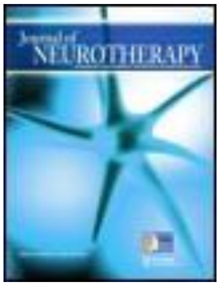

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Individual EEG Alpha Activity Analysis for Enhancement Neurofeedback Efficiency: Two Case Studies

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Individual EEG Alpha Activity Analysis for Enhancement Neurofeedback Efficiency: Two Case Studies

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ABSTRACT. The hypothesis was tested of whether neurofeedback training applied in order to increase or decrease power of individual EEG frequency ranges is more efficient than neurofeedback training of standard EEG frequency ranges. The sessions of decreasing the theta/beta ratio and reinforcing alpha neurofeedback training were carried out on two outpatients with attention deficit disorder (a schoolboy) and functional pain contraction (a professional musician). The neurofeedback utilizing standard EEG frequency ranges (theta 4-8, alpha 8-12, beta 13-18) was inefficient and even resulted in aggravation of symptoms in both cases. The individualized neurofeedback that utilized individual frequency ranges resulted in substantial clinical improvement.

KEYWORDS. EEG, individual alpha band width (IABW), individual alpha peak frequency (IAPF), individual amount of alpha suppression (IAAS), neurofeedback

INTRODUCTION

Neurofeedback, also called electroencephalogram (EEG), biofeedback, or neurofeedback is an operant conditioning procedure whereby an individual modifies the amplitude, frequency, or coherence of the neurophysiological dynamics of their own brain (Schwartz & Andrasik, 2003). The rationale for using neurofeedback therapeutically is that it corrects deficits in brain cerebral regulatory function related to arousal, attention, vigilance, and affect (Othmer, Othmer, & Kaiser, 1999). The designated frequency band determines which brain state is rewarded (Othmer et al., 1999). The exact physiological foundations of this process are not well understood; however, the practical ability of humans to directly modify their EEG through feedback is a well-established fact (e.g., Monastra, Lynn, Liden, Lubar, Gruzelier, & LaVaque, 2005; Sterman, 2000).

As pointed out by several studies, EEG biofeedback is not a "kid's toy," because in the hands of a professional it is a strong and effective methodology and must be

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treated with great respect and competence (Lubar, 1997; Schwartz & Andrasik, 2003; Sterman, 1996). In spite of this great developed technology, an important issue of neurofeedback training is that its efficiency runs up to no more than 75 to 80% (Monastra et al., 2005). It has been suggested that such a limitation could be due to several reasons. Often the objective assessment of the strengths and weakness of the neural organization in a given patient are not used and neurofeedback protocols were not individualized based on the EEG features and anatomy most deviant from normal (Hammond & Kirk, 2008; Thatcher, 1998).

So it is assumed that knowledge about the individual spectral EEG profile, which is being modified by the patient under the neurofeedback training, is important and that deeper knowledge stemming from a more thorough assessment can only benefit the patient, the therapist, and the field of neurotherapy. It is in this spirit that the present article reviews electrophysiological analyses as they pertain to EEG biofeedback and discusses the use of "individual alpha activity peculiarities" to aid the professional neurotherapist in evaluating the electrophysiological status of their patients prior to therapy, thereby providing a guide for the development of therapeutic strategies using EEG biofeedback.

For example, neurofeedback training to reduce the theta/beta ratio usually produces wakefulness and attentiveness in attention deficit hyperactivity disorder (ADHD) children (Lubar, 1997), but Monastra and coauthors (Monastra, Monastra, & George, 2002) did not statistically demonstrate correlations between quantitative EEG (QEEG) changes and attention performance. It is possible that high theta activity in some cases is actually misnamed and it is merely an immature manifestation of the alpha rhythm (the child's dominant frequency). Therefore, 4–8 Hz may be theta for some and alpha for others (Kaiser, 2001). In addition, it is possible that neurofeedback that reinforces alpha in the standard alpha range could aggravate clinical conditions in the cases when the individual alpha peak frequency lies outside the standard 8–12 Hz range.

The human alpha rhythm is defined as oscillations in electric potential within the 8- to 12-Hz range, normally recorded as sinusoidal waves with larger amplitudes over posterior regions, present in roughly 95% of healthy adults, especially during eyes-closed rest (Berger, 1929; Pfurtscheller, Stancak, & Neuper, 1996). Functionally, alpha has been interpreted as a rhythm that diminishes when eyes are opened or during mental activity. According to this classical definition, the first feature of the alpha rhythm is prominent frequency in posterior brain regions. The individual alpha frequency has been found to be a consistent predictor of higher cognitive capacities. This index has been argued to reflect the speed of processing in thalamo-cortical networks (Klimesch, Doppelmayr, Schimke, & Pachinger, 1996). As shown by Hooper (2005), the power at peak alpha represents a relatively individuated process, and the contrasts in upper and lower alpha bands may be explained in terms of the variability or distribution of the peak alpha frequency itself. Peak alpha frequency is fairly stable (10 ± 0.5 Hz) in most individuals during a single session and from day to day, and it is consistent for various subject populations (Posthuma, Neale, Boomsma, & de Geus, 2001).

Because Posthuma and coauthors did not find evidence of a genetic correlation between alpha peak frequency and any of the four Wechsler Adult Intelligence Scale-dimensions, they concluded that smarter brains do not seem to run faster. So there must be additional EEG indexes predicting cognitive ability (Posthuma et al., 2001). Using a fixed frequency band could, therefore, blur the real alpha peak, masking the age- or functions-related modifications. Thus, alpha measures are influenced by the boundaries chosen for the frequency band. Yet no definitive division of the human EEG frequency range has been found. More than 20 arbitrary frequency boundaries have been specified in the literature for studying the alpha rhythm (e.g., 7.81–14.06 Hz, 7.03–12.89 Hz, 8–15 Hz; Etevenon et al., 1989; Moretti et al., 2004). Lack of standardization in specifying the alpha frequency band fosters confusion between laboratory findings but may be required due to the range of variables addressed by quantitative EEG.

As an example, let us consider a subject with a low alpha peak frequency and assume that the lower alpha band of this individual falls below the frequency window of the standard (8–12 Hz) fixed band, which would then cover only the upper alpha and some portions of the lower beta bands. In this case, event-related changes in the lower alpha band would not be detected and changes in the upper alpha band would be misinterpreted if a fixed band were used. This example demonstrates that frequency bands should be adjusted individually for each individual. There is a body of evidence showing that the analysis of individual EEG frequency bands could reveal additional information about the neurophysiology of brain electrical activity (Klimesch, 1999; Köpruner, Pfurtscheller, & Auer, 2003; Niedermayer, 1997). Two of the most important outcomes of this approach are the identification of different subbands in the range of the alpha frequency subserving different cognitive functions and discrimination of neighboring frequency boundaries. Accordingly, one method applied in earlier studies was to use the center gravity or individual alpha frequency as an anchor point for distinguishing a lower from an upper alpha band (Klimesch, Doppelmayr, Pachinger, & Russegger, 1997). Although this method proved superior to the use of fixed frequency bands, the question still is whether the bandwidth may be considered a constant value that does not vary or individual variable. Obviously the plus or minus 2.5 or 2 Hz in association with the peak alpha frequency is artificial and is one of those compromises plentiful in psychophysiology, based on both empirical data and ease (Klimesch et al., 1997). But, it is known that some participants will have a narrow dominant frequency, others might hit the mark exactly, and a third group have a wider frequency (Sterman, 1996; Thatcher, 1998). Perhaps a refinement of the formula is needed, including a mixture of percentage attenuation and topography. This might produce a truly customized dominant frequency bandwidth. From there we build toward the other bandwidths of interest.

According to the second part of classical Berger's definition of alpha rhythm, its functional feature is the ability to diminish when eyes are opened or during mental activity. This decrease is less pronounced in the children and elderly compared to the adults (Lar'kina & Kirenskaya, 2005; Shmelkina, 1999). The failure of alpha-attenuation is probably associated with the fact that the mechanism of the alpha blocking desynchronizing system has not matured functionally and morphologically in children, and in the elderly it is weakened. A few studies showed that open eyes-induced changes of the spectral parameters of the EEG (orienting response). differ between normals and schizophrenics and between acute and remitted schizophrenics (Koukkou & Lehmann, 1987; Michel, Koukkou, & Lehmann, 1993). As an example, Verstraeten and Cluydts (2002) compared good and bad performers in a task-switching paradigm and found that good performance was positively associated with the amount of EEG alpha suppression.

The large variance in alpha peak frequency, bandwidth, and intensity of alpha suppression in response to eye opening begs the hypothesis that a neurofeedback protocol should entail individualized EEG settings. Neurofeedback training for attention deficit disorder, for example, without individualized parameters may result in aggravation of a clinical picture (Hammond, 2010; Hammond & Kirk, 2008; Kaiser, 2001). By contrast, highly efficient neurofeedback training has been reported where the individual alpha activity EEG parameters were used (Hanslmayr, Sauseng, Doppelmayr, Schabus, & Klimesch, 2005). Eventually we may find out that restricting our analysis to such unique alpha activity indices based on QEEG analysis can improve the reliability and validity of our conclusions and outcomes. In this investigation we use individual alpha peak frequency, as an anchor for discriminating individual alpha-1 and alpha-2 ranges, and individual amount of alpha suppression in response to eyes open and alpha band width as an indices of functional characteristics alpha activity.

The main objective of the present investigation was to demonstrate efficiency of the neurofeedback when individual alpha activity indices are in use.

METHODS

Participants[1]

Two male patients (Patient C, a 7–year-old schoolboy diagnosed with ADHD, and Patient A, a 50-year-old professional musician with functional contracture) were investigated.[2]

Procedure

In both cases, the procedure consisted of two stages:

1. Twenty-min neurofeedback sessions with the use standard frequency domain power of the ranges (SNFB): theta (4–8 Hz), alpha (8–12 Hz), and beta-1 (13–18 Hz). Ten sessions of training to reduce the theta/beta ratio in Patient C, and 1 session of simultaneously reinforcing upper alpha EEG and inhibiting EMG training in Patient A.
2. Twenty-min neurofeedback sessions with the use individual frequency domain power (INFB) (8 sessions in Patient C and 1 session in Patient A. The EEG and EMG were recorded in resting eyes closed and eyes-open condition prior and after every neurofeedback session.

Measures

Prior to the beginning and after neurofeedback trainings, Patient C completed Schulte's attention test (performance time and errors; Weinstein, Schulte, & Cascallar, 1983), and his parents reported the behavioral dynamic of child. Patient A was asked to perform music while his electromyogram (EMG) was recorded.

Apparatus

The EEG from two monopolar derivations at P3 and P4, according to the International 10–20 system and the EMG of the surface arm muscles mm carpi radialis and carpi ulnari, were recorded with the help of the multichannel interface BOSLAB (Novosibirk, Russia). The impedance was kept below 5 KΩ across all recording sites. The EEG and EMG signals were amplified, sampled at 720 Hz rate, and stored for offline analyses. For spectral analysis, all EEG epochs with artifacts due to muscle movements (eye movements—including eye and eyelid movements, head movements, movements of the skull) and muscle tension artifacts were removed automatically from further analysis with the help of independent component analysis.

Biofeedback

Patient C's feedback was contingent on the production of beta-1 activity in the absence of theta activity (theta/beta BFB; Lubar, 1997). Patient A had the prescriptions for biofeedback to simultaneously reinforcing upper alpha power and decreasing EMG activity (alpha-EEG/EMG-BFB) training, which helps to reduce the tension and pain associated with movements of fingers and which has been found to be effective in treating the symptoms of functional contracture (Bazanova, Gvozdev, Mursin, Verevkin, & Shtark, 2003). During neurofeedback sessions, patients learned to produce desirable brain wave patterns displayed on a computer screen.

Feedback was provided from the Cz electrode in Patient C and from the P3 electrode in Patient A. First we explained to participants the procedure of biofeedback training and provided a test session in an eyes open condition for illustration of the procedure. Then a 20-min training session was provided in an eyes-closed condition with an audio feedback signal. Feedback took the form of "applause" sounds. Band amplitude values were transformed online into audio-visual feedback representations. Operant contingencies determined that reward (points displayed on screen) was contingent upon increments in theta/beta-1 in the Theta/beta protocol in Patient C or Alpha-EEG/EMG protocol in Patient A.

It was suggested to Participant C that the aim of the biofeedback was "to attain a state at which achieving high rate solving of arithmetic tasks would be complimented with a feeling of easiness and comfort." A PC monitor simultaneously displayed theta power in the form of a blue curve in one window and the beta-1 power as a red curve in another window. The curves of both ranges of EEG power were obtained from the unfiltered EEG signal by its filtering in the standard/individual theta and beta ranges. A training episode was considered successful if the power of the beta-1 rhythm increased simultaneously with a decrease in the theta for at least 5 s. Episodes with opposite changes were considered unsuccessful. The percentage of the total duration of successful episodes during a biofeedback session served as an estimate of the training efficiency.

The biofeedback session for Patient A was aimed at training the patient to simultaneously increase the power of the upper-alpha EEG band and decrease the muscle tension not involved in the movements (Alpha-EEG/EMG-BFB). It was suggested to Participant A that the aim of the biofeedback was "to attain a state at which achieving high quality musical performance would be complimented with a feeling of easiness and comfort." A PC monitor simultaneously displayed the IEMG power in the form of a blue curve in one window and the individual alpha-2 power as a red curve in another window. The curve of the-alpha-2 power was obtained from the unfiltered EEG signal by its filtering in the individual/standard alpha-2 range. A feedback audio signal imitating applause was generated if the red curve reflecting the power of the alpha-2 rhythm was higher than a set threshold value and, at the same moment, the blue line was lower than IEMG threshold value. The thresholds were determined as the power of the alpha-2 band and IEMG for the baseline state with the eyes closed.

A training episode was considered successful if the power of the alpha-2 rhythm increased simultaneously with a decrease in the IEMG for at least 5 s. Episodes with opposite changes were considered unsuccessful. The percentage of the total duration of successful episodes during a biofeedback session served as an estimate of the training efficiency.

EEG Analysis

Sixty-s eyes-closed and 30-s eyes-open EEG recordings were used to assess the individual alpha band width (IABW) and individual amount of alpha suppression (IAAS). The IABW was defined as the frequency range that encompasses the part of the EEG spectrum, which showed suppression of the amplitude at least 20% as a reaction to eye opening compared to the eyes-closed condition (Bazanova & Aftanas, 2008). Individual alpha peak frequency (IAPF). was defined as the dominant frequency rhythm in individual alpha band (Figure 1). The alpha subband ranges were adjusted individually according to IAPF and IABW. Alpha-1 frequency band was restrained between the low boundary of IABW to IAPF. Alpha-2 range started from IAPF and finished at the upper boundary of IABW. The individual theta range was between 3 Hz and the low alpha boundary; beta-1 lies between upper alpha boundary and 18 Hz (Figure 1). For example, if a participant had an IAPF of 9.5 Hz and IABW from 8 to 14 Hz, alpha-1 band between 8 and 9.5 Hz, whereas alpha-2 was defined as the range between 9.5 and 14 Hz, theta between 3 and 8 Hz, and beta-1 between 14 and 18 Hz. The power in 4–8 Hz as theta, 8–10 Hz as alpha-1, 10–12 Hz as alpha-2, and 13–18 Hz for beta-1 were adjusted for neurofeedback sessions with standard EEG ranges (SNFB).[3]

We used the usual approach to average the integrated EMG power (IEMG) in the EMG signal over 100 ms (Merletti, 1999). The IEMG was therefore the area under a voltage curve, measured in μV^2.

Changes in psychometric, EMG, and EEG indices (band power, IAPF, IABW, IAAS) were defined as the percentage of decrease or increase in posttraining period

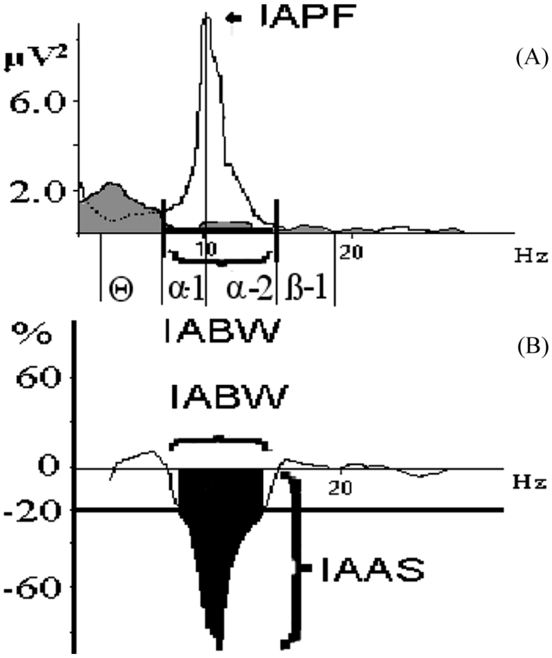


FIGURE 1. The individual alpha peak frequency (IAPF), individual alpha band width (IABW), and individual amount of alpha suppression (IAAS). *Note*. A. The EEG spectral band power over the posterior derivations at rest in the eyes closed (white) and eyes open (gray) conditions. Individual alpha band limits marked by black. On the plot B—mean change EEG (%) spectral band in eyes-open versus eyes-closed condition. The x-axis: frequency (Hz); the y-axis on the plot A–EEG power (μV^2). The y-axis on the B plot—percentage of change spectral power in response to eyes-open condition.

of the SNFB and INFB as compared to the reference baseline condition (BL) before training onset.

RESULTS

Patient C

The IAPF of Patient C in an eyes-closed resting condition was 7.9 Hz, which was below of average mean for the appropriate age group (9.31 ± .71 Hz according the data of Clark et al., 2004). The individual frequency ranges of Patient C were theta, 3–6 Hz; alpha, 6–8 Hz; beta-1, 11–15 Hz. (Figure 2).

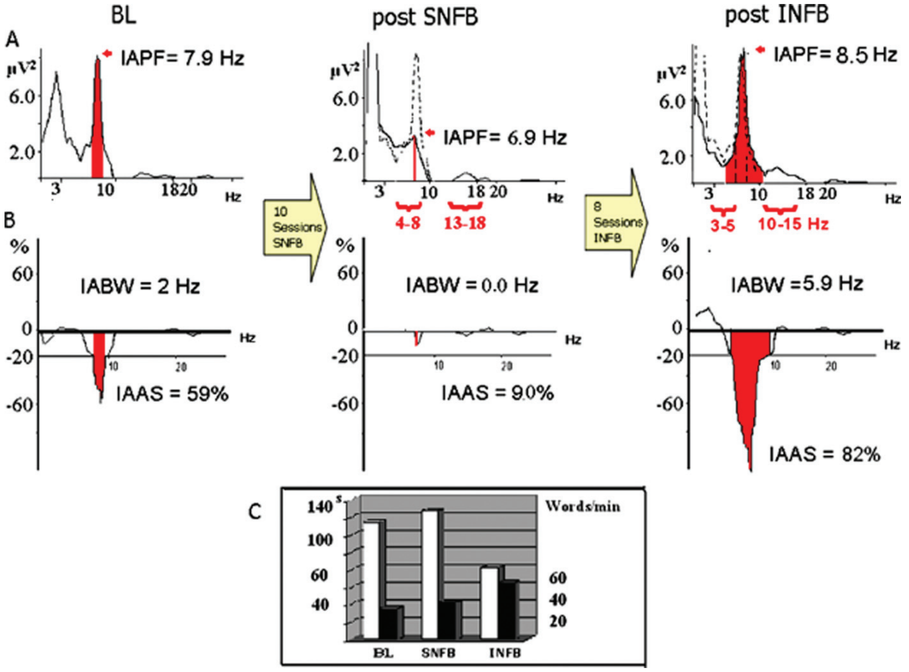
Electroencephalographic status of Patient C was the same as in children with ADHD: increased theta and decreased beta-1 activity. Theta/Beta ratio training usually produces wakefulness and attentiveness (Lubar, 1997). After 10 sessions of SNFB (reducing standard frequency theta/beta ratio). Patient C performed poorly on tests to attention such as reading comprehension and time of completing Schulte table. Moreover symptoms of excitation, irritability, sleeplessness, and aggression also appeared. His EEG showed decreased alpha band power, IABW, IAPF, IAAS, and increased theta and beta-2 band power (Figure 2). The average efficiency of 10 SNFB was 0.52%. The SNFB training aggravated the patient's electrophysiology (increased theta, IEMG, and decreased level of the individual alpha activity indices: IAPF, IABW, and IAAS), psychometric (deceasing test score), and behavioral (reduced impulsivity control and enhanced aggressiveness) dependent measures.

Following eight sessions of INFB (with individual frequency domains) training, EEG investigation indicated that Patient C successfully decreased theta while increasing beta-1 and alpha activity. He manifested also significant improvement of Schulte test performance and parent ratings following INFB training. Individual alpha activity indices IAPF, IABW, and IAAS increased (Figure 2). The average efficiency of eight NFBF session reached 57%.

Patient A

In contrast to Patient C, the IAPF of Patient A was above the average mean: 11.7 Hz in comparison with appropriate age group norms of 9.61 ± .71 Hz (Clark et al., 2004). In Patient A after one session of Alpha-EEG/EMG-BFB with the use of standard frequency range (SNFB) symptoms of headache and irritability were marked. His morbidity had amplified in the field of functional contracture, and EMG parameters of muscles had increased. His EEG showed a decrease in alpha band and an increase in theta and beta band power

FIGURE 2. A plots—the EEG band power values for the averaged parietal derivates. B plots—the percentage of change of EEG spectral power in response to eyes open. C plot—Schulte test performance time (s)—white bars, left y-axis; and number of readable words per minute (black bars, right y-axis) before (BL), after standard frequency ranges neurofeedback (SNFB) and after individual frequency ranges neurofeedback (IFNB). *Note*. The x-axis displays the frequency range (3–30 Hz), Red areas—spectral power of alpha band. IAPF = individual alpha peak frequency; IABW = individual alpha band width; IAAS = individual amount of alpha power suppression in response to eyes open. The frequency range colored in red under brakes reflects frequencies for neurofeedback.

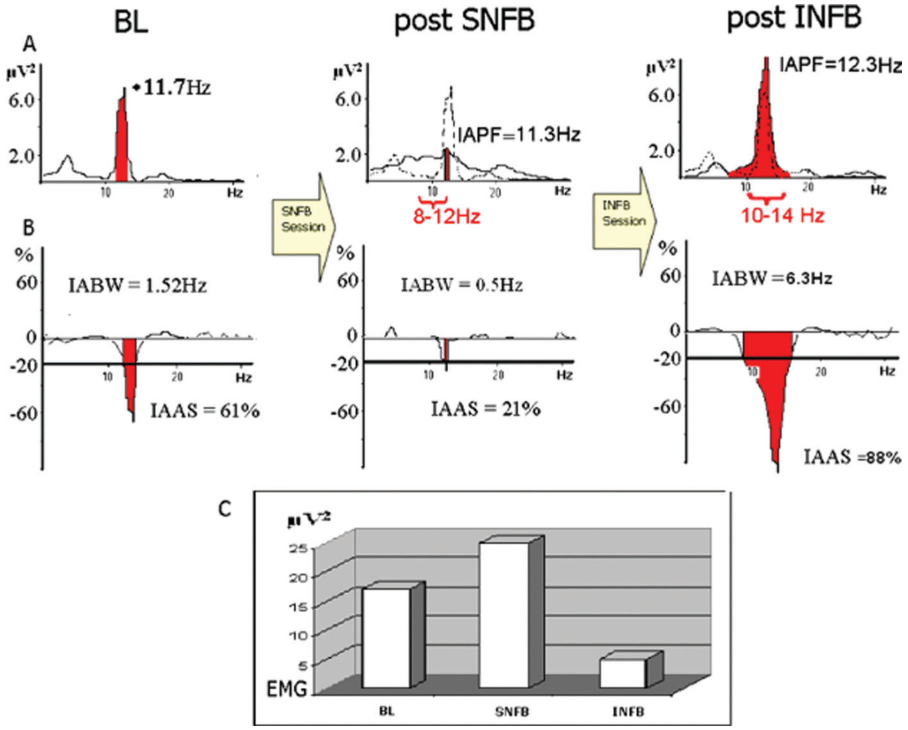


(Figure 3). This condition has been found to reflect increased slump and fatigue (Lal, Craig, Boord, Kirkup, & Nguyen, 2003). The SNFB training had aggravated Patient A's symptoms, including both electrophysiological (depression of alpha power, narrow IABW, weak IAAS, increased EMG), and behavioral (headache and irritability) domains. The efficiency of SNFB was 0.05% (Figure 3).

The EEG showed decreased theta and beta-1, increased alpha features: IAFP, IAAS, and IABW following the run of INFB training (with individual frequency domains). The EMG of muscles decreased (Figure 3). The INFB training was associated with subjective feelings of relaxation, emotional calm and centeredness, an obvious result of upper alpha training (Othmer, Othmer, & Kaiser, 1999).

In both patients, the reaction to eye opening was rigid in the baseline rest condition: The amount of alpha suppression (IAAS) was weak (59% in Patient C and 61% in Patient A) and alpha range that was involved in this reaction (IABW) was narrow (2 Hz in Patient C and 1.52 Hz in Patient A). Moreover, the alpha reactivity more reduced in response to eyes open after SNFB but reached a state near optimal level after INFB trainings in both patients. These two important similarities—narrowing of alpha band width (Figures 2, 3) and weak suppression of alpha band power—probably reflected infringements of optimum performance of sensomotor and cognitive tasks (Craig et al., 2000; Hord, Tracy, Lubin, & Johnson, 1975; Micheloyannis et al., 1996), reduction or even loss of adaptability (Basar & Schurmann, 1996; Kerick, Douglass, & Hatfield, 2004).

FIGURE 3. A plots—the EEG band power values for the averaged parietal derivates. B plots—the percentage of change of EEG spectral power bands in response to open eyes. C plots—EMG of mm carpi radialis and carpi ulnaris before (BL), after standard frequency ranges neurofeedback (SNFB), and after individual frequency ranges neurofeedback (IFNB). *Note*. The x-axis displays the frequency range (3–30 Hz), the y-axis in A plots represents the spectral power (μV^2), the y-axis in B plots represents the percentage EEG power changes, the y-axis in C plot represents integrated EMG power.



It is known that the "rigid EEG" itself can be the reason of reduced effectiveness of neurofeedback training (Benjamins, 1996).

According to statements by Hammond (2010; Hammond & Kirk, 2008) and the Othmers (Othmer et al., 1999) that neurofeedback protocols should entail individualization of certain EEG parameters, the use of an SNFB in this study resulted in iatrogenic activity as compared with a protocol that focused on increasing specific individual alpha activity. As a result, behavioral, psychometric, and electrophysiological conditions worsened. In contrast, highly efficient neurofeedback training was demonstrated in both patients when individualized EEG parameters were used. Following INFB training, alpha EEG reactivity, alpha bandwidth, and individual alpha peak frequency increased, reflecting the improvement of adaptability (Dussault, Jouanin, Philippe, & Guezennec, 2005; Kerick et al., 2004).

CONCLUSIONS

Improvement of psychometric traits, increased individual alpha peak frequency, expansion of alpha bandwidth, and the increase of EEG reactivity after neurofeedback that used individualized ranges supports our belief that the individualization of neurofeedback technology may increase the efficiency of training. In the present research, due to the individual EEG frequency analysis, the importance of an individualization of the approach to neurofeedback training was convincingly shown.

NOTES

1. Because we hypothesized that using neurofeedback with fixed standard range could aggravate the clinical picture, this investigation was provided in just two cases and could not be repeated from ethical point of view.

2. Patient A and parents of Patient C gave informed consent to participate in the study, which was approved by the ethics committee of the Institute of Physiology of the Siberian branch of Medical Academy of sciences (Novosibirsk, Russia).

3. The statistical cutoff criterion of 20% resulted from 10 consecutive eyes closed/eyes trials carried out with 22 male participants in the separate experiment. It was evidenced that confidence intervals of individual alpha suppression indices over all EEG electrodes to eyes-open condition did not extend 20%.

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