeared 25 times) and each one fluctuated between 250 ms and 900 ms. Participants were instructed to respond by pressing the zero (0) key to each stimulus in the most accurate and possible way and to minimize errors by not responding to the "ball" stimuli. This task was executed on the E-prime platform (Psychology Software Tools, 2012).

Emotion Regulation Questionnaire (ERQ). This 10-item scale measures the tendency of participants to regulate their emotions in two ways: cognitive reassessment of emotions and expressive suppression of emotions (Gross & John, 2003). The participants responded to each item using a 7-point Likert scale on intervals ranging from 1 (*strongly disagree*) to 7 (*very much in agreement*).

Attention-Related Cognitive Errors Scale (ARCES). This 12-item scale explores daily mistakes that a person makes as a result of not paying enough attention to a task (Cheyne et al., 2006). Participants responded to each item in a 5-point Likert scale on intervals ranging from 1 (*never*) to 5 (*very often*).

Mindful Attention Awareness Scale (MAAS). This 15-item scale measures the dispositional capacity of a person to be attentive and aware of the experience of the present moment in everyday life (Brown & Ryan, 2003). The respondents answered each item in a 6-point Likert scale on intervals ranging from 1 (*almost always*) to 6 (*almost never*).

Procedure

Participants signed the inform consent to join the study and they completed a sociodemographic questionnaire and each of the scales (i.e., SART, ERQ, ARCES, MAAS). After randomization, the experimental groups (NFB and NFB+Music) received between 10 and 20 training sessions, 2 to 3 days a week for 4 to 8 weeks. The number of sessions was determined according to each participant's mastery level, availability, and desire to continue sessions based on his or her perceived quality of life improvement.

At the start of each training session, participants sat down with eyes open in a comfortable chair and were instructed to learn to control their brain activity. Muscle relaxation was encouraged throughout the sessions. The average of NFB sessions was 13.85 (*SD* = 2.35) and each one lasted around 30 min. If a participant reported tiredness prior or during the NF session, a 15-min training was conducted. After the session, participants were given the opportunity to verbally report their experiences. Participants were reassessed with the previously mentioned scales and tasks after completing the training sessions.

Analyses

Data were calculated and analyzed using SPSS (version 23, IBM) and Excel (Microsoft). IGT net scores were obtained by subtracting the number of favorable selections represented in the C + D cards, minus the number of advantageous selections represented in A + B cards, segmented in blocks of 20 trials. The following formula, (C + D) − (A + B), was calculated for each block selection from 1–20, 21–40, 41–61, 61–80, and 81–100. An ANOVA 3 X 5 (group X blocks) was used to identify possible interaction effects, group X blocks in the pretest, and then in the posttest. Then, an ANOVA 3 (group) x 2 (group X pre and post) was conducted to identify pre and post changes for each block in relation to the groups. After the task completion, participants were asked to explain their task strategies.

SART performance was analyzed calculating the errors by omission (not responding to the stimuli: GO) and errors by commission (respond to the ball stimulus: NoGo), and reaction times. A mixed ANOVA was conducted to evaluate within-group and between-group changes for errors by omission and commission errors and reaction time for Go stimuli.

Reliability tests were evaluated for all self-report measurements using the pretest data. A mixed ANOVA was conducted to calculate within-between groups mean differences. A Pearson correlation coefficient was conducted to explore associations across self-report measurements.

SMR EEG amplitude grand mean were calculated for session #1, session #6, and session #11. Repeated-measures ANOVA were performed to compare SMR amplitude changes on experimental groups. A mixed ANOVA 3 X 2 was conducted to identify Time X Group interaction. A series of paired *t*-tests were conducted to compare between a pair of sessions. Descriptive analysis for all scores was also carried out.

Results

Effects on IGT

An ANOVA 3 (group) x 5 (blocks) on the net scores (C + D) − (A + B), using the correction for the degrees of freedom of Huynd-Feldt, did not reveal Group X Block interaction in the pretest, *F*(8, 160) = 0.63, *p* = .74, *η2* = .031. The net scores between the groups for the five blocks of cards did not differ in the pretest. However, using the Huynd-Feldt correction, the same analysis revealed a Group X Block interaction effect in the posttest, *F*(5.91, 160) = 2.22, *p* = .04, *η2* = .10. The finding revealed potential changes over time in the selection of the blocks among the groups.

The ANOVA 3 (group) x 2 (pre and post block) for evaluating the interaction of the effect of time for each block in relation to group, revealed no significant differences in the scores for the 1–20 selection block, *F*(2, 40) = 0.037, *p* = .96, *η2* = .00. The same was found for the 21–40 selection block, *F*(2, 40) = 0.039, *p* = .96, *η2* = .00; and the 41–60 selection block, *F*(2, 40) = 1.22, *p* = .30, *η2* = .05. However, we found significant differences in the scores for the 61–80 selection block, with a medium effect size, *F*(2, 40) = 3.26, *p* = .04, *η2* = .14. Time difference scores for each group in this block were the following: control group (pre: *M* = −0.88, *SD* = 4.73; post: *M* = −0.25, *SD* = 4.49), NFB (pre: *M* = −2.29, *SD* = 4.21; post: *M* = 4.00, *SD* = 8.44), and NFB+Music (pre: *M* = −1.00, *SD* = 4.83; post: *M* = 4.62, *SD* = 8.57).

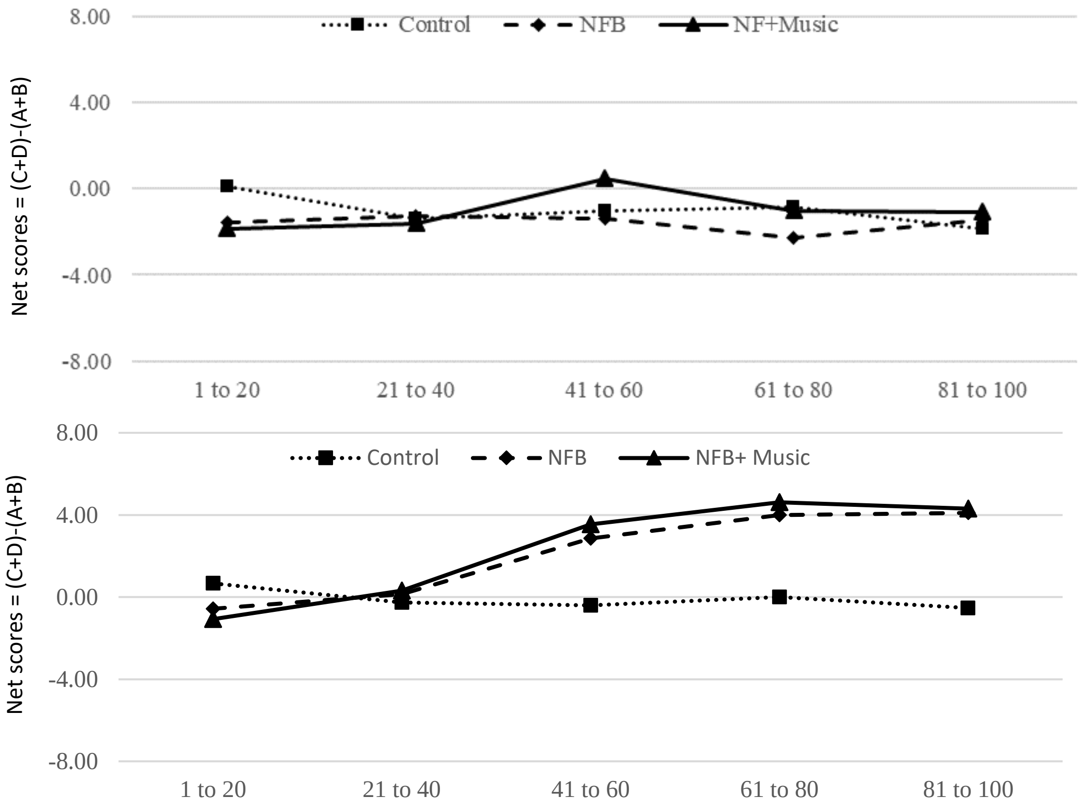
In the 81–100 selection block, we found no significant differences in the scores, but the effect size remained medium, *F*(2, 40) = 2.55, *p* = .13, *η2* = .09. Subsequent comparisons revealed no differences in scores between the experimental groups across all selection blocks.

Regarding the card selection strategy, most participants used a selection pattern intercalating choices between the set of cards in both the pretest and posttest. For example, a participant would select the set of cards in the order that they appeared on the screen or with a skipping strategy (i.e., selecting A + C, then B + D). In the pretest, only 16% of the sample could explain with precision the task and identified favorable versus unfavorable blocks of cards. However, despite constant losses, participants were inclined to continue selecting the disadvantageous cards because “they earned more money” with those.

A similar pattern was observed in the posttest. In the experimental groups, although the selection pattern showed a tendency to favorable card blocks, 63% of the participants could not describe conceptually which blocks of cards were more favorable and continued intercalating their choices despite the losses. However, 37% of the participants in the experimental groups (*n* = 10), described the task conceptually and were able to distinguish favorable from unfavorable blocks (*n* = 6 in NFB+Music, *n* = 4 in NFB). For the most part, they changed their course of selection toward favorable blocks of cards. Of those 10 participants, one participant who belonged to the NFB+Music group described the task conceptually accurately; however, the performance showed a tendency toward unfavorable cards in the posttest.

In the control group, 25% of the participants (*n* = 4) were able to identify the advantageous sets of cards from the unfavorable ones in the posttest. However, they did not change their card choices in the last blocks of the task.

Figure 1. *IGT Pretest (Above) Versus Posttest (Below) Net-Scores by Blocks of Trials*.



Effects on SART

Omission errors analysis in the SART showed that, although an improvement was shown in the experimental groups, there was no significant effect between Time X Group interaction, $F(2,40) = 2.19$, $p = .12$, $\eta 2 = .09$. Analysis of commission errors revealed a significant difference with a large effect size on the Time X Group interaction, $F(2, 40) = 6.19$, $p = .00$, $\eta 2 = .236$. This result suggests that the participants of the experimental groups NFB (pre: $M = 27.85$, $SD = 14.28$; post: $M = 18.50$, $SD = 18.50$) and NFB+Music (pre: $M = 17.46$, $SD = 10.72$; post: $M = 10.30$, $SD = 5.89$) were more efficiently inhibited to the NoGo stimulus compared to control (pre: $M = 23.00$, $SD = 16.33$; post: $M = 22.75$, $SD = 15.87$). Reaction time analysis revealed no significant effect on the Time X Group interaction, $F(2, 79) = .311$, $p = .73$, $n2 = .01$.

Table 2
SART Omission Errors, Commission Errors, and Reaction Time for GO Stimulus Averages

Groups	Omission Errors		Comission Errors*		Reaction time GO	
	Pre (*SD*)	Post (*SD*)	Pre (*SD*)	Post (*SD*)	Pre (*SD*)	Post (*SD*)
Control	23.00 (16.33)	22.75 (15.87)	12.63 (5.32)	13.44 (4.45)	398.42 (62.39)	378.53 (58.62)
NFB	27.36 (14.28)	18.50 (15.14)	15.21 (5.70)	10.93 (5.99)	388.22 (70.31)	370.29 (54.41)
NFB+Music	17.46 (10.72)	10.31 (5.89)	14.54 (5.57)	8.38 (3.92)	378.79 (40.45)	376.20 (66.35)

Note. * < .01

Effects on ARCES

ARCES reliability analysis revealed an *α* value of 0.869, proving to be a reliable instrument to assess the SUD population. A mixed ANOVA showed no significant main effect of the group variable on the ARCES scores, *F*(2, 40) = 2.02, *p* = .146, *η2* = .09. However, a significant effect and a large effect size were found between Time X Group interaction, *F*(2, 40) = 15.76, *p* = .000, *η2* = .44. Time difference scores for each group were the following: control group (pre: *M* = 40.19, *SD* = 9.36; post: *M* = 40.31, *SD* = 9.99), NFB (pre: *M* = 44.50, *SD* = 12.69; post: *M* = 27.57, *SD* = 12.67), NFB+Music (pre: *M* = 45.38, *SD* = 16.14; post: *M* = 20.77, *SD* = 5.51). These findings suggest that participants in the experimental groups improved their scores over time, after SMR NFB.

Effects on MASS

MASS reliability analysis revealed an *α* value of 0.819, proving to be a reliable instrument to assess the SUD population. A mixed ANOVA analysis showed no significant main effect of the group variable on the MASS scores, *F*(2, 40) = 2.67, *p* = .81, *n2* = .11. However, significant difference with a large effect size was found between Time X Group interaction, *F*(2, 40) = 13.22, *p* = .00, *η2* = .398. Time difference scores for each group were the following: control (pre: *M* = 52.31, *SD* = 12.46; post: *M* = 53.50, *SD* = 14.39), NFB (pre: *M* = 43.86, *SD* = 18.01; post: *M* = 67.36, *SD* = 18.95), NFB+Music (pre: *M* = 50.69, *SD* = 16.52; post: *M* = 77.15, *SD* = 6.17). These findings suggest that participants in the experimental groups significantly improved their scores over time, after training with SMR NFB.

Effects on ERQ

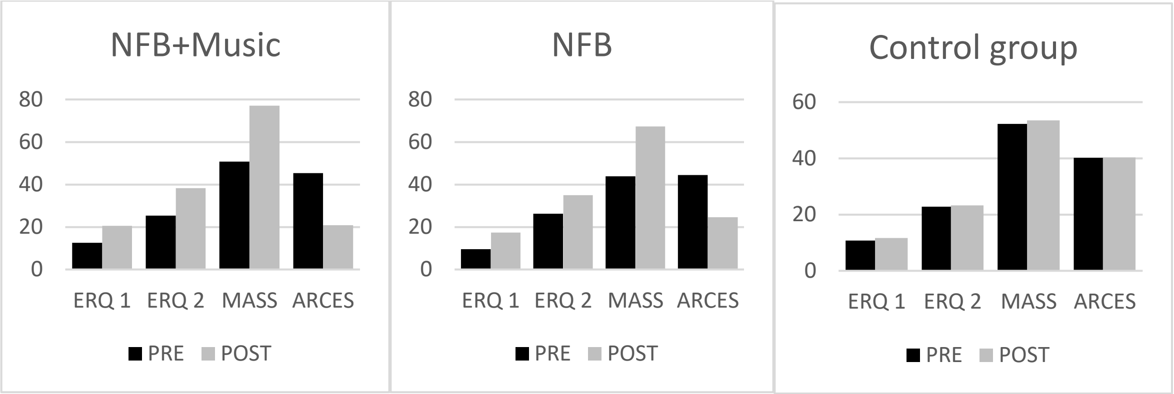
Reliability analyzes for the ERQ initially revealed little reliability for the Emotional Suppression subscale (*α* = 0.65) in this population. Leaving the subscale item #2 out of the analysis (i.e., “I keep my emotions to myself”), it reached an *α* value of 0.731. Therefore, score analyzes in this subscale were made after eliminating item #2. In this scale, the Likert scale values were inverted; the value of 7 represents a positive value (i.e., emotional expression) and lower values represent a negative value (i.e., no emotional expression). The Cognitive Evaluation subscale obtained an initial *α* value of 0.719 and the Likert scale values were not inverted during analysis.

Cognitive Reappraisal Subscale. A mixed ANOVA showed a significant main effect of the group variable with a large effect size, *F*(2, 40) = 6.92, *p* = .003, *η2* = .25. In addition, a significant difference with a large effect size was found on Time X Group interaction, *F*(2, 40) = 6.41, *p* = .004, *η2* = .24. Multiple comparisons from the Bonferroni method showed significant differences in the posttest in the control group (*M* = 23.31, *SD* = 9.33) compared to the NFB group (*p* < .05; *M* = 34.93, *SD* = 6.86) and NFB+Music group (*p* < 0.01; *M* = 38.31, *SD* = 4.07). The NFB groups without Music and NFB+Music did not differ significantly (*p* > .05).

The scores for each group as a function of time are as follows: control (pre: *M* = 22.81, *SD* = 9.56; post: *M* = 23.31, *SD* = 9.33), NFB without Music (pre: *M* = 26.29, *SD* = 8.90; post: *M* = 34.93, *SD* = 6.86), NFB+Music (pre: *M* = 25.38, *SD* = 9.39; post: *M* = 38.31, *SD* = 4.07).

Expression Suppression Subscale. A mixed ANOVA showed a significant main effect of the group variable and a large effect size on the subscale of Emotion Expressive Suppression, *F*(2, 40) = 6.38, *p* = .004, *η2* = .24. However, no significant interaction effect was found for Time X Group, although a large effect size was obtained, *F*(2, 40) = 3.21, *p* = .051, *η2* = .13. Multiple comparisons from the Bonferroni method showed significant differences in the control group (*M* = 11.62, *SD* = 7.20) compared to the NFB group (*p* < .05; *M* = 17.14, *SD* = 7.32, *p* = .02) and NFB+Music group (*p* < .05; *M* = 20.53, *SD* = 4.92, *p* = .00) in the posttest. The NFB and NFB+Music groups did not differ significantly (*p* > .05). Scores for each group as a function of time were as follows: control (pre: *M* = 14.88, *SD* = 5.63; post: *M* = 11.63, *SD* = 7.20), NFB (pre: *M* = 16.36, *SD* = 4.65; post: *M* = 17.14, *SD* = 7.32), and NFB+Music (pre: *M* = 14.46, *SD* = 5.63; post: *M* = 20.53, *SD* = 4.92).

Figure 2. *Pre Versus Post Self-report Measurements Review.*



Note. ERQ 1: Cognitive Reappraisal subscale. ERQ 2: Suppressive Expression subscale.

Effects on the EEG

Significant changes and large effect size were observed on the main effect of time (average values on training sessions #1, #6, and #11) on the SMR mean amplitude for the experimental groups, *F*(2, 50) = 11.38, *p* = .00, *η2* = .31. Paired *t*-test for a pair of sessions revealed no significant differences from session #1 to session #6, but significant differences from session #6 to session #11, *t*(26, *N* = 27) = −4.86, *p* = .00, *d* = .38; and from session #1 to session #11, *t*(26, *N* = 27) = −2.90, *p* = .00, *d* = .27. The average values for each training sessions were as follows: session #1 (*M* = 5.44, *SD* = 1.64), session #6 (*M* = 5.25, *SD* = 1.48), and session #11 (*M* = 5.86, *SD* = 1.67). No interaction effect was found on Time X Group, *F*(2, 50) = .312, *p* = .73, *η2* = .01. Averages for the groups were the following: session #1, NFB group (*M* = 5.13, *SD* = 1.64) and NFB+Music (*M* = 5.77, *SD* = 1.39); session #6, NFB group (*M* = 4.95, *SD* = 1.63) and NFB+Music (*M* = 5.57, *SD* = 1.28); session #11, NFB group (*M* = 5.64, *SD* = 1.89) and NFB+Music (*M* = 6.09, *SD* = 1.44). Figures 3 and 4 illustrate the results of changes in SMR amplitude in microvolts (μV).

Figure 3. *SMR (μV) Average Amplitude for the Experimental Groups.*

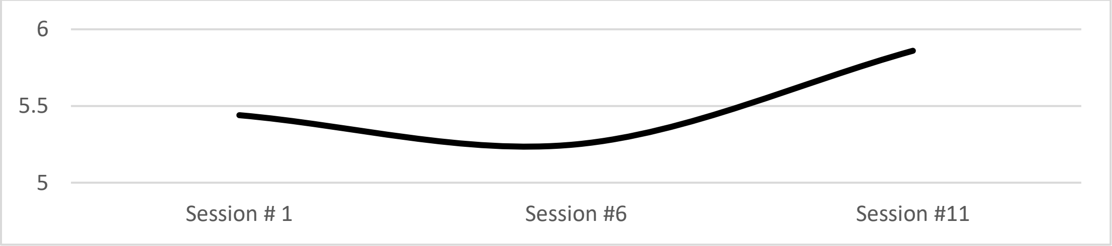
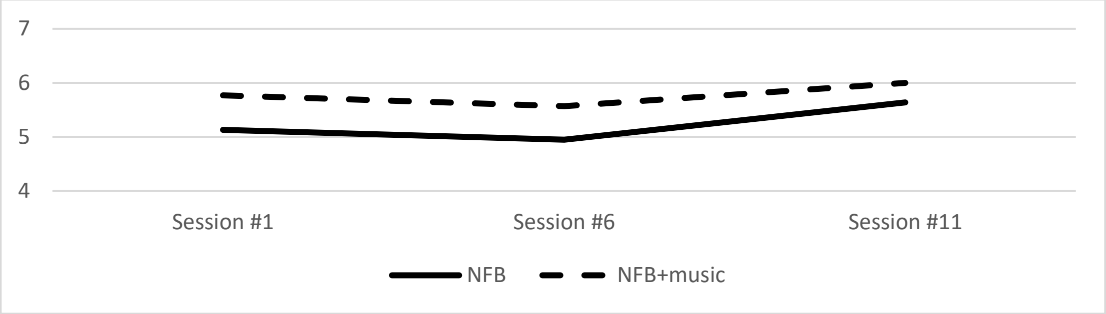


Figure 4. *SMR (μV) Amplitude NFB Versus NFB+Music.*



Discussion

We measured the effects of combined SMR NFB and music on executive functions in individuals with SUD. To the best of our knowledge, this is the first study testing assisted NFB training with “music” on a Puerto Rican SUD sample. Additionally, this study used a control group and cognitive tasks as assessment tools to specifically measure executive function. Here we discuss relevant results and highlight peculiarities of the training procedure. We also identify challenges, limitations, and recommendations for future research.

Effects of NFB and Music on IGT

IGT pretest results confirmed previous findings within the SUD population (Bechara & Damasio, 2002). These individuals typically do not achieve adequate performance in this cognitive task. According to Martínez-Selva et al. (2006), this phenomenon may be due to different factors: (a) preference for high-risk options; (b) inability to evaluate and distinguish favorable from unfavorable letters; (c) hypersensitivity to reward; (d) insensitivity to punishment; (e) problems with executive function (e.g., working memory); (f) low attentional performance; and (g) problems with impulse control. According to Bechara (2005), a myopia occurs over the future consequences of the decision, possibly due to dysfunctional connectivity in neural networks involved in the integration of bottom-up interoceptive signaling in decision-making processes (e.g., prefrontal cortex, amygdala, somatosensory regions, insula). The usual decisional behavior in individuals with SUD begins with an increased tendency to select card blocks in the middle, toward favorable cards, and then resume a decisional pattern for unfavorable cards (Bechara & Damasio, 2002). Bechara and Damasio (2002) have linked this decisional pattern to the lack of generation of anticipatory autonomic signals (i.e., somatic markers) that direct the decision based on previous experience. The results of our study suggest that NFB can potentially optimize interoception by modifying the SMR frequency generated by brain areas involved in this process.

The activity of SMR has been linked to the promotion of inhibitory mechanisms on the thalamo-cortical loop, which reduces motor interference, allowing optimization of cognitive processing and enabling the improvement of interoception, perception of the body, or body awareness (Egner & Gruzelier, 2004; Noël et al., 2013). Interoception refers to processes by which the bodily states (or somatic states) are transmitted back to the brain, giving rise to the awareness of the internal state and motivating the behavioral responses for homeostatic internal state (Verdejo-Garcia, Clark, et al., 2012). SMR NFB might promote the acquisition of somatic states (corporal and affective sensations) and more adaptive responses as we observed in the posttest. This regeneration of somatic states might suggest the regulation of autonomous bottom-up signals originating from the amygdala, which are involved in objective-oriented cognitive processes and the willpower to resist drugs (Bechara, 2005). It is in this sense that Noël et al. (2013) have recommended technologies and interventions of biofeedback and meditation as compatible methods to optimize interoception.

The optimization of decision-making through SMR NFB is evident in both experimental groups when compared to control, particularly at the penultimate block (61–80). Nonetheless, it is important to note that the averages did not approach what is considered an optimal task performance in the posttest. Bechara (2003) considers a good performance equivalent to a net-score close to 10 in individuals without SUD or brain lesions. In this study, participants reached a net-score close to 4 in the last blocks of the IGT in the posttest. The statistical significance between the groups decreased in the last block (81–100), which suggest that maybe a higher number of training sessions are needed for this score become close to 10.

The changes on IGT performance after training might be also associated with variations in the execution strategy and aspects of working memory (Bagneux et al., 2013). Deficits in working memory decrease the chances of selecting favorable cards and lower individuals' capacity to identified favorable cards. However, in the posttest, the experimental groups simultaneously changed their selection course to more favorable card blocks as they conceptually figured out the task. Although working memory was not a variable considered in this study, results suggest possible neurocognitive changes in this function. The link between SMR training and changes in short-term visual memory in both clinical and healthy populations has also been studied previously (Kober et al., 2015). We suggest the use of objective measures and the implementation of NFB for optimizing memory-related variables.

Effects of NFB on Attentional Variables

Previous studies have shown that SMR NFB training induces less commission and omission errors, better attention, and impulse control in Go/NoGo tasks in SUD population (Kaiser & Othmer, 2000; Keith et al., 2015; Scott et al., 2005) This type of training protocol has been shown to have an effect in fronto-striatal circuits (bilateral caudate and left black substance) during tasks that involve executive cognitive functions such as attention (Keith et al., 2015). This is important because this circuit also plays a central role in decision-making in people with SUD (Keith et al., 2015; Keramati & Gutkin, 2013). In the present study, significant differences were only found in commission errors analyses which demonstrates the effectiveness of SMR NFB training to enhance inhibitory mechanisms that enable impulse control (Kaiser & Othmer, 2000). However, not significant changes were found on reaction times and omission errors. Greater inhibition in the NFB+Music group was found, although the reaction times didn't change. The NFB group showed better reaction times than the NFB+Music group. Although the control group also showed remarkable improvements on reaction times, this improvement was not related to a better task performance.

NFB and Emotional Regulation

Considering the link between decision-making and emotion (Bechara, 2005), training with NFB (with or without music) in this study proved to be effective in generating changes in cognitive appraisal and expressive suppression of emotions. A novel result of our study is that NFB+Music induced changes related to emotional regulation, particularly in the expressive suppression domain. Accordingly, the presence of music during NFB training promoted the expression of emotions, which is consistent with previous research evaluating the effects of music on mood, emotion, and affectivity (Baker et al., 2007; Koelsch, 2014; Lundqvist et al., 2009; Panksepp & Bernatzky, 2002; Rickard et al., 2005). Given that the suppression of feelings might be an obstacle to addiction recovery (Baker et al., 2007), listening to music as a therapeutic element could help the person to approach and express feelings during the rehabilitation process.

In terms of cognitive appraisal, the results reveal that, at the end of the training, participants of both experimental groups were able to link the changes in thought with subsequent changes in emotion (e.g., item #8: "when I want to feel a more positive emotion, I change the way I am thinking about the situation"). Additionally, we found better cognitive appraisal over negative emotions (e.g., item #5: "when I find myself in a stressful situation, I make myself think about it in a way that helps me maintain the calm").

Effects on the SMR Amplitude

The inhibition of theta and high beta frequencies, combined with a reinforcement of SMR frequency has proved effective on executive function processes in clinical or healthy samples (Arns et al., 2014). Although the results in this study do not show significant changes in the SMR frequency, it does obtain a large effect size, which makes the magnitude of the change relevant in both experimental groups. The findings in this study show an initial tendency to decrease the SMR wave amplitude in the first sessions (approximately in sessions #5 and #6) and then a tendency to increase. These findings are consistent with previous studies in clinical and healthy populations, such as the study by Arns et al. (2014). In this study, the authors trained adult patients with ADHD, using the SMR amplitude as one of their protocols. Interestingly, the authors found significant training effects of this frequency and an increase in the density of the sleep spindles concurrently with the decrease in the delay of sleep onset. This suggests that the mechanisms by which SMR training operates and its effects at the level of cognitive processing are mediated by variables associated with sleep variation. In other words, a decrease in the delay of the onset of sleep (ergo better quality of sleep) has particular effects on cognitive processing. SMR NFB may act as a moderating factor in improving cognitive processing, through the optimization of the circadian rhythm.

In this study, approximately 65% of the participants in the experimental groups were able to increase the SMR amplitude through the sessions. Arns et al., (2014) argued that the SMR NFB protocol is not about increasing the EEG amplitude in a specific frequency range, but about regulating the activity within a functional network (reticulo-talamocortical network), increasing the long-term potentiation which increases the synaptic sensitivity and the likelihood of future activations in that network. Based on this view, the researchers argued that the important thing in this protocol is that the participant learns to modulate the frequency amplitude either by decreasing it or increasing it, not necessarily increasing units in amplitude for each session; both strategies result in the increase in the density of the sleep spindles.

Process Evaluation

One of the aspects verbalized most spontaneously during training sessions in this study was the continuous description of changes in sleep patterns by the participants. Previous research has linked the common presence of sleep disorders in populations with SUD, a phenomenon also associated with the high relapse rate (Mahfoud et al., 2009). Several participants of this study expressed suffering from insomnia, frequent sleep interruptions, and difficulty falling asleep, among other manifestations. Research has revealed the effect of SMR training on circadian modulation in patients suffering from insomnia and ADHD (Arns et al., 2014; Cortoos et al., 2010). Although this was not considered as a variable in this study, most of the participants in the experimental groups perceived an immediate effect of SMR training on the quality of their sleep through the sessions. Ninety percent of the participants expressed that their sleep, each time after the sessions, seemed to be interrupted less at night. They described their sleep as deep and with a high frequency of lucid dreams.

Interestingly, the content of dreams in this population involved some interaction with the drug (e.g., buying and consuming the drug, even smelling the drug). A participant expressed his concern about his perception of an increase frequency of lucid dreams in which he sensuously experienced the consumption of the drug. This caused concern to the participant and to other participants who subsequently experienced the same. Although this phenomenon has been investigated very little, with more or less discrepancy, the literature reveals that the frequency of lucid dreams that involve consumption of the substance are very common and are indicators of recovery (Colace, 2006; Flowers & Zweben, 1998). Future research should address circadian rhythm variations as an effect of training with SMR NFB in this population.

It has been seen that SMR training has an effect in inducing a feeling of calmness and tiredness (Gruzelier, 2014). Almost all participants who were on medication expressed their intended to lower the dose of their medications because they felt calmer. Particularly the participants in the NFB+Music group, who rated the music as soothing and peaceful, which could assist in the maintenance of relaxation states in this group. The calming effect was sometimes confused with a lethargic or drowsy feeling. It was very common to identify this particular sensation and sleep during the first sessions, manifestations that have also been observed in other studies (Keith et al., 2015). These sensations showed some kind of initial adjustment to the trainings. Once a couple of initial sessions were held and participants learned to inhibit theta, they felt more resilient, managing to maintain a very stable attentional state during the sessions. Although this was the norm, two participants had to start with 10-min sessions and gradually increase the time during the next sessions, because they were not able to maintain a considerable state of alertness for more than 20 min. Most of the participants expressed a good level of mastery approximately at session #8.

Limitations

In the present study, although we tried to control different factors in the training process, the "novelty effect" and the hypermotivation of the participants could have increased observed effects. Due to the high costs of the technology and the time involved in carrying out the training, it was also not feasible to use a placebo group where training with virtual simulation of the EEG would be carried out. The diffusion of the intervention to the control group by the participants in the experimental groups caused deception feelings twice. In these cases, the participants were reoriented about the information contained in the informed consent they had signed. The presence of a placebo group, instead of a control group without training with NFB, could have lessened the feeling of disappointment of these participants in the control group.

This type of strategy has been widely debated in the NFB area in recent years (Fovet et al., 2017). Divergent opinions have questioned how ethical it is to have a subject trying to regulate physiological signals produced by a simulation, which can produce unsuspected results. In addition, it is difficult to produce a realistic simulation, for example, like the feedback of the detection of muscular movement that a normal system would offer you. In that sense, the experimental simulation condition could act as a normal training condition while the subject is being taught to try to be still and regulate. It is more desirable to explore the specific electrophysiological mechanisms in which the NFB could produce neuronal plasticity.

With respect to the amount of the sample and characteristics of the population, although the sample used in this study was considerable with respect to the number of participants available in the residency programs, a more robust study would require a larger population sample.

With respect to the analysis, in this study there is no glimpse of quantitative and qualitative data triangulation with first-person reports during the sessions. A subsequent publication should address in more detail the linkage of the neurophysiological changes with the content of the mental strategy the participants used to regulate their brain activity. Validating the neurophysiological changes with verbal self-reports or interviews would contribute more precisely to the application of the neurophenomenology project proposed by Varela (1996).

Recommendations

The use of a group with placebo training (e.g., with simulation of training or "sham NFB") could have strengthened the current design, generated more experimental control, and mitigated the "novelty effect" produced by the use of this technology. Future studies should consider the incorporation of a placebo group to control the effects of random factors, so that the benefits of NFB training can be seen more clearly. However, the realization of this type of study should seek a realistic simulation, the use of specific neurophysiological measures to explore neuroplasticity such as pre- and post-qEEG map reports and mitigate unsuspected effects that could cause induced self-regulation with signals that are not specific to the subject.

The inclusion of larger samples and the use of longitudinal designs (follow-ups) are necessary to increase the level of validity of the results in future investigations. The incorporation of qEEG measures, before and after training, would strengthen the observation of possible changes in brain activity in specific brain areas. With respect to the training protocol, individualized sLORETA *Z*-score training should be considered. The implementation of a tailored protocol, instead of a standard protocol for all participants, contributes to obtaining greater specificity by evaluating the effects of training based on individual differences.

Future studies might incorporate autonomic monitoring in the IGT performance and during the NFB protocol in order to evaluate possible changes in the re/generation of autonomic signaling (e.g., skin conductance). Similarly, the inclusion of this measure during training would provide information on physiological and affective changes in real time while the subject tries to self-regulate.

Conclusion

As other authors have suggested, no treatment or therapy program cures a disease by itself (Gossop et al., 2002). Considering the complexity of the dimensions of SUD, it is needed to articulate the therapies and treatments within a biopsychosocial scope. The results of this study suggest that brain entrainment with or without music, can potentially optimize executive functions (decision-making and inhibitory control) as well as aspects related to emotional regulation in SUD population. Certainly, the SMR NFB should be considered as a paradigm to be integrated with other clinical methods (such as pharmacology and psychological therapy) to mitigate the harmful effect of drugs from a neuropsychological perspective. Future studies should investigate and replicate these findings in more controlled studies with larger samples.

Acknowledgement

The authors gratefully acknowledge the support from the Biostatistics, Epidemiology & Research Design Core from The Hispanic Alliance for Clinical and Translational Research (Alliance, NIGMS Award Number U54GM133807).

Author Declaration

The authors declare no conflicts of interest with respect to the research, authorship, and publication of this study. There is no financial interest or benefit that has arisen from this research.

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Received: April 20, 2023
Accepted: May 29, 2023
Published: June 29, 2023