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# Roadmap for Enhancing the Efficiency of Neurofeedback

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## Abstract

This article presents a roadmap of ways to improve the effectiveness of EEG neurofeedback training (NFT) based on a literature review and our own research on internal and external factors affecting NFT outcomes. Here we provide a justification for the expediency of using individually determined EEG indices as a feedback signal, based on an analysis of the alpha peak frequency and the level of neuronal activation. As personalization of the NFT for self-regulation means receiving information from a unique neurophysiological parameter inherent only to this individual, the basic internal socioeconomic, psychological, and physiological factors play an important role in training efficiency. Also, external factors such as the delay and modality of feedback presentation, valence of reinforcement, electrode localization, visual condition, body position, duration, and number of NFT sessions, forehead muscle tension and EMG artifact contamination will be discussed. A rationale for each step of this roadmap will be given from the point of view of how this or that factor can influence the personalization and consequently, the effectiveness of self-regulation training with NFT. The article provides a forward-looking opportunity to optimize NFT, providing a sketch setting out the necessary steps.

***Keywords***: neurofeedback technology; electroencephalography; individual alpha peak frequency; neuronal activation; feedback presentation

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## Introduction

Neurofeedback training (NFT) is a brain-computer technology for awareness and learning to control one's own quantifiable neurophysiological parameters that are signs of cognitive and psychomotor functions and affective processes. This means that when the participant's brainwaves are functioning effectively and efficiently, the brain is stimulated in the form of feedback as a reward (Birbaumer, 2024; Kamiya, 1969; Ros et al., 2020). Despite the fact that the principle of any kind of biofeedback technology, based on the use of feedback signals from one's own psychophysiological parameters, assuming high personalization in learning to control these functions, the effectiveness of this technology for self-regulation training still remains a subject of debate (Alkoby et al., 2018; Arns et al., 2013; Ros et al., 2020; Schönenberg et al., 2017; Sokhadze et al., 2008). However, the impact of several internal and external factors, which are often not taken into account when organizing protocols and analyzing NFT results on the effectiveness of NFT, has not yet been definitively determined. It is assumed that internal factors involve the initial psychological (Fontanari, 2017; Fyfe et al., 2015; Kadosh & Staunton, 2019) and physiological (Bazanova, Nikolenko, et al., 2017; Kerson et al., 2020) state of the subject, including the genetically determined individual electroencephalographic (EEG) frequency pattern (Bazanova, 2012; Hanslmayr et al., 2005).

The external factors include some technical issues such as delay (Smetanin et al., 2020) and modality (Dessy et al., 2020; Steel et al., 2016; Wächter et al., 2009) of feedback presentation, duration (Yeh et al., 2021), frequency (Weber et al., 2020), number (Domingos et al., 2021), and ergonomics (Mouchnino et al., 2017; Pirini et al., 2011) of NFT sessions.

The purpose of this article is to provide a roadmap of scientific and technical possibilities for improving the efficiency of NFT.

Here we will not consider types of NFT that use brain hemodynamic indices based on hemoencephalography measurements (Dias et al., 2012), slow cortical potentials (Castermans et al., 2014), the low-energy neurobiological control system (Zandi Mehran et al., 2015), functional magnetic resonance imaging (fMRI; Fede et al., 2020), and near-infrared spectroscopy (Kohl et al., 2020) as feedback. These types of feedback are unsuitable for self-control training because of their long feedback presentation latency—not less than 1–3 s. In connection with the above, the EEG-NFT is more promising, since in comparison with the NFT types listed above, the main advantage of the EEG-NFT is high temporal resolution. This advantage makes it possible to estimate the magnitude of rapid changes in neuronal activity under current conditions, making EEG-NFT the most suitable technology for obtaining immediate feedback from fast-flowing cognitive and psychomotor functions and affective processes (Smetanin et al., 2020).

Meanwhile, there are still restrictions on the EEG-NFT use too. In particular, the so-called "*z*-score" is an NFT based on comparing the given patient's EEG power in the standard traditionally adjusted frequency ranges with a normative EEG database (Collura, 2010), which assumes that the EEG indices in the standard fixed bands corresponds to a Gaussian distribution. However, psychometric evidence for this assumption has not been provided (Jobert et al., 2013). Moreover, the presence of asymmetry and kurtosis of the EEG power histogram in standard bands indicates a deviation of the distribution from normality (Thatcher et al., 2003; Wood et al., 2024). These deviations may be the result of inaccuracies or errors in the registration, processing and subsequent analysis of EEG signals (Gutmann et al., 2018). In other words, the most likely reasons that distinguish the distribution of EEG spectral power indicators from normal may be due to the following factors: (a) lack of an individual approach to determining the boundaries of frequency bands (Bazanova & Vernon, 2014; Klimesch et al., 1998); (b) contamination of EEG by electromyographic (EMG) low-amplitude low-frequency artifacts (Goncharova et al., 2003; Gutmann et al., 2018; Halliday et al., 1998); and (c) ergonomic conditions such as body position (Slobounov et al., 2009), biological rhythmicity (Bazanova et al., 2018; Gertz & Lavie, 1983), duration (Vernon et al., 2004) and sequence of EEG recording with open and closed eyes (Hardt & Kamiya, 1976). All these factors reduce the accuracy of EEG analysis and consequently the NFT efficiency, jeopardize the reproducibility of the research results, lead to unpredictable effects of treatment and possibly even to a deterioration of the patient's condition, thereby discrediting the biofeedback technology (Bazanova & Aftanas, 2010; Ros et al., 2020).

It is important to note that we will not discuss here how the effectiveness of NFT is evaluated, nor will we conduct a meta-analysis comparing the level of effectiveness of NFT for the following reasons: (a) published meta-analyses evaluating the efficacy of EEG-NFT have demonstrated a wide variety of paradigms; (b) most meta-analysis data have limitations reported by the researchers, such as the use of different types of NFT, making it difficult to determine the most effective approach; and (c) the most common problem is the lack of standardized protocols, treatment procedures and duration, making complicated the comparison of results across studies (Askovic et al., 2023). Only one meta-analysis of double-blind randomized controlled trials demonstrated comparable results of NFT that use alpha EEG power as feedback (Xiang et al., 2018). Moreover, these meta-analyses did not take into account external and internal factors influencing the EEG-NFT efficiency. This highlights the need to establish scientific and technical challenges and opportunities for enhancing EEG-NFT efficiency and developing a roadmap for creating the optimal NFT protocols, which becomes more challenging when NFT is considered as a form of individualized medicine.

## Methods

The algorithm for searching information in the databases PsyINFO, PubMed, Google Scholar, and eLibrary was carried out according to the requirements of PRIZMA (Brown et al., 2019; Moher et al., 2015). In accordance with the set goals of the search, abstracts, methodological recommendations, and textbooks were not taken into account. English was chosen as the search language. Experimental articles from 1968 to April 2024 were analyzed. The search queries have been adapted to various databases using Boolean operators AND and OR. The following keywords were used in the literature search: "Neurofeedback" AND "Efficiency" OR "Effectiveness" OR "Efficacy," "EEG," "Personality," "Cognitive Functions," "Awareness," "Emotional State," "Individual Alpha Peak Frequency," "Alpha Power Suppression," "Forehead Muscles EMG," "Biological Rhythmicity," "Feedback Delay," "Feedback Modality," "Reinforcement Valency," "Session's Duration," "Sessions Number," "Open Eyes," "Closed Eyes," "Electrodes Localization," "Body Position."

The articles selection was carried out by three reviewers (Alexandr Zakharov, Ekaterina Nikolenko, & Olga Bazanova), who independently reviewed various databases, eliminating duplicates and checking that the articles met the selection criteria.

## Results

The literature analysis has shown that there is a large number of experimental studies of EEG-NFT efficiency performed both in healthy subjects and in various pathologies ($n$ = 775 literature sources according to the query in PubMed). At the same time, the number of studies devoted to the influence of internal and external factors on NFT efficiency is significantly lower. The studies considering the above-mentioned main factors are presented in Table 1.

### Impact of Internal Factors on the NFT Efficiency

Personalization of the NFT for training in self-regulation means receiving information from a unique neurophysiological parameter inherent only to this individual (Birbaumer, 2024). In this regard, the basic socioeconomic, psychological, and physiological factors as a learning predisposition state play an important role in self-regulation training efficiency (Gorev & Semenova, 2003; Rahman et al., 2023; Ros et al., 2020). Meanwhile, much NFT research has not been predicated upon the assumption that a baseline recorded at session outset is reliable.

### Socioeconomic Status

Rahman and coauthors showed that lower family income and poor parental communication predicted lower academic achievement (Rahman et al., 2023; Schibli et al., 2017). Schibli explained that poor environments, social isolation, or deprivation associated with low socioeconomic status can cause stress reactions and anxiety, which in turn affect cognitive development and academic achievement (Schibli et al., 2017). Particular, children with low socioeconomic status, when learning new things, pay attention to information indiscriminately and are late in filtering out information that is not relevant to the task (D'Angiulli et al., 2008). On the other hand, for children with high socioeconomic status, adaptive parenting styles, supportive role models, and self-regulation learning skills have been suggested as potential factors contributing to emotional stability and better academic outcomes (Flouri et al., 2014).

Thus, socioeconomic factors, influencing the self-regulation training efficiency, contribute to such psychological factors as personality features, attention, emotional stability, and motivation to learn.

### Psychological Factors

The effects of individual psychological features of the subject on the efficacy of application of the neurofeedback technique have attracted the attention of researchers (Ancoli & Green, 1977; Kadosh & Staunton, 2019; Schlatter et al., 2022; Yamaguchi, 1981). Optimal cognitive functioning is an important prerequisite for effective learning. However, in the learning process, as well as from the point of view of intrapersonal factors, Ancoli and Green (1977) mentioned that such features of the personality as authoritarianism, trustfulness, and introspectivity exert a significant influence on the efficacy of NFT; at the same time, effects of the levels of extraversion and empathy were not found (Ancoli & Green, 1977). H. Yamaguchi examined the dependence of the efficacy of alpha NFT sessions on the external versus internal locus control of the subject. Externals could significantly increase alpha power, while internals could not show such enhancement of alpha during the NFT (Yamaguchi, 1981). Better understanding of the relationships between the Big Five personality traits and emotion regulation are a prerequisite for feasible and effective NFT from designer's point of view (Travis et al., 1974). For example, biofeedback coping interventions have a greater effectiveness in individuals presenting higher score of openness to experience (Schlatter et al., 2022). It was found that most successful at the NFT were the subjects with low scores on Extraversion and moderately high scores on neuroticism (Chernyshev et al., 2013).

Cognitive abilities encompass those processes involved in controlling, organizing, and integrating information (Diamond & Ling, 2016). Participants with better overall cognitive function are better able to use biofeedback to promote learning (Kettlety et al., 2024). Such factors as attention and language skills explain performance variability (Kettlety et al., 2024). For this reason, cognitive abilities are crucial in NFT efficiency because they allow planning, reasoning, making decisions, and control and regulate emotions (Nguyen et al., 2019). In particular, inhibition represents the ability to control one's behavior, thoughts, and emotions (Diamond & Ling, 2016) through an adaptive internal feedback afferentation loop (Bernstein, 1945; Sudakov, 1997) and consequently, this ability, as reflected by EEG alpha power, could increase biofeedback training efficiency (Doppelmayr et al., 1998; Doppelmayr et al., 2002). Diamond (2013) proposed that cognitive flexibility and/or creativity designates the ability to change one's approach to a problem in order to adjust to new demands from the changing environment such as biofeedback technology (Boynton, 2001; Diamond, 2013; Pinho et al., 2014). Pinho showed that more creative individuals have greater functional connectivity, which may reflect a more efficient exchange of information in associative networks and thus increase the effectiveness of NFT (Pinho et al., 2014). Because cognitive functions and ability to control emotions change across the lifespan (Katsantonis, 2024), they could associate with different NFT efficiency: in childhood and adolescence academic achievement could predict more effective self-regulation (Katsantonis, 2024). In adulthood cognitive functions, self-control and learning ability are related to mental and physical health, marital harmony, public safety, etc. (Smith et al., 2019). In old adulthood cognitive and self-control abilities and strongly contribute to daily functioning and maintaining autonomy (Jefferson et al., 2011).

Sometimes, it is difficult to provide evidence of the NFT effectiveness without subjects in the experimental and control groups being in the same conditions: baseline sociopsychological and physiological states, modality of feedback, number of training sessions, and awareness of the goals of NFT, in addition to the fact of true feedback. Meanwhile, awareness of NFT goals and ways to promote self-regulation learning are rarely addressed in research on NFT effectiveness (Bazanova et al., 2013; Kvamme et al., 2022; Matsunaga & Genda, 2005; Min et al., 2023).

Awareness is a construct of considerable importance in many demanding tasks (Endsley, 2013). Situation awareness is formally defined as "the perception of the elements in the environment, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988). Situation awareness is related to cognitive events rather than passive monitoring of the course of treatment (Festa et al., 2024; Fontanari, 2017). As such, increasing awareness is important for the development and testing of NFT system designs and self-regulation training programs.

It was shown that instructional recommendations (Bazanova et al., 2013; Kvamme et al., 2022) and mindfulness practice (Crivelli et al., 2019; Min et al., 2023) could increase awareness of the NFT. Matsunaga and Genda considered using human physiological information as input because it reflects human feelings better (Matsunaga & Genda, 2005). The results showed that psychological techniques such as mindfulness (breathing, relaxation, imagination, etc.) without feedback cues are less effective for teaching self-regulation than NFT (Bazanova et al., 2013; Chikhi et al., 2023). Importantly, short breaks between NFT sessions, in which the neurofeedback awareness questionnaire can be embedded, may help to realize the goal of awareness, and could improve the NFT efficiency (Vernon, 2005). Thus, utilizing informative guidelines to increase awareness and psychophysiological techniques to enhance NFT performance may be reliable tools for conducting double-blind neurofeedback studies.

The influence of the baseline emotional state on the effectiveness of NFT is poorly understood. However, it can be hypothesized that if a person is tired, stressed, anxious, or experiencing other negative emotions, it can greatly affect their ability to concentrate, make decisions, and control their thoughts and actions (Labrague et al., 2017). Conversely, positive emotional states can increase the effectiveness of NFT by helping a person to better concentrate, make decisions, and control their actions. Just a few researchers have demonstrated that neurofeedback was more effective for patients with more severe than for milder emotional disturbance (Choi et al., 2023; Hardt & Kamiya, 1978; Konareva, 2005). So, in a group with a relatively high level of anxiety, it was found that as a result of NFT the alpha power increased in persons with moderate values of anxiety but was suppressed in individuals with the highest anxiety levels (Hardt & Kamiya, 1978). Later, similar results were obtained showing that biofeedback therapy was more effective for patients with high than low levels of job stress (Konareva, 2005; Wang et al., 2018).

The above studies have identified several psychological factors that need to be controlled and/or isolated in order to successfully register EEG characteristics reflecting the baseline condition and to predict the effectiveness of NFT. At the same time, it was shown that the impact of psychological factors manifested within the very first NFT stages (Ancoli & Green, 1977). This NFT period determines to a significant extent the efficacy of the entire training cycle, but this effect has not been systematically examined.

### Physiological Factors

Several works used multiple physiological signals such as electrocardiogram (ECG; Pourmohammadi & Maleki, 2020), galvanic skin response (GSR; Azzalini et al., 2019), skin temperature (Arza et al., 2019), arterial blood pressure (ABP; Arza et al., 2019; Shuda et al., 2020), and plasma cortisol level (DeGood & Redgate, 1982; Paul et al., 2020; Quaedflieg et al., 2016) to detect the stress impact on cognitive efficiency. This allows us to assume that the above physiological parameters can affect the NFT effectiveness. Moreover, the study of Quaedflieg et al. (2016) demonstrates the influence of plasma cortisol level on frontal alpha asymmetry change after NFT. Overall, these studies argued that employing only a single marker cannot comprehensively assess the person's stress response. As far as EMG and EEG variables, it was shown that such signs of stress as increasing the scalp EMG amplitude (Cacioppo, 2004; Pourmohammadi & Maleki, 2020) and decreasing the EEG alpha power (Bazanova & Vernon, 2014; Lopes da Silva, 2013) can serve as indicators of psychoemotional tension.

### EMG Factors Influencing NFT Efficiency

The ability to control forehead muscle tone contributes to self-regulation capacity of mood and could be used in practice of EMG biofeedback training (Blumenstein & Orbach, 2014). At the same time, scalp EMG of low frequency and low amplitude could be a factor that might mask the stress-related EEG features and/or generate EEG features that could be misinterpreted as being stress-specific (Enders & Nigg, 2016; Halliday et al., 1998). These include the widespread increase of EEG in beta and gamma ranges that result from scalp EMG generated by the facial expressions that often accompany stress (Enders & Nigg, 2016; Halliday et al., 1998). So, one of NFT's disadvantages to date is the lack of consideration of EEG contamination by low-frequency EMG components (Castermans et al., 2014; Halliday et al., 1998). EMG artifacts, shown to be a problem during EEG NFT (Enders & Nigg, 2016; Shackman et al., 2009), have a larger influence on the data as they do not diminish when averaging many trials and epochs, and, consequently, when constructing NFT designs incorrectly. Therefore, the probability of EMG artifacts must be considered when selecting channels for NFT: the maximum probability of EMG artifacts is observed in frontal, temporal, and occipital regions (Nekrasova et al., 2022).

To overcome these EMG artifacts that are signs of psychoemotional stress, researchers and clinicians have developed NFT to enhance alpha production while simultaneously controlling frontal muscle tension (Markovska-Simoska et al., 2008; Petrenko et al., 2019; Wang et al., 2018). For example, NFT aimed at simultaneously reducing theta/beta ratio and forehead EMG was more effective in reducing impulsivity and reaction time in ADHD children than NFT without controlling frontal muscle tension (Arns et al., 2014; Bazanova et al., 2018; Strothmann, 2024). Thus, to improve the effectiveness of EEG-NFT, it is necessary to take into account the EMG of the scalp muscles.

### Resting EEG Features

In classical EEG studies, resting EEG refers to both amplitude (power) and frequency parameters of the EEG, as well as their changes in standard functional tests, such as the Berger test (Bazanova & Vernon, 2014; D. A. Kaiser, 2001; Livanov, 1984; Lopes da Silva, 2013).

Baseline brain activity measures such as EEG amplitude or power spectral density before training were mainly investigated to predict psychophysical performance (Linkenkaer-Hansen et al., 2004) and particular the NFT success (Alkoby et al., 2018; Su et al., 2021; Weber et al., 2020). For instance, learning beta/theta control can be predicted by resting beta power prior to training (Nan et al., 2015), learning of the sensorimotor or alpha rhythm can be predicted by the amplitude/power of the initial sensorimotor rhythm (Reichert et al., 2015) or alpha power (Wan et al., 2014). Because lower alpha band power is associated with greater mental effort during problem solving (Golonka et al., 2019), this lower alpha band power of the resting EEG may predict a poorer outcome of NFT. Despite these findings, EEG amplitude itself is a highly fluctuating parameter influenced by excitation level, conduction, ECG and EMG artifacts (Bazanova & Vernon, 2014; Lopes da Silva, 2013). Therefore, amplitude values may be poorly predictive of the outcome of NFTs.

Until now, the boundaries of EEG frequency ranges have been determined by general agreement, without theoretical justification, and without taking into account the functional features of EEG waves (D. A. Kaiser, 2001; Klimesch et al., 1997). For example, there is a substantial body of evidence supporting the existence of functionally independent frequency subbands in the broader alpha range (Barry & De Blasio, 2017; Klimesch et al., 1997). Accordingly, determining the alpha power in a particular standard frequency band is likely to reduce the sensitivity of the experiment and increase the probability of typical error (Bazanova & Aftanas, 2010; Bazanova et al., 2018; Doppelmayr et al., 1998; D. A. Kaiser, 2001).

The results of the literature analysis presented in Table 1 indicate the rare use of individual spectral frequency characteristics as a feedback cue in EEG-NFT. At the same time, out of 19 works studying EEG-NFT, using amplitude in fixed ranges calculated on the basis of individual alpha peak frequency (iAPF) as a biofeedback, only six studies are devoted to the study of NFT conducted on EEG magnitude within individually established boundaries of frequency bands (Bazanova & Aftanas, 2010; Bazanova et al., 2018; Escolano et al., 2014; Gutmann et al., 2018; Parsons & Faubert, 2021; Petrenko et al., 2019). At the same time, a comparison of the NFT effectiveness conducted to reduce the theta/beta ratio in children with ADHD according to individually established EEG ranges and standard ones (4–8 Hz theta and beta 13–18 Hz) showed a significantly higher probability of reducing impulsivity, reaction time in the test and hyperactivity in children who underwent training according to individually established ranges (Bazanova et al., 2018). In addition, several studies have demonstrated the expediency of determining the iAPF as a predictive criterion for the effectiveness of NFT (Bazanova et al., 2018; Hanslmayr et al., 2005; Petrenko et al., 2019), and also to determine the strategy of neurotherapy (Pérez-Elvira et al., 2021; Voetterl et al., 2023). For example, the ability to train in a single NFT session is higher in people with iAPF > 10 Hz, and the effectiveness of NFT, as assessed by the magnitude of changes in trained performance, is higher in people with low iAPF < 10 Hz (Bazanova et al., 2013; Petrenko et al., 2019).

Thus, one of the most important EEG alpha rhythm parameters, individual alpha peak frequency, which determines the positive or negative type of emotional reactivity (Tumyalis & Aftanas, 2014), success of cognitive (Doppelmayr et al., 2002; Klimesch et al., 1997; Rathee et al., 2020) and psychomotor task performance (Bazanova et al., 2013), can predict the effectiveness of NFT.

## Baseline Intensity of Neuronal Activation

In most subjects, EEG alpha wave amplitude is higher when the eyes are closed and decreases when eyes are open. This decrease in EEG alpha power in the eyes-open (EO) condition, relative to the eyes-closed (EC) condition is used as one of the outcome measures of neuronal activation (Barry et al., 2011) and for the artifact correction (Kirschfeld, 2005; van der Meer et al., 2016). It was shown that magnitude of neuronal activation depends on the phase of menstrual cycle in women (Bazanova, Nikolenko, et al., 2017) and the time of day (Compton et al., 2019). Less alpha attenuation with eyes open has been associated with such disorders as inattention (Barry & De Blasio, 2017; Bazanova, 2012), schizophrenia (Koukkou et al., 2000), and as well as with developmental and age-related factors, including both younger and older age (Barry & De Blasio, 2017). Thus, because this baseline EEG parameter could predict cognitive efficiency (VaezMousavi et al., 2007), we propose that it could be used as a target for NFT and in prediction of NFT efficiency (Bazanova, 2012). Although decreased overall alpha power likely reflects the neuronal activation, the alpha band is subdivided (Babiloni et al., 2004) because lower (Babiloni et al., 2004; Klimesch et al., 1997) and high alpha subbands (Jensen et al., 2002; Klimesch et al., 1997, 1998) have been associated with somewhat different cognitive processes. Lower-frequency (i.e., lower than iAPF) alpha rhythms tend to reflect the more diffuse cortical loops regulating global attentional processes, such as alertness (Babiloni et al., 2014). Higher-frequency (i.e., higher than iAPF) alpha rhythms have been associated with more selective neural systems, including those involved in anticipating and processing specific sensory input and cognitive control (Bazanova & Vernon, 2014; Klimesch et al., 1998). Thus, we might take into account the preexisting neurocognitive vulnerability by studying EEG measures within these alpha subbands.

Since the EC/EO effect is different for each subject in terms of the frequency band, we determined an upper and lower frequency threshold (i.e., those frequencies in which the EC/EO effect is most pronounced), and for the topological distribution we determined a channel selection (i.e., in which channels the EC/EO effect is most pronounced; van der Meer et al., 2016). Examination of the average power in posterior channels (Pz, PO3, POz, PO4, Oz) allows us to determine the frequency range associated with neuronal activation and therefore where the EEG-NFT effect will be most pronounced.

So, it is advisable to register EEG before the NFT both with open and closed eyes to determine the endophenotypic marker of iAPF and the level of neuronal activation, which are of important prognostic meaning for the NFT effectiveness (Bazanova & Vernon, 2014).

### Biological Rhythmicity

As we know, biological rhythmicity has never been taken into account, and even the time of day is rarely reported in researching NFT efficiency. The majority of EEG-NFT studies have involved short-term (generally less than an hour) experimental procedures. In light of findings demonstrating independent rhythmicity in different physiological systems, such as gastric motility, renal excretion, as well as performance and physiological indices of arousal, a multioscillatory ultradian system has been proposed (Kripke, 1974; Lavie & Kripke, 1981). In this line, Gertz and Lavie (1983) demonstrated that efficacy of NFT may depend on the baseline condition, related mainly to the ultradian rhythmicity of about 200 min/cycle seen in EEG indices, particularly iAPF, and in subjectively assessed arousal (Gertz & Lavie, 1983).

The study of Pérez-Medina-Carballo et al. (2024) clarifies too the changes in EEG parameters that occur in women after menopause across circadian phases. The absent and dampened circadian variation of upper alpha power (12–15 Hz) in older subjects is consistent with an impaired output of the circadian pacemaker regulating spindle activity (Dijk & Duffy, 2020).

Another type of biological rhythm that affects general well-being and cognitive performance that is rarely considered when evaluating the effectiveness of NFT is the menstrual cycle of women. We and other authors (Bazanova, Nikolenko, et al., 2017; Becker et al., 1982; Brötzner et al., 2014) have demonstrated that both iAPF and the intensity of neuronal activation change significantly depending on the level of sex steroids (Bazanova, Nikolenko, et al., 2017). Moreover, it has been shown that the highest learnability for self-regulation is observed during the phase with the highest progesterone levels.

Thus, the analysis of EEG-NFT efficacy and the design of an NFT experiment including women as subjects should take into account the biological rhythms of women's hormonal state.

### External Factors

The fundamental components of the biofeedback system include two groups of external factors that influence the effectiveness of NFT: (a) the acquisition and presentation of feedback signals (feedback signal presentation delay, feedback signal modality and reinforcement) and (b) the design elements of the NFT procedure (duration and number of NFT sessions, ergonomic factors of the procedure).

### Acquisition and Presenting Signals for Feedback

This group of factors include signal detection, digital conversion (facilitating signal processing by a digital computer), signal processing utilizing software, signal display, and signal storage.

The signal processing step of digital conversion is of paramount importance as the rate at which the signal is converted from its analog form to its digital counterpart determines the quality of the signal representation for the remainder of the process (Montgomery, 2001). Essentially, the frequency at which a signal is measured will dictate how that signal can be processed by the computer.

### Electrode Localization for Determining NFT Target Area

Unlike fMRI-NFT, where the choice of the target area of NFT is a problem, EEG-NFT does not need a special localization of the electrode as a target of self-regulation, because the signal obtained at this electrode always reflects generalized neuronal activity (Acharya & Acharya, 2019; Ebrahimzadeh et al., 2022; Klug & Gramann, 2021; Tenke et al., 2013). Accordingly, neurofeedback protocols that utilize the EEG signal for feedback may not limit training effects to specific brain regions (Gruzelier, 2014; Güntensperger et al., 2020). Moreover, it is known that changes in the amplitude of the dominant EEG frequency amplitude induced by NFT at one site are accompanied by similar changes in other brain regions (Bazanova, 2011; Gruzelier, 2014). Most likely, the effects of NFT occur at a more global level and therefore the NFT procedure affects several functionally different brain regions simultaneously (Güntensperger et al., 2020). Beside it, the probability of the highest amplitude and the least contamination by artifacts of EMG and ECG is higher in the parietal region than in the frontal and temporal regions (Jobert et al., 2013; Tenke et al., 2013). This means that the effectiveness of feedback presentation in NFT will be higher from signals from the parietal region, where iAPF is most stable and reproducible (Bazanova, 2011).

Thus, the fast and brain-wide processes of voluntary self-regulation that occur during NFT suggest that the effectiveness of NFT does not depend on the electrode location.

### The Delay of the Feedback Signal Provided

The timing of feedback is critical to the effectiveness of training in general, and it appears to the effectiveness of NFT in particular. The delay of the feedback cue depends on the proper setting of NFT latency, that is the time interval from the occurrence of a neural activity till the delivery of the feedback of that activity to the subject. If the experimenter uses the EEG power in a given range as a feedback signal, then the delay from such feedback will be greater than if the feedback on the envelope amplitude was used as feedback (Smetanin et al., 2020). The reason for the greater delay in the feedback from the EEG power is the need to conduct fast Fourier transform (Tarasov, 2007).

NFT latency specifies the reinforcement schedule (Sherlin et al., 2011) and as such it affects the outcome of NFT (Matsunaga & Genda, 2005; Schoenfeld, 1970). This issue has been addressed rarely in previous studies is the effect of the reference signal delay and modality in a biofeedback system (Matsunaga & Genda, 2005; Table 1). We have hypothesized that the shorter the delay, the faster the healthy subject will be able to recognize their condition and change it accordingly to feedback cue. To this end, real-time algorithms are needed that would shorten the delay while maintaining an acceptable speed-accuracy trade-off. Ossadtchi and colleagues showed that using the operating at zero latency, the weighted least-squares complex-valued filter approach yielded 75% accuracy when detecting alpha-power episodes, as defined by the amplitude crossing of the 95th-percentile threshold (Smetanin et al., 2020). Although, there is no work that specifies the optimal feedback delay for improving deliberation performance, this research demonstrates the effectiveness of a short delay in presenting feedback because brief delays of feedback are beneficial sometimes encourage anticipation of the upcoming feedback (Smetanin et al., 2020).

This latency time depends not only on the technical capabilities of the feedback signal processing, but also on the initial subject’s psychoemotional state before learning. Thus, the results of the study by Paul et al. (2020) showed that stress, through an increase in the level of cortisol, affects the neural mechanisms of processing feedback. Instead of accelerating the reaction to control the emotional state under stress, the authors noted a decrease in cognitive control under stress. Depending on feedback timing, the neural structures involved in learning differ, in dependence on the dopamine system that could being more important for learning from immediate than delayed feedback (Paul et al., 2020). Similar, the results from a study of children attention-deficit/hyperactivity disorder (ADHD) by Mullaney et al. (2014) showed that delaying feedback up to 8 s after stimulus presentation in verbal memory tasks improved learning performance to a greater extent than delaying results for a short period of time after the response. For instance, Baghdadi et al. (2020) showed that shorter feedback signal delay is more effective in NFT only for healthy patients. The authors demonstrated that for children with ADHD, a long feedback delay is more effective than an immediate feedback cue, which is consistent with longer reaction times in children with ADHD. In this case, feedback of 1200 ms in children with ADHD demonstrated a greater effect relative to feedback with a 200 ms signal delay (Baghdadi et al., 2020). Considering a coupling between the reward and attention circuits (Ibanez et al., 2012), attention is crucial for efficient neurofeedback learning (Kadosh & Staunton, 2019). It’s a reason explaining the impairment of reward processing has been reported in children with ADHD (Ibanez et al., 2012). The second reason why the longer delay of feedback could be more efficient than immediate is slowing reaction time connected with slowing iAPF in ADHD in comparison with healthy subjects (Bazanova et al., 2018; Samaha & Postle, 2015). Samaha and Postle (2015) demonstrated that subjects with lower iAPF have slower temporal resolution of visual stimuli than those one with higher iAPF. Insufficient research on the influence of the delay of signal presentation does not allow us to say which time values should be optimal for effective NFT. However, at this point we can say that the choice of delay time is influenced by baseline physiological condition.

Overall, these data indicate the importance of selecting the delay of reference signal in NFT systems according to the individual baseline characteristics of each participant, such as iAPF.

### Level of Thresholds

The factors that determine the NFT effectiveness also include a technical approach to determining the reward threshold (the appearance of a feedback signal). Threshold magnitude is an important aspect of NFT, as it should be set at a level that allows for an adequate amount of feedback information to allow the learner to identify their state, feelings, and thoughts that trigger the required activity (Ros et al., 2020).

If the threshold is set too low, the individual may have little motivation and/or need to do anything to elicit positive feedback. Conversely, if the threshold is set too high, not enough information will be provided for feedback and the participant is likely to be frustrated (Katkin & Murray, 1968; Prfwett & Adams, 1976; Vernon, 2005). NFT research data does not always justify the choice of a particular reinforcement threshold, and in some cases such information is not reported (Angelakis et al., 2007; Escolano et al., 2014; Konareva, 2005; Wacker, 1996). Based on data from Arnold's neurofeedback collaborative group (2024) and Bazanova et al. (2013) the use of a “variability” threshold protocol involving a gradual increase in the difficulty of a training task is always effective regardless of the baseline alpha peak frequency level. Meanwhile, lowing the threshold across the NFT training could help enhance the motivation for subjects with low iAPF (Bazanova et al., 2013; A. Kaiser et al., 2024).

Thus, the choice of threshold level for NFT should depend on the initial psychological status (motivation) and the dominant EEG frequency.

## The Modality of the Feedback Signal Provided

It is important to take into account the sensory modality of the presented stimulus when organizing the NFT (Gong et al., 2021). Despite the availability of several feedback modalities, there is still a lack of systematic studies that compare their effects across protocols and individual baseline condition. In general, learners’ characteristics and practical considerations affect the choice of feedback modality (Gong et al., 2021). Studying the alpha NFT efficiency (Bucho et al., 2019) demonstrated minimal differences between the “visual” and “auditory” groups, indicating that auditory reinforcement signals may be just as effective as visual signals commonly used in neurofeedback: both audio and visual reinforcement signals led to significant increases in upper alpha brain wave activity (Bucho et al., 2019). Following NFT, effects were observed not only in the target frequency of upper alpha, but also in the lower-alpha and theta bands, as well as in posterior brain regions. From the other hand, the use of auditory feedback cue could be more applicable for training protocols conducted in mobile settings, enabled by the growing prevalence of wireless EEG system (Bucho et al., 2019). Meanwhile, the visual analyzer has the most accurate temporal resolution and therefore the time delay of the stimulus should be minimal (Habes et al., 2016).

Multimodality feedback approaches have been gaining attention in several application domains. Dual-modality feedback is far superior to either single-modality feedback approach in terms of preventing the object from breaking or dropping (Kober et al., 2015; Li & Brown, 2023). Kober et al. (2015) used multimodal feedback signals to enhance the effectiveness of NFT, particularly in stroke rehabilitation. They showed that using two types of modalities, visual and auditory, is more effective than only one type of feedback. To reduce possible sensory conflicts, the overlap of sensory information should be taken into account, which can be observed with simultaneous vestibular stimulation and auditory feedback in rehabilitation with feedback of balance disorders (Probst & Wist, 1990). However, these findings may only apply to a specific sport performance NFT scheme and has not been extensively confirmed (Vernon et al., 2004).

According to some researchers, the interaction of visual and auditory feedback may be influenced by mutual interference (Lal et al., 1998; Vernon et al., 2004). Without proper integration, these feedback modes can potentially confuse participants and diminish their effectiveness. Proponents of utilizing both types of feedback argue that the combination can prevent individuals from overlooking one source of feedback and instead rely on the other to prompt them to persevere in their training (Lal et al., 1998; Vernon et al., 2004). According to this example, it is believed that the visual function of the human body is typically engaged in physical movement, suggesting that auditory feedback may be more effective NFT for psychomotor training (Vernon et al., 2004).

## Factors of NFT Design and Procedure

***Duration and Number of NFT Sessions.*** How often and long should training take place? There are no specific rules yet defined for the duration of NFT sessions for optimal results. The duration of NFT sessions depends on the goals and protocol of the study. NFT with a shorter duration (10–30 min) reduces stress, induces relaxation, and increases cognitive skills (Ghaziri et al., 2013). Longer NFT sessions allow the brain to better learn and adapt to new brain patterns, leading to longer-lasting effects (Vernon, 2005). Most meta-analyses report positive effects when sessions last at least 300 min (Lal et al., 1998). Meanwhile, the results presented in research of Reis et al. (2016) suggest that an intensive and short NF protocol enables elders to learn alpha and theta self-modulation and already presents moderate improvements in cognition and basal EEG (Reis et al., 2016).

### Ergonomic Factors

***The Factor of Body Position or Level of Support Afferentation During the NFT.*** An analysis of the NFT literature has demonstrated that both the neurofeedback procedure itself and EEG registration, with rare exceptions (Bazanova, Kholodina, et al., 2017; Enz et al., 2022), is performed in a reclining position, when the activation of the support afferentation is reduced. We believe that the activation of support afferentation, in addition to the evolutionary and biomechanical effect on sensorimotor integration, has a purely technological advantage. The results of EEG analysis obtained during registration in the supine position are not suitable for comparison with subsequent recordings made while performing cognitive and/or psychomotor tasks usually performed in the sitting position (Jobert et al., 2013). In other words, for self-regulation training with the help of neurofeedback, the skills of which can be used in everyday life, it is recommended to register EEG at rest in conditions that will then be used during NFT (i.e., subjects should be in an upright sitting position; Jobert et al., 2013). There are several reasons why weight transfer to the feet is necessary when sitting during EEG recording: (a) with a decrease in body weight transfer to the feet, there is a weakening of the support afferentation (Kozlovskaya et al., 1988; Kozlovskaya et al., 2007), which reduces sensorimotor integration and increases the perceptual load on other sensory modalities (Mouchnino et al., 2017); (b) the correct load on the feet on the appropriate footrest makes patients more stable (Mouchnino et al., 2017); (c) weight transfer to the plantar sole (e.g., in a standing position) increases the EEG power in the upper alpha frequency range (SMR; Bazanova, Kholodina, et al., 2017; Kozlovskaya et al., 2007; Kozlovskaya et al., 1988) and reduces neuronal activation (Swerdloff & Hargrove, 2023); and (d) when conducting EEG testing, it is important to remember that weight transfer to the plantares leads to reduction of EMG of the forehead muscles (Bazanova, Nikolenko, et al., 2017; Slobounov et al., 2009), which means that it reduces psychoemotional stress (Mouchnino et al., 2017; Pirini et al., 2011; Slobounov et al., 2009), which also minimizes EMG artifacts (Urigüen & Garcia-Zapirain, 2015). Gravity stimulates the arterial baroreceptors, and the brainstem modulates the autonomic nervous system (Mouchnino et al., 2017), thereby affecting brain waves (Chang et al., 2011). Thus, the posture during which EEG recording and the NFT procedure are performed affects the NFT effectiveness.

## Discussion

The analysis of the literature devoted to the study of the scientific and technical challenges and opportunities for enhancing the EEG-NFT efficiency allows us to identify the strengths and weaknesses of different approaches. It is logical to assume that when using individually set of psychological and physiological internal factors, NFT adapts more precisely to the characteristics of a particular person's brain activity and allows for more effective results. Our review and a recent analysis of the literature on NFT outcomes (Himmelmeier & Werheid, 2024) showed that individual alpha peak frequency is one of the most important internal factors influencing other internal and even external factors of NFT efficiency. Using standard protocols with the fixed EEG frequency ranges lead to less accurate correction of brain activity and, as a result, less significant training results. The question arises, “why does a large pool of randomized placebo-controlled alpha-EEG-NFT studies conducted in standard frequency bands demonstrate the clinical effectiveness of this type of NFT in about 70% of cases?” (Ros et al., 2020). We believe that this may be due to a number of reasons. Firstly, for some healthy subjects, the standard alpha ranges (8–12 Hz or 7–13 Hz) may coincide with individually determined frequency ranges, and for some they may be higher or lower than individually set ones. As shown in some research (Arns et al., 2014; Markovska-Simoska et al., 2008; Petrenko et al., 2019), the part of the subjects whose iAPF is less than 10 Hz, the range of 8–12 Hz will represent an individual alpha-2 range and for them alpha power training in the NFT will be more effective than for subjects with an iAPF greater than 10 Hz (Petrenko et al., 2019). Moreover, alpha training in standard bands for subjects with a high iAPF frequency may be accompanied by undesirable phenomena such as headache (Bazanova & Aftanas, 2010), since a shift in the EEG spectrum to the left or an increase in the power ratio in the low-frequency alpha-1 to alpha-2 range is associated with an increase in pain perception (Mckenzie et al., 1974; Pan et al., 2023). Another reason why alpha NFT training can be successful in standard ranges is that it was conducted for people with a low iAPF due to either childhood or old age (Edgar et al., 2022; Mierau et al., 2016; Orekhova et al., 2006), or for women in the cycle phases with initially low progesterone levels (Bazanova, Nikolenko, et al., 2017).

Finally, NFT is usually conducted for the purpose of adjuvant care and cognitive rehabilitation for people with anxiety, conversion, affective disorders, Alzheimer's disease, Parkinson's disease, depression, schizophrenia, autism spectrum disorders, stroke, posttraumatic stress disorder, etc. (Markiewcz, 2017; Renton et al., 2017; Steingrimsson et al., 2020; Tazaki, 2024). Since psychiatric disorders are generally associated with decreased iAPF (Harris et al., 2006; Stoffers et al., 2007), using the standard alpha range (8–12 Hz) as an NFT target may serve as a “personal upper alpha range” training for them. Upper alpha NFT training is evidenced used to train self-regulation (Hanslmayr et al., 2005).

Based on the presented results, it can be concluded that the effectiveness of EEG-NFT will be influenced by internal factors that could affect the baseline iAPF level: (a) age (Clark et al., 2024; Duffy et al., 1984), (b) menstrual cycle phase (Bazanova, Nikolenko, et al., 2017; Becker et al., 1982); (c) sleep quality (Zhao et al., 2021); and (d) substances use of tobacco (Banoczi, 2005), alcohol, coffee, tea, or energy drinks (Barry et al., 2011).

NFT efficiency can also be influenced by the external factors that influence iAPF discussed above. First of all, these are such factors of feedback signal acquisition and processing as: (a) electrode localization; although neurofeedback protocols may not limit the training effect to specific brain regions (Gruzelier, 2014; Güntensperger et al., 2020), from a technical point of view, the probability of highest amplitude and least contamination by artefacts is higher in the parietal region than in the frontal and temporal regions (Ebrahimzadeh et al., 2022), which means that the effectiveness of feedback presentation for NFT will be higher in the parietal region, where iAPF is the most stable and reproducible (Bazanova, 2011); (b) the choice of latent time in feedback presentation should depend on the baseline condition, namely reaction time (Baghdadi et al., 2020) and finally on the baseline iAPF (Samaha & Postle, 2015); and (c) the choice of valency of feedback reinforcement in NFT depends prevailing susceptibility to negative or positive stimuli in high and low iAPF subjects (Tumyalis & Aftanas, 2014). Secondly, factors of NFT sessions duration and number also depend on the baseline iAPF: (a) the iAPF may change as a result of a long session due to decreased vigilance over time (Birbaumer, 2024; Livanov, 1984); and (b) NFT session number that are needed for positive outcome also depends on baseline iAPF: less sessions number for high-iAPF subjects than low-IAPF subjects (Bazanova et al., 2013; Petrenko et al., 2019). The use of individually set frequency bands in brain activity control training using EEG is usually a more effective strategy, since it allows to more accurately adapt training to individual human needs.

Thus, iAPF and the individually specified frequency ranges used in NFT were the main factors that determined our choice of studies to include in the discussion in Table 1, even though they are not randomized control trials (RCT).

Meanwhile, we found only 19 studies on NFT that take into account an individually determined EEG frequency ranges as a training target (Table 1). Among them only two works showed higher NFT efficiency provided in individually adjusted EEG rangers compared to outcomes of NFT in standard frequency ranges (Bazanova & Aftanas, 2010; Bazanova et al., 2018). Perhaps, because all of the studies listed in the table were conducted using as a target the individualized EEG ranges, positive NFT results were obtained. However, other RCT works not included in this table also have positive outcomes. It seems that not only iAPF but also other factors are relevant for increasing the NFT efficiency.

One such factor determining the psychophysiological state of the subjects is the actual hormonal background. Most of the analyzed works did not take into account the menstrual cycle phase of the women included in the study (marked in red in the table). This factor influencing the effectiveness of NFT (Bazanova, Nikolenko, et al., 2017) requires further study.

The studies discussed here rarely take into account one of the intrinsic factors, EMG of the tone of the forehead and temples muscles, which is a marker of psychoemotional tension (Cacioppo, 2004). Consideration for decreased forehead EMG in NFT training reducing the individually determined theta/beta ratio (TBR) showed greater reductions in impulsivity and reaction time in ADHD children 6 months after the end of training than in children with similar NFT training without accounting for EMG (Bazanova et al., 2018). Similar results were received by Arns and colleagues (Arns et al., 2014).

**Table 1**

*The Research Considering the Main Internal and External Factors Determining the Opportunities of Increasing the EEG NFT Effectiveness*

| | Trained EEG feature | RCT | iAPF | Individualized ranges | Account to menstrual cycle phase in women | Feedback delay less 500 мс | Positive reinforcement | EC | EMG stop | EMG control | Posture | Threshold variable | Feedback modality | Outcomes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alexeeva et al., 2012 | Alpha/EMG | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | Audio | 🟩 |
| Arns et al., 2012 | TBR SMR-power | 🟩 | 🟩 | 🟩 | 🟥 | ? | 🟩 | 🟥 | 🟩 | 🟩 | ? | 🟩 | Visual | 🟩 |
| Bazanova & Aftanas, 2010 | Alpha/EMG, TBR | 🟥 | 🟩 | 🟩 | Male subjects | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | Audio | 🟩 |
| Bazanova et al., 2018 | TBR/EMG | 🟩 | 🟩 | 🟩 | Children | 🟩 | 🟩 | 🟥 | 🟩 | 🟩 | 🟩 | 🟩 | Visual | 🟩 |
| Petrenko et al., 2019 | Alpha/EMG | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | 🟩 | Audio | 🟩 |
| Cowley et al., 2016 | TBR SMR-power | 🟩 | 🟩 | 🟩 | 🟥 | ? | 🟩 | 🟥 | 🟥 | 🟥 | ? | 🟩 | Visual | 🟩 |
| Escolano et al., 2012 | Alpha-2 power | 🟩 | 🟩 | 🟩 | 🟥 | 🟥 | 🟩 | 🟥 | 🟥 | 🟥 | ? | ? | Visual | 🟩 |
| Grosselin et al., 2021 | Alpha-power | 🟩 | 🟩 | 🟥 | 🟥 | 🟥 1 s | 🟩 | 🟥 | 🟥 | 🟥 | ? | 🟩 | Audio | 🟩 |
| Güntensperger et al., 2019 | Alpha/delta ratio | 🟥 | 🟩 | 🟩 | 🟥 | ? | 🟩 | 🟥 | 🟥 | 🟥 | 🟩 | ? | Visual | 🟩 |
| A. Kaiser et al., 2024 | TBR, SMR-magnitude | 🟥 | 🟩 | 🟩 | Children | ? | 🟩 | 🟥 | 🟥 | 🟥 | ? | 🟩 | Visual | 🟩 |
| Markovska-Simoska et al., 2008 | Alpha/EMG | 🟥 | 🟩 | 🟩 | 🟥 | 🟩 | 🟩 | 🟩 | 🟩 | 🟥 | 🟩 | 🟩 | Audio | 🟩 |
| Nan et al., 2012 | Relative amplitude in individual alpha band | 🟥 | 🟩 | 🟩 | 🟥 | ? | 🟩 | 🟥 | 🟥 | 🟥 | ? | 🟩 | Visual | 🟩 |
| Naas et al., 2019 | Alpha-power | 🟩 | 🟩 | 🟩 | 🟥 | ? | 🟩 | 🟥 | 🟥 | 🟥 | ? | ? | Visual | 🟩 |
| Parsons & Faubert, 2021 | iAPF | 🟩 | 🟩 | ? | ? | 🟥 | 🟩 | 🟥 | 🟥 | 🟥 | ? | 🟩 | Visual | 🟩 |
| Quaedflieg et al., 2016 | iAPF asimmetry | 🟩 | 🟩 | 🟥 | 🟥 | 🟥 | 🟩 | 🟥 | 🟥 | 🟥 | ? | ? | Visual | 🟩 |
| Reis et al., 2016 | Alpha-power, theta-power | 🟩 | 🟩 | 🟩 | > 55 years | 🟩 | 🟩 | 🟥 | 🟥 | 🟥 | ? | 🟩 | Visual | 🟩 |
| Strothmann, 2024 | TBR | 🟩 | 🟩 | 🟥 | 🟥 | ? | 🟩 | 🟥 | 🟩 | 🟥 | 🟥 | 🟩 | Visual | 🟥 |
| Veilahti et al., 2021 | TBR, SMR-power | 🟥 | 🟩 | 🟩 | 🟥 | ? | Positive and negative | ? | 🟥 | 🟥 | ? | 🟩 | Visual | 🟩 |
| Wan et al., 2014 | Alpha-magnitude | 🟥 | 🟩 | 🟩 | 🟥 | ? | 🟥 | 🟥 | 🟥 | 🟥 | ? | 🟥 | Visual | 🟩 |

**Note.** Green color means that this factor was taken into account, red means that it was not; question mark (?) means that the paper does not indicate whether the factor was taken into account or not; iAPF - individual alpha peak frequency; TBR - theta/beta ratio; SMR - sensorimotor rhythm; RCT - randomized control trails; EMG - electromyography.

The research on the influence of support afferentation on psychophysiological functions and their neurobiological markers, in particular on EEG and EMG, has been insufficient to date. In this connection the majority of EEG and NFT works are carried out without taking into account this important ergonomic factor. In most of the studies we analyzed, EEG registration and NFT was either performed in a semireclined position or was not indicated at all.

Another rarely considered factor that can affect the efficiency of NFT is the latency of the feedback signal. This may be due to technical difficulties in implementing NFT and lack of evidence of the need to use a particular feedback latency interval.

For the moment, caution is required when interpreting the table's results given a number of limitations in addition to the issues raised with regard to the nature of the trials. The level of methodological rigor specifically related to RCT was generally unclear (Hammond & Kirk, 2008; Pigott et al., 2021). The level of blinding was insufficient in many studies (Pigott et al., 2021). A complementary checklist for neurofeedback trials, including guidelines of preexperiment, control groups and measures, feedback specifications, and outcome measures that are important to improve the level of evidence of NFT efficiency (Ros et al., 2020). Because not all factors that have an impact on NFT efficiency were taken into account in this table, we agree with the opinion of that academic community that calls for more empirical research to fill these knowledge gaps (Ros et al., 2020; Vernon, 2005).

Further research, characterized by greater methodological rigor, is therefore needed to determine the effectiveness of NFT and the superiority, if any, of this type of training over the single administration of either.

## Conclusion

This roadmap provides a comprehensive review of the internal and external factors that influence the efficiency of EEG-NFT including the socioeconomic, psychological, and physiological aspects, as well as technical considerations related to the feedback signal's acquisition, processing, and presentation. Internal factors such as socioeconomic status can significantly impact learning efficiency during NFT, with lower socioeconomic backgrounds potentially leading to reduced cognitive function due to stress and anxiety. Psychological traits like personality and cognitive abilities also play a role, with certain traits being more conducive to effective learning during NFT. Physiological factors, including muscle tension and resting EEG features, are crucial as well. For instance, EEG alpha power can predict NFT success, but it is also susceptible to artifacts from muscle tension, which must be managed for accurate feedback. External factors discussed include the delay and modality of feedback signals, the duration and number of NFT sessions, and the ergonomic setup during training. The document emphasizes that the optimal delay of feedback signals is influenced by individual baseline characteristics, such as reaction time, the iAPF. The choice of feedback modality, whether visual or auditory, and the reinforcement strategy, whether positive or negative, also significantly affect NFT outcomes.

The review highlights the importance of considering individual differences in baseline EEG characteristics, such as iAPF, to enhance NFT effectiveness. Establishing NFT protocols based on the use of individual EEG frequency characteristics would contribute to increasing the credibility of the research results and increasing the efficiency of their practical application. However, here we also note the challenges in standardizing NFT protocols, given the variability in individual responses and the complexity of factors involved. The review concludes by calling for more rigorous research to better understand and optimize the factors that influence NFT efficiency.

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