

Theta/SMR Neurofeedback Training Works Well for Some Forensic Psychiatric Patients, But Not for Others

Citation for published version (APA):

Fielenbach, S., Donkers, F. C. L., Spreen, M., Smit, A., & Bogaerts, S. (2019). Theta/SMR Neurofeedback Training Works Well for Some Forensic Psychiatric Patients, But Not for Others: A Sham-Controlled Clinical Case Series. *International Journal of Offender Therapy and Comparative Criminology*, 63(14), 2422-2439. <https://doi.org/10.1177/0306624x19849562>

Document status and date:

Published: 01/10/2019

DOI:

[10.1177/0306624x19849562](https://doi.org/10.1177/0306624x19849562)

Document Version:

Publisher's PDF, also known as Version of record

Document license:

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Theta/SMR Neurofeedback Training Works Well for Some Forensic Psychiatric Patients, But Not for Others: A Sham-Controlled Clinical Case Series

International Journal of
Offender Therapy and
Comparative Criminology
2019, Vol. 63(14) 2422–2439
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DOI: 10.1177/0306624X19849562
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Abstract

Electroencephalographic (EEG) neurofeedback could be a promising treatment for forensic psychiatric patients. Increasing evidence shows some patients are unable to regulate cortical activity. Before neurofeedback can be applied successfully, research is needed to investigate the interpersonal mechanisms responsible for patients' ability to respond to neurofeedback. A single-case experimental design allows for close monitoring of individual patients, providing valuable information about patients' response to the intervention and the time frame in which changes in clinical symptoms can be observed. Four patients with *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev.; *DSM-IV-TR*) substance use disorder and various comorbidities participated in a sham-controlled clinical case study. Self-report level of impulsivity and craving were assessed. Results indicate that one patient showed more improvements on behavioral measures after the neurofeedback training than did the others. This patient reported less impulsivity and reduced levels of self-reported craving. However, these findings could not be attributed to the neurofeedback intervention. The findings suggest that there is insufficient evidence for the beneficial effects of a theta/sensorimotor rhythm (SMR) neurofeedback intervention on

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measures of impulsivity and craving, and that there may be great interindividual differences in patients' ability to regulate cortical activity.

Keywords

neurofeedback, impulsivity, substance use disorder, offenders, EEG learning

Introduction

Forensic patients are characterized by the presence of diverse and complex problems, such as persistent and comorbid psychiatric disorders, cognitive disorders, and serious criminal offenses (Palijan, Radeljak, Kovac, & Kovacevic, 2010). One of the most common disorders in these patients is substance use disorder (SUD; Schuringa, Heininga, Spreen, & Bogaerts, 2016). The association between substance abuse, crime, and violence has been established across a wide range of addictive substances and mental disorders, such as psychotic disorders (Swanson et al., 2002) or personality disorders (e.g., Paim Kessler et al., 2012). Drug abuse is a strong predictor of violent behavior, and subsequent violent criminal recidivism (Duke, Smith, Oberleitner, Westphal, & McKee, 2018; Macdonald, Erickson, Wells, Hathaway, & Pakula, 2008). Therefore, treatment of SUD is undoubtedly one of the most important goals in the treatment of forensic psychiatric patients.

However, forensic psychiatric patients also often present with externalizing disorders characterized by high levels of impulsivity (e.g., Schuringa et al., 2016; Van Nieuwenhuizen, Bogaerts, Ruijter, Bonges, & Coppens, 2011), which can seriously hamper treatment success (e.g., Charney, Zikos, & Gill, 2010; Van der Veen, Lucieer, & Bogaerts, 2016). Their behavior is oftentimes rash and impulsive and can, in some cases, lead to "acting-out behavior" with significant negative consequences in the long term, such as the use of violence and committing criminal acts (Pompili, Carlone, Silvestrini, & Nicole, 2017; Samuels, 2011).

High levels of impulsivity are strongly associated with the development, maintenance, and relapse in substance abuse and addiction (e.g., Jentsch & Taylor, 1999; Volkow, Fowler, & Wang, 2003). Alcohol, stimulant, and opioid abusing individuals tend to also have higher levels of impulsivity as compared with nonabusing controls (Loree, Lundahl, & Ledgerwood, 2015). Higher levels of impulsivity have shown to affect severity of symptoms of substance dependency as well, and patients high in impulsivity report higher levels of drug craving (Bornoalova, Levy, Gratz, & Lejuez, 2010; Tziortzis, Mahoney, Kalechstein, Newton, & De La Garza, 2011).

Highly impulsive patients present with changes in electroencephalographic (EEG) frequencies that are thought to underlie the clinical and behavioral symptoms of impulsive behavior. Elevated theta activity (3.5-7.5 Hz) has been linked to higher levels of impulsivity (e.g., Bresnahan & Barry, 2002; Hermens, Kohn, Clarke, Gordon, & Williams, 2005; Stenberg, 1992), whereas increased sensorimotor rhythm (SMR, 12-15 Hz) activity is linked to increased inhibition mechanisms (Sokhadze, Stewart, Tasman, Daniels, & Trudeau, 2011; Serman, 1996).

Neurofeedback training uses real-time display of brain activity and aims at normalizing EEG frequencies by means of operant conditioning. In attention deficit hyperactivity disorder (ADHD), for instance, neurofeedback protocols often aim at targeting the overrepresentation of slow wave activity such as delta (0.5-3.5 Hz) and theta (3.5-7.5 Hz) frequency, and the underrepresentation of faster waves such as the SMR frequency (12-15 Hz) (Arns, Heinrich, & Strehl, 2014; Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003). The alterations in theta and SMR frequency bands have also been observed in patients with substance abuse (Sokhadze et al., 2011). A common neurofeedback protocol for the treatment of addiction is the Scott–Kaiser modification of the Peniston protocol, where the same theta/SMR protocol (followed by an alpha/theta training protocol) is applied that is also used in neurofeedback protocols targeting ADHD (Scott, Kaiser, Othmer, & Sideroff, 2005). However, it can be argued that for any substance abuse treatment to be successful, dysregulation of impulse control should be a prime candidate, as this dysregulation places individuals at risk of poor response to SUD treatment (Loree et al., 2015; Stevens et al., 2014; Tomko, Bountress, & Gray, 2016). Usually, patients treated for SUD are well aware that continuation of substance use has negative consequences, but despite this, they are unable to inhibit substance intake due to reduced inhibitory control. A theta/SMR neurofeedback training protocol aimed at reducing impulsivity might help patients to resist substance intake, resulting in beneficial effects on symptoms of substance abuse. EEG-based neurofeedback training could, therefore, be a promising treatment method for forensic psychiatric patients. It is increasingly used in the treatment of various psychiatric disorders (see Fielenbach, Spreen, Donkers, Visser, & Bogaerts, 2018).

The effectiveness of this type of training can be assessed in two complementary ways: (a) through changes in cortical brain activity posttraining, that is, normalization of deviant brain wave patterns, or increase/decrease of EEG activity in particular frequency bands, and (b) through improvements at the behavioral level underlying specific clinical symptoms (e.g., the ability to inhibit prepotent actions in favor of more suitable behavior) (Rogala et al., 2016).

There is increasing evidence that not all patients benefit from neurofeedback training, as they seem unable to learn to regulate cortical activity through neurofeedback within the number of sessions provided (e.g., Zuberer, Brandeis, & Drechsler, 2015). These patients do not show the assumed effects within the trained frequency bands, with as many as 25% of participants being categorized as so-called “non-responders” (Enriquez-Geppert et al., 2013; Zoefel, Huster, & Herrman, 2011). Other studies show that patients do achieve regulation of deviant brain frequencies, but without showing improvements in clinical symptoms posttraining (Fielenbach et al., 2018). It can be argued that successful regulation of brain activity is a necessary (but not sufficient) condition for achieving behavioral symptom improvement.

However, there are a limited number of studies that report how many patients achieved successful regulation of cortical activity and that also link successful regulation to behavioral outcomes. Also, most of these studies use a randomized controlled trial (RCT) design in which the group receiving the training is compared with another group that receives treatment-as-usual (TAU). This approach does not reveal

individual differences that might well exist between patients (Alkoby, Abu-Rmileh, Shriki, & Todder, 2017). Before neurofeedback can be applied successfully in populations with vulnerable patients, additional research is needed to investigate these inter-individual mechanisms between participants, which are (at least partially) responsible for a patient's ability to respond to neurofeedback training.

Clinical case studies involve an experimental design of a specific person, group, or event. This design offers the possibility to investigate the effect of a treatment over time. It allows for close monitoring of an individual patient, providing valuable information about a patient's response to the intervention and the time frame in which changes in clinical symptoms can be observed (Van Yperen, Veerman, & Bijl, 2017). It has also been shown that a series of well-conducted clinical case studies can provide the same level of experimental rigor and high level of internal validity as an RCT (Byiers, Reichle, & Symons, 2012; Rizvi & Nock, 2008; Task Force on Promotion and Dissemination of Psychological Procedures, Division of Clinical Psychology, American Psychiatric Association, 1995). A clinical case study will provide practitioners with detailed information about treatment effects in the current environmental setting, thereby reducing the gap between research and practice (Morgan & Morgan, 2001) and providing valuable insights for further research.

The current study is the first to apply a restricted sham-controlled series of clinical case studies in male forensic psychiatric patients. Two single-case experimental designs employed a theta/SMR neurofeedback protocol, where the SMR frequency (12-15 Hz) was enhanced and the theta frequency (3.5-7.5 Hz) was inhibited, whereas two other clinical case studies employed a sham neurofeedback protocol. Between-session effects of mean theta and SMR magnitude were monitored. Throughout the course of the study, self-report measures of impulsivity (using the Barratt Impulsivity Scale-11 [BIS-11]) and craving (using a modified version of the Desire for Alcohol Questionnaire-Short Form [DAQ-SF]) were monitored frequently.

Method

Design

A single-subject ABA design was employed (Rizvi & Nock, 2008). With this single-case experimental design, a no-training baseline phase (A¹) is followed by a neurofeedback training phase (B), which is then followed again by a no-training follow-up phase (A²). In Phase B, participants received eight sessions of theta/SMR neurofeedback training during 4 weeks (Figure 1). Throughout the course of the study, self-report measures of impulsivity and levels of craving of the participants were repeatedly measured 2 times a week. In the no-training phases A¹ and A², participants followed TAU only. TAU was different for every participant, as the different treatment modalities depend on the specific diagnosis and behavioral complaints of each patient.

Participants were randomly assigned to either real- or sham-neurofeedback training. The study was single-blind, with participants not knowing which type of feedback they were receiving. We hypothesized that after eight neurofeedback sessions, patients

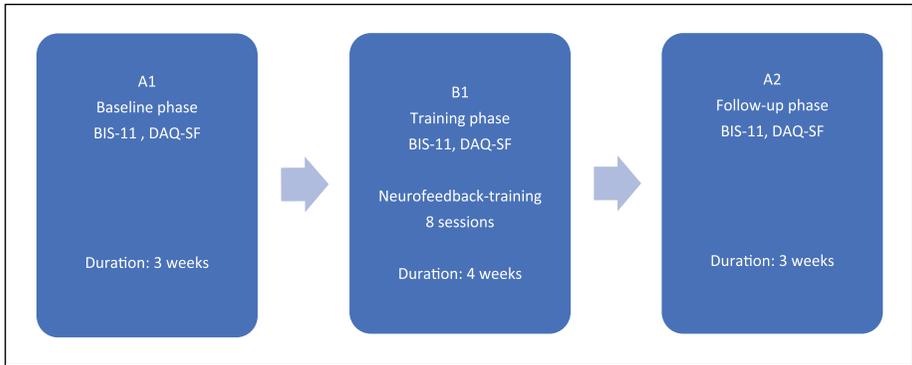


Figure 1. Flowchart of the study design.

Note. BIS-11 = Barratt Impulsivity Scale-11; DAQ-SF = Desire for Alcohol Questionnaire-Short Form.

receiving real-neurofeedback training should show (a) evidence of being able to regulate cortical activity by enhancing SMR frequency and reducing theta frequency and (b) at least a trend toward behavioral improvement through reductions in BIS-11 and/or DAQ-SF scores. Patients who received the sham training were thought to not benefit from the neurofeedback training and show less of a reduction in BIS-11 and DAQ-SF scores.

Participants

All four participants in the current study were male forensic psychiatric patients residing in the Forensic Psychiatric Centre (FPC) Dr. S. van Mesdag, situated in the Netherlands. They all had at least one *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev.; *DSM-IV-TR*; American Psychiatric Association [APA], 2000) diagnosis of SUD and a minimum of one comorbid axis I or II disorder, such as schizophrenia or personality disorder (APA, 2000). They were receiving compulsory treatment by order of the state, after committing a violent crime with a minimum penalty of at least 4 years according to Dutch jurisdiction (called Terbeschikkingstelling, or TBS; van Marle, 2002). Due to mental illness, these patients were held only partially responsible for the crime they committed. The patients participating in the current study were selected from the control group of an ongoing RCT investigating the effects of neurofeedback on impulsivity, craving, and substance use (<insert reference here later>). Participants in the control group of this RCT received TAU only, without previous neurofeedback training, but participated in assessing self-report scores of impulsivity (BIS-11) and craving (DAQ-SF). The patients for the current study were selected based on their high scores on the BIS-11 and the DAQ-SF. Patients received information about the study and gave informed consent.

The study was conducted according to the principles of the Declaration of Helsinki (version 59, Seoul, October 2008), and in accordance with the Medical Research

Table 1. Patient Characteristics.

Patient	Age	Axis I diagnoses	Axis II diagnoses	IQ (range)	Type of substance use	Type of NFB
1	30	PTSD	Borderline PD Antisocial PD Histrionic PD	70-80	Cannabis	Real
2	29	—	Antisocial PD	74-83	Cannabis Alcohol	Real
3	43	Schizophrenia (paranoid subtype) Exhibitionism	Antisocial PD	60-70	Stimulants Amphetamine Methylphenidate Cannabis Alcohol	Sham
4 ^a	32	—	Antisocial PD Narcissistic PD Mental retardation	Mental retardation (precise IQ score unknown)	Cannabis Amphetamines Alcohol Cocaine	Sham

^aThis patient dropped out after phase A¹. PD = personality disorder; PTSD = posttraumatic stress disorder; NFB = neurofeedback.

Involving Human Subjects Act. It has been approved by the Medical Ethical Council of Brabant, The Netherlands (study number NL46390.008.13).

Patient characteristics can be found in Table 1.

Measures

BIS-11. The BIS-11 (Patton, Stanford, & Barratt, 1995) is a self-report questionnaire measuring the behavioral and personality construct of impulsivity. It consists of 30 items scored on a 4-point Likert-type scale ranging from 1 (*rarely/never*) to 4 (*almost always/always*). The total score can be subdivided in three second-order factors: motor, attentional, and nonplanning. The BIS-11 has been shown to be an internally consistent measure of impulsivity among inmate populations (Cronbach’s $\alpha = .80$; Patton et al., 1995). The Dutch version of the BIS-11 was used (Lijffijt & Barratt, 2005).

Modified DAQ-SF. The DAQ-SF is a self-report questionnaire measuring desire for alcohol at the moment of assessment. It consists of 14 items scored on a 7-point Likert-type scale, ranging from 1 (*strongly disagree*) to 7 (*strongly agree*). The DAQ-SF has shown to be a reliable measure to assess craving in a substance-dependent population (Cronbach’s $\alpha = .70$; Courtney et al., 2013). For the purpose of this study, the word “alcohol” was replaced by the word “drugs” for all questions. Participants were instructed to assess the level of craving at the moment of measurement for drugs in general, with an extra instruction indicating that drugs can range from alcohol to soft

and hard drugs with examples provided. The Dutch version of the questionnaire was used (Franken, Rosso, & Honk, 2003).

Intervention: Neurofeedback

Neurofeedback was applied as implemented in the BrainMarker software engine (BrainMarker Device, BrainMarker B.V. Gulpen). For both training protocols (sham or real), training was performed on the EEG signal recorded from electrode position Cz against a right ear mastoid reference. EEG magnitude was measured across delta (0.5-3.5 Hz), theta (3.5-7.5 Hz), alpha (7.5-12 Hz), beta (12-20 Hz), SMR (12-15 Hz), high beta (20-32 Hz), and gamma (32-49 Hz) frequency bands. For the real-neurofeedback condition, an SMR-enhancement protocol was used, where SMR (12-15 Hz) was enhanced, and theta (3.5-7.5 Hz) was inhibited. For the sham-neurofeedback condition, higher beta bands were randomly selected for training (20-23, 23-26, 26-29, and 29-32 Hz). No specific higher beta frequency band was trained systematically.

Neurofeedback training consisted of simple video games and movie-based feedback. During the training sessions, a visual representation of frequency magnitudes was displayed on a computer screen in the form of simple video games. Participants were instructed to find the most successful strategy to keep the main character of the game above a certain threshold by using cognitive strategies such as relaxed focus. See Figure 2 for an example of one of the video games. Patients received positive feedback by achieving points once a frequency band was maintained within a set threshold for 80% of the time. Verbal encouragement by the neurofeedback therapist was also given. Each round of video games lasted about 60 s, with short breaks in between rounds. Whenever a patient seemed to be able to successfully control EEG activity, the feedback threshold was adjusted manually to a greater level of difficulty. During the sessions, a movie-based neurofeedback paradigm was also used. With this paradigm, patients could pick a movie of their choice, which was displayed on a computer screen in front of them. During the movie, black "curtains" appeared over the computer monitor. To be able to keep watching the movie, participants were challenged to regulate the frequency bands in the same way they did during the video games. When they were unsuccessful, the black curtains started to move further over the screen; when they were successful, the curtain moved away from the screen. For each patient, about 10 rounds of video game-based feedback were employed. For movie-based feedback, about 10 to 15 rounds were employed. A neurofeedback training session lasted for approximately 45 min, including preparation and clean-up. During training, participants were consistently encouraged to engage in the training and to not only stare at the screen.

Statistical Analysis

Nonoverlap of all pairs. For single-case studies, nonoverlap of all pairs scores (NAP scores) are proposed by some authors as a standard for evaluating single-subject progress (Horner et al., 2005). The NAP indicates data overlap between training

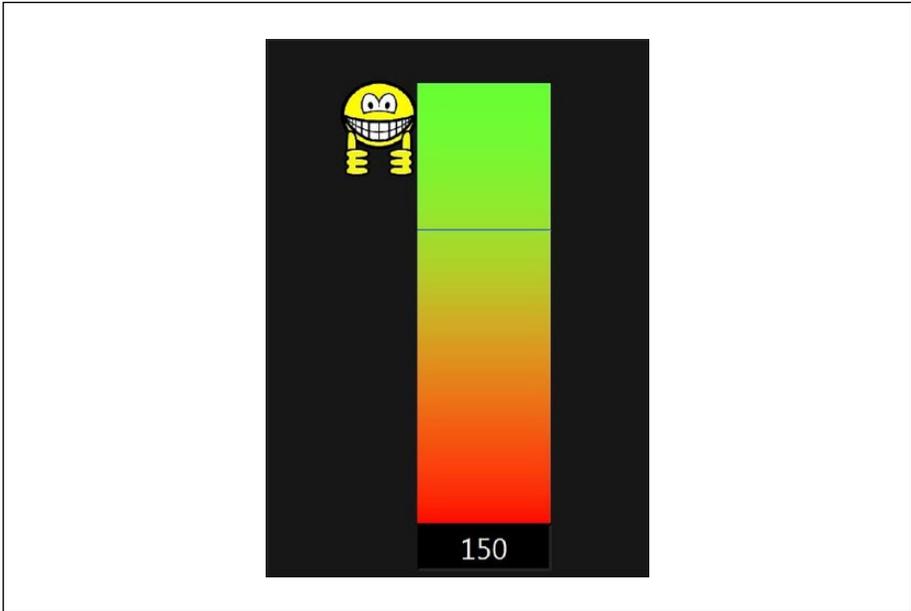


Figure 2. Impression of one of the neurofeedback games, using one frequency band.

and no-training phases in single-case studies and is seen as one of the best indexes to provide insight into the effect of intervention (Parker & Vannest, 2009). NAP scores are calculated through pairing every data point between two predetermined phases (e.g., between data from a no-training Phase A and data from a training Phase B). The NAP score is determined as the proportion of all pairs for which the baseline score is different from the intervention score in the hypothesized non-overlapping direction (Van Yperen et al., 2017). A NAP score can range from 0 to 1, with .50 indicating chance level. Parker and Vannest (2009) propose calculating effect sizes for NAP scores, with NAP scores from .00 to .65 indicating weak effects, .66 to .92 indicating medium effects, and .93 to 1.0 indicating large or strong effects. For a more detailed description regarding calculating NAP scores, see Parker and Vannest (2009).

NAP scores were used to analyze changes in BIS-11, DAQ-SF and to assess changes in mean magnitude of theta and SMR frequency bands due to neurofeedback training. A McNemar change chi-square test was performed to assess significance of the NAP scores. All data were analyzed with SPSS version 22 (IBM Corp.).

Simulation Modeling Analysis. A statistical approach that takes autocorrelation into account is Simulation Modeling Analysis (Borckardt et al., 2008). SMA can test changes in level and slope factor of an outcome measure between two phases (Van Yperen et al., 2017). The slope is correlated with five possible models of trend, indicating the goodness of fit of the different models. Model 1 indicates a decrease in outcome measure during Phase 1, which is then followed by an increase during Phase 2;

Model 2 indicates a stable Phase 1, with a decrease during the second phase; Model 3 describes a decrease during Phase 1 and subsequently a stable Phase 2; Model 4 indicates a decrease during Phase 1, which continues during Phase 2; and Model 5 describes a decrease during Phase 1, and a subsequent stable but then decreasing Phase 2. SMA scores were analyzed with the software package “SMA—Time series analysis program for short time series data streams” (Borckardt, 2006).

BIS-11 and DAQ-SF. To assess changes in scores on BIS-11 and DAQ-SF for each participant, data from the no-training phase was compared with data from the training phase. Specifically, to test for significant differences on outcome measures pre- versus post-training, data from the baseline phase A¹ were paired with data from the follow-up phase A². It was expected that scores on self-report questionnaires in follow-up Phase A² would be significantly lower than in baseline Phase A¹ for the two patients that received evidence-based neurofeedback training, but not for the two patients that received sham-neurofeedback training. To test for changes between no-training and training, data from no-training Phases A¹ and A² were compared with data from training Phase B¹.

First, NAP scores for all comparisons were calculated for each participant. Next, SMA scores were analyzed.

Change in frequency bands. Standardized values for each session of neurofeedback were calculated for theta and SMR magnitude. Training rounds in which the frequency magnitude differed more than two standard deviations from the mean were excluded, as these rounds were most likely influenced by artifacts (e.g., due to eye blinks and/or movement). Subsequently, NAP scores were calculated, comparing the magnitude of theta and SMR frequency during the first four sessions of neurofeedback with the magnitude of theta and SMR frequency during the last four sessions of neurofeedback.

Results

Three out of four patients completed phases A¹, B¹, and A². A fourth patient resigned from participation in the study during phase A¹. Data from this patient were not included in the analysis.

None of the patients was able to follow neurofeedback training as originally scheduled (2 times a week). Due to scheduling issues, lack of motivation, and/or temporary declines in psychological well-being, Phase B¹ took slightly longer than the scheduled 4 weeks for all patients (mean duration 5.4 weeks). When patients did not attend neurofeedback training during this phase, the questionnaires were still administered.

Patient 1 (Real Neurofeedback Training)

Patient 1 showed a significant decrease of BIS-11 scores over the course of the study. When comparing pre- and posttraining phases (baseline Phase A¹ vs. follow-up Phase A²), he showed a significant decrease in BIS-11 total score, with NAP scores showing

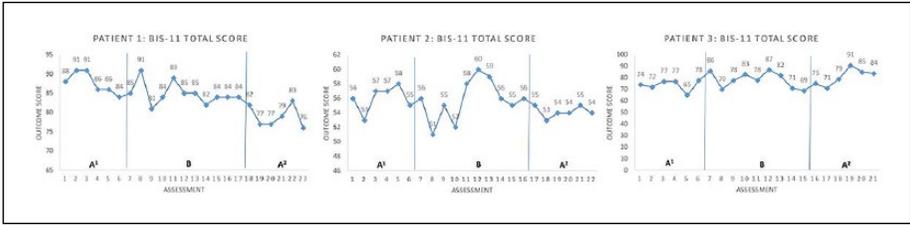


Figure 3. BIS-11 total scores for Patients 1, 2, and 3 over all study phases. Note. BIS-11 = Barratt Impulsivity Scale-11.

a strong effect ($NAP = 1.00, p \leq .001$). When correcting for autocorrelation of NAP scores, SMA analysis revealed a significant level change ($r = -.85, p \leq .05$). The decrease in BIS-11 scores correlated significantly with Model 4 of SMA ($r = -.86, p \leq .05$), indicating a decrease in BIS-11 scores that was already present during baseline Phase A¹ and that continued during the intervention Phase B and follow-up phase A². It can, therefore, not exclusively be attributed to the intervention itself (as the decrease in impulsivity levels was already observable before the start of the neurofeedback training).

Reduction in BIS-11 scores was observable in the total score of the BIS-11, but also in the subscales “motor” and “non-planning.” When comparing scores on the motor subscale of the BIS-11 for baseline Phase A¹ with follow-up Phase A², the decrease fit best with Model 4 of SMA ($r = .82, p \leq .05$), indicating a decrease in scores that was already present at baseline. For the non-planning scale, scores fit best with Model 3 ($r = -.70, p \leq .05$), indicating a decrease in outcome measure during baseline Phase A¹, followed by a plateau during follow-up Phase A². Results regarding the DAQ-SF showed that Patient 1 had a significant reduction in DAQ-SF scores when comparing baseline Phase A¹ with follow-up Phase A² ($NAP = 1.00, p \leq .001$). This effect was still highly significant when correcting for autocorrelation with SMA (level change $r = -.96, p \leq .001$). The decrease in DAQ-SF scores fitted best with Model 2 ($r = -.91, p \leq .05$), indicating a stable baseline Phase A¹, followed by a decrease in follow-up Phase A². See Figures 3 and 4 for a graphical display of BIS-11 and DAQ-SF scores. Patient 1 showed a significant increase in mean SMR magnitude when comparing the first four training sessions with the last four training sessions ($NAP = .75; p \leq .05$). However, this effect did not remain significant when controlling for autocorrelation with SMA ($r = .53, p = \geq .05$), although the partial correlation was reasonably robust. Changes correlated by trend with Model 2 ($p = .07$), indicating a stable number of first sessions and an increase during the later sessions. Theta magnitude did not change significantly ($NAP = .38, p \geq .05$).

Patient 2 (Real Neurofeedback Training)

Patient 2 showed a significant reduction in BIS-11 total score when comparing baseline Phase A¹ versus follow-up Phase A² ($NAP = .82, p \leq .001$); however, this effect did

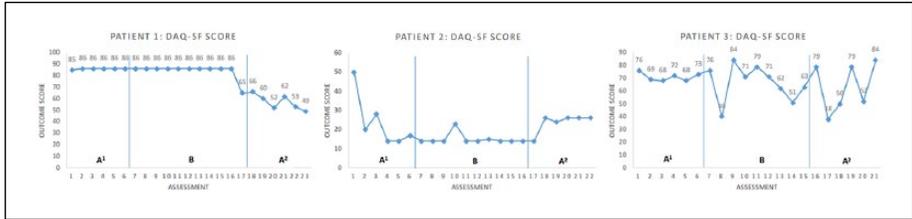


Figure 4. DAQ-SF scores for Patients 1, 2, and 3 over all study phases.

Note. DAQ-SF = Desire for Alcohol Questionnaire.

not remain significant when controlling for autocorrelation with SMA ($r = -.59$, $p = \geq .05$). The decrease in BIS-11 scores did not significantly correlate with any of the SMA models. Reduction in BIS-11 scores was observable not only in the total score of the BIS-11 but also in all subscales when analyzed with NAP scores; however, these results did not remain significant when controlling for autocorrelation with SMA. Results regarding the DAQ-SF showed that Patient 2 had a significant slope change ($r = -.67$, $p \leq .05$) that fitted best with SMA Model 1, indicating a decrease during baseline Phase A¹, followed by an increase in follow-up Phase A². SMR magnitude showed a decrease between the first four sessions and the last four sessions (NAP = .19, $p \leq .01$), but this effect did not remain significant when controlling for autocorrelation with SMA. Changes in theta magnitude were not significant (NAP = .50, $p \geq .05$).

Patient 3 (Sham Neurofeedback Training)

Patient 3 showed a significant increase in BIS-11 total score by the end of follow-up Phase A² (NAP = .22, $p < .001$), although this effect did not remain significant when controlling for autocorrelation with SMA. DAQ-SF score remained unchanged (A¹ vs. A²: NAP = .50, $p \geq .05$; A¹ vs. B: NAP = .64, $p \geq .05$; B vs. A²: NAP = .60, $p \geq .05$). SMR magnitude showed a significant decrease by the end of follow-up Phase A² (NAP = .25, $p < .05$), but this effect did not remain significant when controlling for autocorrelation with SMA. Theta magnitude increased significantly (NAP = .81, $p < .01$).

Discussion

To the best of our knowledge, this is the first study to employ a sham-controlled, clinical case experimental study among forensic psychiatric patients, investigating the efficacy of theta/SMR neurofeedback training in reducing levels of impulsivity and craving. Four patients were randomly assigned to either eight sessions of theta/SMR or eight sessions of sham-neurofeedback training. During the course of the study, patients' self-reported level of impulsivity with the BIS-11 and self-reported levels of craving with a modified version of the DAQ-SF were assessed.

One of the patients showed significantly greater improvements at the end of the study than any of the other patients. This patient reported significantly less impulsivity, as well as reduced levels of self-reported craving over time. The patient showed a decrease in impulsivity that was already observable during the baseline phase and that was continued during and after the intervention. It is not clear what happened during the baseline phase that set reduction in levels of impulsivity in motion already at this phase, but given that the decrease in impulsivity scores was already present at baseline, these effects cannot be solely attributed to the neurofeedback intervention. It is possible, though speculative, that the neurofeedback intervention helped to further decrease impulsivity levels and that these levels would have otherwise plateaued. It is also possible that the decrease in impulsivity was related to the fact that the patient was aware that his impulsivity measures would be monitored during the course of the study and that he was, therefore, more aware and reflective of his actions, which may have led to a decrease in impulsivity scores. However, this patient was also the patient with the most severe diagnoses concerning cluster B personality disorders, with a diagnosis of borderline, antisocial, and histrionic personality disorder. This patient showed the highest impulsivity scores at the start of the study (as compared with the other two patients). Despite this, he was apparently better able to reduce impulsivity over the course of training. Also, a significant decrease in craving scores was observable for this patient, but this effect only became observable after the neurofeedback training. It is possible, though speculative, that effects of the neurofeedback training took a while to manifest for this patient, and that, therefore, a decrease in craving levels was first observable after the last training session had finished.

Only one patient (Patient 1) was able to (at least partially) increase his SMR magnitude, although this was no longer significant when controlling for autocorrelation. This patient showed different patterns of change in EEG magnitude for SMR and theta frequency. For SMR, changes correlated by trend with Model 2, indicating a stable number of first sessions and an increase during the last four sessions. As this was only significant by trend, it is possible that more neurofeedback training sessions would have led to a stronger increase in SMR magnitude. Unfortunately, correlations between changes in frequency bands and changes on behavioral measures were not calculated, so no conclusions can be drawn about the effects of changes in frequency bands on behavioral outcome measures.

Patient 2 did not seem to benefit much from the neurofeedback intervention, although he received real theta/SMR neurofeedback training as opposed to sham training. It can only be speculated as to why this patient did not respond as well to the training as Patient 1. As there are no clear guidelines about the necessary number of neurofeedback training sessions to achieve significant effects in terms of increase or decrease in magnitude of the targeted frequency bands, it is possible that the employed eight sessions of training were simply not enough to result in a significant decrease in mean SMR and/or theta amplitude. Common neurofeedback protocols range from 12 to 30 sessions (see, for review, Fielenbach et al., 2018); hence, a decrease in mean magnitude of the targeted frequency band might take more than eight sessions to

manifest. However, previous research has shown that performance in early neurofeedback training sessions predicts performance in later training sessions (Weber, Köberl, Frank, & Doppelmayr, 2011). Hence, more training sessions may not necessarily result in more clinically relevant results.

In conclusion, the results of this study indicate that for the forensic psychiatric patients participating in this study, the neurofeedback training did not result in significant changes in levels of impulsivity and craving. Several possible psychological mechanisms that may influence neurofeedback performance have been suggested in the literature. Witte, Kober, Ninaus, Neuper, and Wood (2013) showed that participants' belief regarding their ability to gain control over technological devices predicted their performance in an SMR neurofeedback training protocol. Participants' level of locus of control over the neurofeedback device showed a negative correlation with the power of the SMR. Witte et al. (2013) suggest that participants who strongly believe in their ability to control a neurofeedback device consume additional cognitive resources. The higher effort may interfere with the state of relaxation necessary to achieve higher SMR power (i.e., SMR increases times of relaxation; see Pfurtscheller, Brunner, Schlogl, & Lopes da Silva, 2006; Pfurtscheller & Lopes da Silva, 1999; Witte et al. (2013) showed that participants who reported that they did not apply any specific mental strategy to achieve SMR regulation showed better performance during training. It is also suggested that, with SMR neurofeedback training, participants' motivation is related to successful learning response (Nijboer et al., 2008; Nijboer, Birbaumer, & Kübler, 2010). In this study, motivation for treatment was not assessed, which is a limitation to this study. Motivational (self-report) questionnaires should be assessed in future studies to help gain insight into the role motivation of study participants plays with regard to neurofeedback performance.

Some studies have suggested that a pattern of EEG-learning should be observable over every session of neurofeedback training (Weber et al., 2011). In our study, only Patient 1 showed a significant change in EEG magnitude, but this change was not observable over every session, as the change in SMR magnitude correlated only by trend highest with SMA Model 2, indicating a stable number of first sessions and an increase later in the intervention. For theta, the change in mean magnitude indicated a decrease in mean magnitude at the beginning of training, followed by an increase in theta, which then again decreases later on in the intervention. It is possible that for patients with severe mental disorders, the patterns of EEG-learning are not congruent with patterns of learning occurring in healthy subjects.

Although offered, none of the patients was willing to undergo more than the eight training sessions provided during the first treatment phase. While it is possible that this reflects forensic psychiatric patients' low motivation for treatment in general, it is also possible that patients experienced insufficient behavioral improvements to be willing to continue further neurofeedback training. Future research on neurofeedback should focus on investigating which patients will benefit from this type of intervention and which will not. Burdening patients with an intervention they are most likely not going to benefit from can be considered unethical.

Limitations

It is possible that differences in the ability to learn successful regulation of cortical brain activity is at least partially influenced by interindividual differences in clinical diagnosis, IQ, type of SUD, or other (unknown) factors. In this study, one of the patients who received real neurofeedback training benefited more from the training than the patient who received sham neurofeedback, but this patient also had higher IQ scores, and a less severe substance use diagnosis than the patient who received sham neurofeedback. Because the current study did not investigate the influence of other external factors on the effectiveness of neurofeedback training, more research is needed to be able to tell which type of patients will most likely benefit from neurofeedback treatment.

Also, as the DAQ-SF was adjusted to fit the needs of this study, it is possible that this adjustment influenced the reliability and validity of the questionnaire.

The current study did not investigate possible influences of medication use on the trainability of patients. It therefore remains unclear whether some patients showed better results than others due to differences in medication status. Forensic psychiatric patients tend to use various kinds of medication; it is possible that some patients perform better/worse than others in neurofeedback training due to medication that helps/hinders to regulate frequency bands in the desired direction.

Conclusion

The results of this our clinical case studies suggest that there may be great interindividual differences in forensic psychiatric patients' ability to regulate cortical activity through neurofeedback, as well as in the effectiveness of the training in reducing clinical symptoms.

Additional research is needed to identify the most efficient number of training sessions, to examine possible influences of medication on trainability of patients, and to investigate factors that maximize the possible beneficial effects of neurofeedback training for forensic psychiatric patients. As Alkoby et al. (2017) have stated, "Finding possible predictors that are linked to underlying mechanisms of cortical learning will help to identify important factors that should be taken into account to promote neurofeedback efficacy."

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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