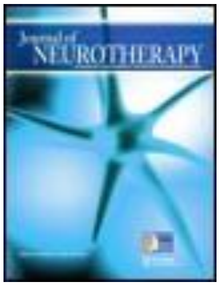

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Alpha Neurofeedback Training for Performance Enhancement: Reviewing the Methodology

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Alpha Neurofeedback Training for Performance Enhancement: Reviewing the Methodology

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ABSTRACT. *Introduction*. Considerable interest has been, and still is, generated by the potential performance enhancing benefits of alpha neurofeedback training (NFT) for healthy participants. A plausible rationale for such training, with an aim to improve mood and/or enhance cognition, can be made based upon what is already known of the links between alpha EEG activity and behavior. However, designing an optimal NFT paradigm remains difficult because a number of methodological factors that may influence the outcome of such training remain largely unexplored.

Method. This article focuses on these methodological factors in an attempt to highlight some of the unanswered questions and stimulate future research.

Results. Specifically, this article examines the NFT training schedule; the variety, basis, and setting of reward thresholds; the nature and modality of the feedback signal provided; unidirectional as compared to bidirectional NFT; the establishment of a target frequency range for alpha; whether NFT should be conducted with eyes open or closed; and the identification of a clear index of learning.

Conclusions. Throughout, the article provides a number of suggestions and possible directions for future research.

KEYWORDS. Alpha, EEG, methodology, neurofeedback, peak performance

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INTRODUCTION

Ever since Kamiya (1968) suggested that it was possible for healthy individuals to perceive and obtain a degree of conscious control over the production of their own alpha brainwave activity and that this in turn may influence their behavior, there has been interest in the potential performance enhancing applications of neurofeedback training (NFT; see e.g., Gruzelier, Egner, & Vernon, 2006; Vernon, 2005; Vernon & Gruzelier, 2008). However, the potential performance enhancing benefits of NFT remain unclear because a number of methodological factors that may impact the effectiveness of such training are unexplored. Hence, this article explores the research to date in an effort to provide some useful insights into developing more effective NFT procedures, which in turn may offer guidance and stimulate additional research.

NFT, also referred to as electroencephalographic (EEG) biofeedback and brain–computer interface training, is often defined as an operant conditioning paradigm based on a sophisticated form of biofeedback (Vernon, 2009). The aim is to provide the individual with explicit information regarding specific aspects of his cortical activity in an easy-to-understand format and in doing so encourage him to alter particular target components, such as amplitude or frequency. Outside of the clinical arena alpha NFT has been aimed at relieving anxiety or improving mood (e.g., Moore, 2000; Norris, Lee, Burshteyn, & Cea-Aravena, 2001; Putman, 2000) and/or enhancing cognition (e.g., Angelakis et al., 2007; Bazanova & Aftanas, 2006; Bazanova, Mernaya, & Shtark, 2009; Hanslmayr, Sauseng, Doppelmayr, Schabus, & Klimesch, 2005).

The rationale for undertaking alpha NFT to alleviate anxiety and enhance mood is based originally on research showing that individuals in meditative states exhibited increased amplitude alpha activity along with greater levels of relaxation (Kasamatsu & Hirai, 1969). Such findings have been replicated a number of times with researchers showing that advanced meditative practitioners, that is, those with more than 10,000 hr of practice, exhibited elevated levels of alpha activity compared to nonmeditating controls (Aftanas & Golocheimine, 2005; Herbert & Tan, 2004; for a review see Cahn & Polich, 2006). Furthermore, Singer (2005) reported that enhancing 11–16 Hz, which overlaps with the upper alpha range, led to a reduction in the level of anxiety for healthy dancers. Not all, however, have found that alterations in mood are reflected by concomitant changes in alpha activity. For instance, Frost, Burish, and Holmes (1978) reported that induced stress, which elicited changes in pulse rate and skin conductance levels, failed to produce any changes in alpha activity. Such findings have led to suggestions that alpha is not sensitive to changes in stress and/or arousal and as such alpha NFT would be expected to have little or no effect. Indeed, Potolicchio, Zukerman, and Chernigovskaya (1979) found no changes in mood, as measured by the Profile of Mood States questionnaire, for those showing increases in alpha as a function of alpha NFT. In addition, Holmes, Burish, and Frost (1980) found that alpha NFT was ineffective in helping participants decrease their levels of arousal during a stressful situation, and Hardt and Kamiya (1978) reported that alpha enhancement training was associated with reduction in state anxiety but only for high trait anxiety participants. These conflicting findings have been suggested to result from methodological differences, particularly in terms of level and measures of anxiety, measurement of the EEG as well as sensor placement across the scalp (see Moore, 2000). As such, the notion that alpha NFT can enhance the mood of healthy individuals has yet to be firmly established.

In terms of cognition, it may have been the case that alpha was originally viewed as the idling rhythm of the brain (Adrian & Matthews, 1934). An alternative model is that alpha works in a top–down fashion (von Stein & Sarnthein, 2000) to actively inhibit nonessential or conflicting processes within the brain, thereby increasing the signal to noise ratio and improving efficiency (Cooper, Croft, Dominey, Burgess, & Gruzelier, 2003; Klimesch, Doppelmayr, Röhm, Pöllhuber, & Stadler, 2000). According to the *neural efficiency hypothesis* (e.g., Doppelmayr, Klimesch, Hodlmoser, Sauseng, & Gruber, 2005; Haier et al., 1988), effective cognition is not a function of how *hard* the brain works but rather how *efficiently* it works. Thus, if alpha makes completion of a task more efficient by inhibiting nonessential processing, then a greater level of available alpha may enable the individual to inhibit more nonessential activity, which in turn may facilitate performance on the task. Although speculative, this idea is supported by research showing that people classified as more intelligent exhibit greater levels of alpha power compared to those with average levels of intelligence (Anokhin & Vogel, 1996; Doppelmayr et al., 2005; Jausovec, 1996). Jausovec suggested that this is because the intellectually competent, or gifted, individuals activate only the task relevant areas of the brain in a more focused manner, whereas those classified as intellectually average may activate nonessential task irrelevant areas when attempting to complete a task, which in turn interferes with their ability to complete the task. Additional support for this idea comes from Doppelmayr et al., who found that during a particularly difficult semantic processing task participants with higher intelligence exhibited a larger reduction in alpha power over their left hemisphere relative to those with lower intelligence. This was taken to indicate that the more intelligent participants recruited a wider range of cortical processes to complete the difficult task. Taken together, results from these studies appear to show that people with higher levels of resting alpha power may be able to actively inhibit irrelevant processes, or not, depending on the needs of the task.

Of course such findings are associative, in the sense that changes in behavior have been associated with alterations in psychophysiology, and as such caution should be exercised to ensure that such findings are not overinterpreted. Nevertheless, there are some intriguing findings which suggest that the changes in alpha may be more causal than correlational. The first focuses on how modifications in alpha can elicit changes in behavior (Bazanova, Verevkin, & Shtark, 2007; Hanslmayr et al., 2005; Klimesch, Sauseng, & Gerloff, 2003), and the second shows that changes in behavior can produce changes in the alpha component of the EEG (Fink, Grabner, Benedek, & Neubauer, 2006). For example, Klimesch et al. (2003) showed that inducing the upper individual alpha frequency range using repetitive transcranial magnetic stimulation elicited a change in the EEG in line with the stimulation, that is, an increase in upper-alpha power, and was associated with improved performance on a mental rotation task. Hanslmayr et al. (2005) extended this work to show that NFT to enhance upper alpha also led to increased alpha power for some of those undergoing the training. In addition, they reported a clear link between those who were able to increase the power of their upper alpha activity and improved performance on a mental rotation task. Bazanova et al. (2007) have also found that musicians undergoing NFT to enhance their upper alpha were able to show clear changes in their EEG along with enhanced musical abilities. Such findings are consistent with suggestions that increased alpha is associated with improved performance (Bazanova & Aftanas, 2006; Doppelmayr et al., 2005). Conversely, Fink et al. (2006) found that a 2-week training course in divergent thinking led to an increase in the level and originality of ideas generated and an increase in alpha (8–10 Hz) over the frontal regions. They suggested that the increase seen in frontal alpha may be due to an inhibition of the "critical frontal brain" (p. 2245) needed for the individual to produce more novel and/or uniquely original ideas. Overall, these findings suggest a strong link between alpha and cognition, with increases in alpha, leading to benefits in cognitive processing, and vice versa.

Such findings provide a plausible rationale for alpha NFT, which in addition to the possibility of enhancing performance also represents a useful mechanism for exploring the links between EEG and cognition. However, identifying an optimal training paradigm for NFT remains difficult as many methodological factors have yet to be systematically investigated. It is a deceptively simple question to ask, What is the best method to ensure an optimal outcome when conducting alpha NFT? Not surprising, however, it is far more difficult to provide a simple unambiguous answer. Of course, it may be that there is no single "optimal paradigm" eliciting beneficial effects for one and all, and it is entirely possible that the best way forward will be to design bespoke NFT procedures tailored specifically to an individual's needs and desires. Nevertheless, exploring the research to date will help to provide useful insights into developing more effective NFT procedures.

Demographic and methodological factors including age (Woodruff, 1975), gender (Nowlis & Kamiya, 1970; Travis, Kondo, & Knott, 1975), use of strategies (Plotkin, 1976), motivation levels (Kondo, Travis, & Knott, 1975), lighting conditions (Cram, Kohlenberg, & Singer, 1977; Paskewitz & Orne, 1973), and montage (Fehmi & Collura, 2007; Putman, 2001; Rosenfeld, 2000) have been explored elsewhere. Thus, here we focus only on methodological factors that have received relatively little research attention and/or require additional exploration: These include training schedule, reward thresholds, feedback information, unidirectional versus bidirectional training, the frequency range of interest, training with eyes open versus eyes closed, and the index of learning.

METHODOLOGICAL FACTORS

NFT Schedule

Given that the goal of NFT is to elicit changes in the EEG and thereby alter behavior/cognition, three questions emerge. First, how long should each training session last? Second, how often should participants complete such training sessions? Finally, how many sessions are needed?

In terms of how long the session should last, there are no clear guidelines, and past research has utilized sessions that last from minutes to hours (e.g., Bauer, 1976; Nowlis & Kamiya, 1970; Prewett & Adams, 1976; Regestein, Pegram, Cook, & Bradley, 1973). Some have suggested that very short training sessions lasting for only a few minutes may be insufficient to allow learning to occur (Ancoli & Kamiya, 1978; Plotkin, 1976). Such a proposal is consistent with the work of Travis, Kondo, and Knott (1974), who found that it took between 2 and 3 min for participants to produce increments in alpha. However, it is also important to ensure that the duration of the training is not so long that the trainee becomes fatigued and drowsy. Such a possibility could explain the failure of Regestein et al. (1973) to find evidence of changes in alpha following a 4-hr NFT session. Thus, sufficient time needs to be provided for the trainee to obtain some understanding of the relationship between the feedback and the different states experienced, in order to be able to adopt a strategy that will be useful in helping to alter alpha activity but not so long that it has a deleterious effect on the outcome. Given the success many have shown with sessions of between 20 and 30 min, this may be a good place to begin (see, e.g., Angelakis et al., 2007; Bazanova et al., 2007; Fell et al., 2002; Hanslmayr et al., 2005; Norris et al., 2001). Of course, it may be that the most effective approach is to begin with a short duration session and then increase its length as the trainee becomes more adept. However, there are as yet no data available to help inform this decision.

In terms of how often the NFT should be conducted possible options include the notion that all sessions are given in a single day, or that they are spread out across different days, or over a period of weeks. If NFT is similar to other types of learning (see Bahrick, 2000), spacing training out over a period of days and/or weeks should be more effective than training that is massed within a single day. Unfortunately, comparisons of massed versus spaced NFT in the literature have revealed contradictory results. For instance, Albert, Simmons, and Walker (1974) compared the effects of five NFT sessions massed within 1 day to five sessions completed across 5 separate days. They found that the group receiving the spaced NFT at daily intervals exhibited greater levels of alpha compared to those given the massed NFT. This led them to suggest that spaced practice, carried out daily, is more effective than massed practice because it allows greater time for rehearsal and adaptation to the setting and equipment. If this is the case, then weekly practice sessions, which would allow the individual even greater time for rehearsal and provide more opportunity to habituate to the setting, could potentially prove to be more beneficial than daily sessions. However, Yamaguchi (1980) reported that massed training delivered in a single day was more effective at increasing alpha compared to NFT delivered on separate days. Yamaguchi found that only those completing the massed NFT exhibited an increase in alpha, whereas those completing the training spaced across three days failed to show any change in their EEG. Yamaguchi suggested that the benefit seen for massed practice may be due to a reliance on insight used during NFT to help discover possible relationships between the feedback and various states of consciousness associated with the production of alpha and that massed practice makes it easier for the individual to obtain such insights. In addition, Yamaguchi noted that methodological differences between his study and the earlier one of Albert et al. (1974) may account for the distinct pattern of effects. As such, it remains unclear at present whether massed or spaced practice is more effective.

The final question regarding the NFT schedule is how many sessions are needed for changes in the EEG to be seen. Some have suggested that multiple sessions are needed for the individual to learn to habituate to the experimental setting and establish the associative relations between modifications in the EEG and changes to internal states (Hardt & Kamiya, 1976a; Konareva, 2005). This is consistent with reports of changes in the EEG following multiple NFT sessions taking place over a period of weeks (e.g., Angelakis et al., 2007; Cho et al., 2008; Norris et al., 2001). However, others have found changes in the EEG following a single NFT session (e.g., Bazanova et al., 2007; Fell et al., 2002; Hanslmayr et al., 2005). Furthermore, Bazanova et al. (2007) found that single sessions were more successful for those with an alpha peak frequency of greater than 10 Hz. Hence, it may be the case that success with a particular training schedule is influenced by each individual's alpha range and peak. However, there are many methodological differences between these studies, which makes attempts at cross-comparison difficult. Nevertheless, such findings would suggest that a single session may be sufficient to elicit changes in the EEG via NFT. Of course, such changes may be short lived, and it may be that for longer term effects more sessions would be needed. However, at present there are no data addressing this issue.

Overall, it would seem that a single NFT session lasting for between 20 and 30 min should be sufficient to ensure that short-term changes occur in the EEG. However, for longer term and/or permanent changes to occur more sessions may be needed, although whether it would be more effective if such sessions were spaced out or massed together remains to be seen.

Reward Threshold

The reward threshold refers to the level at which feedback information is provided, and this may be fixed or variable. For example, if the reward threshold is fixed at 10 μV during NFT, when the amplitude of alpha exceeds this level an audio and/or visual signal is relayed back to the participant, providing feedback. In contrast a variable reward threshold may change over time, starting at 8 μV and gradually increasing to 12 μV. Unfortunately, it is not always made clear why a particular reward threshold has been chosen and in some cases such information is not reported (e.g., Angelakis et al., 2007; Beatty, 1971; Hardt & Gale, 1993; Johnson & Meyer, 1974; Konareva, 2006; Wacker, 1996). Nevertheless, when such information is reported there is little consistency in its use. For instance, the most common measures reported are amplitude, as measured in microvolts, and measures based on a ratio of the amount of EEG activity seen when at rest. However, reward thresholds based on amplitude have ranged from 10 μV up to

40 μV (e.g., Ancoli & Green, 1977; Hardt & Kamiya, 1976a; Holmes et al., 1980; Kuhlman & Klieger, 1975; Nowlis & Kamiya, 1970; Valle & DeGood, 1977) with some setting additional upper limits of 75 μV and 100 μV (Marshall & Bentler, 1976; Tyson, 1982). There is a similar level of variety when using thresholds based on a proportion of resting EEG activity, with thresholds set at between 50% and 85% of the amount of alpha seen when at rest (e.g., Cho et al., 2008; Cram, Kohlenberg, & Singer, 1977; Norris et al., 2001; Prewett & Adams, 1976; Travis et al., 1974, 1975).

Clearly, identifying the chosen reward threshold would seem an essential aspect of NFT because it needs to be set at a level that ensures an adequate amount of feedback information is provided, allowing the learner to identify states, feelings, and cognitions that elicit the required activity. If the threshold is set too low, making the task very easy, there may be little motivation and/or need for the individual to do anything to elicit positive feedback. In contrast, if it is set too high, insufficient feedback information will be provided and the participant is likely to become frustrated. Both scenarios could potentially inhibit the participant's ability to learn to alter his or her EEG via NFT. However, there is very little guidance identifying optimal reward thresholds. For instance, Knox (1980) suggested that for a threshold to be relevant participants need to exhibit between 25% and 75% above threshold activity during an eyes closed resting baseline period. If they exhibit less than 25% above threshold activity it is likely that participants would receive too little information for the feedback loop to operate effectively. However, this leaves a broad range open for possible use, and it is likely that a threshold based on resting activity, which is only exceeded by 25%, would be substantially more difficult and may involve distinct processes than one that is exceeded by 75%.

Furthermore, it is likely that thresholds based on a ratio of resting EEG activity are more meaningful and possibly more effective than thresholds based on an arbitrary level of amplitude. This is because each threshold relates directly to the individual's natural resting level of alpha activity. For example, Knox (1980) measured the amount of alpha exhibited by participants that exceeded an arbitrary fixed threshold of 15 μV when resting with their eyes closed. She found that the majority of participants (68%) exhibited less than 25% of alpha when using this cut-off point and argued against the use of such arbitrary fixed thresholds based simply on level of amplitude. Thus, setting a reward threshold that fails to relate to the individual's resting level of alpha EEG activity may make the task of NFT more difficult for some and in doing so reduce its effectiveness. As such, additional research is needed to identify an optimal level, or range, of reward thresholds, comparing fixed versus variable thresholds as well as directly comparing the effectiveness of the different measures used, to establish which is the more effective.

Feedback

Neurofeedback researchers and practitioners assume that feedback relating specifically to changes in psychophysiological functioning is both necessary and sufficient. Indeed, it has been shown that feedback contingent upon the presence of alpha activity can help improve the participant's self-control of alpha beyond that which can be achieved by instruction alone (Plotkin, 1976). However, it is still not clear how the modality of feedback and its relationship with the presence/absence of alpha can influence the outcome of NFT. In general the modality of feedback includes audio, visual, and combined audio-visual information, and its presentation may be initiated once alpha exceeds a preset reward threshold.

With regards to audio feedback, pleasant sounds may be more effective than unpleasant ones. For instance, Tyson (1982) found that audio feedback in the form of a sine wave led to the production of more alpha compared to a sawtooth stimulus. He suggested that this is because the sawtooth stimulus can act as a mild stressor, leading to the suppression of alpha, making it more difficult to enhance alpha via NFT. If so, providing participants with audio feedback that is rated as "highly pleasant" may help them to relax, facilitating enhancement of alpha. Further, it may be worth exploring whether sounds rated as generically pleasant are more effective than ones identified by each individual as highly pleasant. For instance, Breteler, Manolova, de Wilde, Caris, and Fowler (2008) recently reported a relationship between changes in SMR (12–15 Hz) via NFT and participants' subjective ratings of pleasantness of the audio feedback stimuli, but only when it was combined with visual feedback. In addition to the nature of the sound used, the relationship between changes in the sound and changes in EEG may also influence the effectiveness of NFT. For instance, some researchers have utilized audio feedback, which turns on or increases in tone and/or volume as levels of alpha increase beyond a set point (e.g., Cho et al., 2008; Holmes et al., 1980; Plotkin, 1976; Schwartz, Davidson, & Pugash, 1976). In contrast, others have used audio tones that decrease in frequency as alpha exceeds a preset threshold or are absent during the presence of alpha (Fell et al., 2002; Kuhlman & Klieger, 1975; Yamaguchi, 1980). Although successes have been reported using both approaches it is interesting to note that only those adopting an inverse relationship between feedback and presence or level of alpha have shown that NFT can lead to enhanced levels of alpha beyond that seen when resting with eyes closed (Kuhlman & Klieger, 1975; Yamaguchi, 1980), a state that may represent an optimal level of alpha activity (Lynch, Paskewitz, & Orne, 1974; Orne & Paskewitz, 1974; Paskewitz & Orne, 1973; Strayer, Scott, & Bakan, 1973). As such, it may be that an inverse feedback relationship between the tone and the level/presence of alpha provides a more effective method of feedback. Such a possibility may be due to the well-known inhibiting effect that attending to a stimulus can have on alpha activity (Jasper & Shagrass, 1941). As such, a reduction or absence of the feedback signal indicating the presence of alpha may have less of an inhibiting effect, allowing the individual the opportunity to enhance their alpha levels beyond an eyes closed baseline. This is a speculative possibility, as no research has yet directly compared the effectiveness of audio feedback tones that vary in their relationship with changes in alpha.

In terms of visual feedback, again there has been a variety of visual stimuli used including lights that simply come on (Kondo & Knott, 1974; Travis et al., 1974), change color (Hanslmayr et al., 2005; Lynch et al., 1974) or patterns that fill in as amplitude increases (Putman, 2000). Once again, however, the relationship between these distinct forms of visual feedback and their effects on the outcome of NFT remains unexplored. Furthermore, given that alpha power is normally blocked or desynchronized during opening of the eyes, training to increase alpha amplitude during eyes open may represent a more difficult task.

With regard to combined audio-visual feedback, two distinct information streams may be more beneficial than one, because a greater amount of information is provided, and if attention to one modality fades the remaining signal may command continued focus. For instance, Hardt and Kamiya (1976a) stated that audio feedback alone may be inadequate as it fails to indicate how well a participant performed overall on each trial of NFT. They suggested that combining the audio signal with visual feedback in the form of a "score" at the end of each trial may be more effective at maintaining motivation and avoiding drowsiness. However, Breteler et al. (2008) found no difference in the efficacy of NFT aimed at enhancing SMR (12–15 Hz) when using combined audio-visual feedback or visual feedback alone. Nevertheless, this work is at an early stage, and at present there is no research directly comparing the effectiveness of combined audio-visual feedback to that of audio feedback alone.

Unidirectional versus Bidirectional Training

The ultimate goal of NFT is for the participant to obtain a degree of conscious control over a particular psychophysiological component of his EEG without the need for feedback. This may be achieved by having the participant learn to enhance or inhibit his or her alpha activity using NFT, often referred to as unidirectional training, or by having the participant alternately enhance and then inhibit alpha, which is described as bidirectional training (Ancoli & Kamiya, 1978). The majority of unidirectional training has been aimed at encouraging participants to learn to enhance alpha (e.g., Angelakis et al., 2007; Bazanova et al., 2007; Cho et al., 2008; Fell et al., 2002), which some suggest is more preferable for participants than inhibiting it (Kamiya, 1969; Lynch et al., 1974). However, inhibiting alpha may be easier than enhancing it (Lynch & Paskewitz, 1971; Paskewitz & Orne, 1973; Peper & Mulholland, 1970; Prewett & Adams, 1976) although findings have been inconsistent (see, e.g., Regestein et al., 1973). Nevertheless, adopting a unidirectional approach that involves isolated training sessions either enhancing or inhibiting alpha may be less effective than a bidirectional training regime, which incorporates both enhancement and suppression, for at least two possible reasons. First, providing NFT that incorporates both enhancing and inhibiting alpha activity is likely to provide more information concerning the underlying mechanisms responsible for dynamic changes in the EEG and as such may enable the participant to obtain a greater degree of conscious control in less time. To some extent this is supported by the findings from Regestein et al., who found no correlation between participants' ability to enhance alpha during a single 12-hr session and their ability to inhibit it. They suggested that this is because distinct and possibly independent mechanisms underpin the augmentation and inhibition of alpha activity. Therefore, providing bidirectional training, which incorporates both, could conceivably provide information on multiple mechanisms of change with regards to alpha activity, which in turn may facilitate the process of conscious control. The second point is more speculative and relates to the notion of natural limits. For instance, research within the field of traditional biofeedback has shown that it is easier to increase heart rates than to decrease them (Stephens, Harris, Brady, & Schaffer, 1975). This may be because there are natural regulators that restrict or limit the variability of such a physiological process. Given this, despite the aim of many to simply enhance alpha activity via NFT, it is unlikely that such activity can be increased ad infinitum. Indeed, some have suggested that it is not possible to enhance alpha beyond that seen at rest with eyes closed (e.g., Lynch et al., 1974; Orne & Paskewitz, 1974; Strayer et al., 1973) although a few have exceeded this (see Kuhlman & Klieger, 1975; Yamaguchi, 1980). Nevertheless, there may be natural limits as to how much, or how little, alpha activity can be produced. If this is the case it may make more sense to utilize a bidirectional training regime to help the individual learn to obtain a degree of conscious control over their alpha activity. As noted this represents a speculative possibility because we are aware of no direct comparison exploring the effectiveness of a bidirectional training regime to a unidirectional approach.

Target Frequency Range

It has been known for some time that alpha occurs predominantly in the parietal region, has been recorded with average amplitudes ranging 30–50 μV (Kamiya, 1968; Lynch & Paskewitz, 1971), and can be seen in the majority (90%) of the population when resting with eyes closed (Drennen & O'Reilly, 1986) and that opening the eyes can reduce the amount of alpha by 80% or more (Wacker, 1996). However, identifying the specific frequency range of the alpha component of the EEG seems less certain. For example, previous attempts to enhance alpha using NFT have identified alpha as operating between 7–15 Hz (Brown, 1970), 7.5–13 Hz (Prewett & Adams, 1976), 8–12 Hz (e.g., Albert et al., 1974; Cho et al., 2008; Fell et al., 2002), 8.5–12.5 Hz (Bauer, 1976), 8–13 Hz (e.g., Angelakis et al., 2007; Hardt & Kamiya, 1978;

Nowlis & Kamiya, 1970), 8.5–13.5 Hz (Valle & Levine, 1975), 8–14 Hz (Konareva, 2005, 2006), and 10 Hz ± 1 Hz (Drennen & O'Reilly, 1986). Such inconsistencies in identifying the frequency range of the training component not only make comparisons between studies problematic but also fail to take into account individual differences. For instance, research has shown that the alpha frequency range can vary to a considerable extent in normal age-matched participants (see, e.g., Klimesch, Schimke, & Pfurtscheller, 1993). Such findings have led some to define individual alpha frequency (IAF) ranges, which have been used during subsequent NFT sessions with positive results (Bazanova et al., 2007; Hanslmayer et al., 2005). Calculation of the individual alpha band is a relatively straightforward procedure that involves comparing EEG spectral power during an eyes-open recording to that of eyes closed and using the individual alpha peak frequency as an anchor point (see Bazanova & Aftanas, 2006). It may be that NFT based on IAF ranges will be more efficient than training based on traditional fixed frequency ranges. Indeed, NFT using IAF has been shown to lead to enhanced levels of alpha (Bazanova et al., 2007; Hanslmayer et al., 2005). However, as yet, no direct comparison has been conducted between the effectiveness of NFT based on IAF relative to traditional fixed frequency ranges to ascertain which is more effective.

Eyes Open versus Eyes Closed NFT

Alpha amplitude is normally a function of reduced sensory input from the thalamic nuclei to the cortex and keeping the eyes open will naturally increase sensory input to the thalamic structures and thus suppress alpha power by default. Furthermore, alpha amplitude at parietal-occipital regions, where alpha NFT is often conducted, is greater when the eyes are closed, reflecting not only a reduced level of stimulus input but also the inhibition of cortical activity, such as visual information processing (see Wacker, 1996). This shows that simply opening or closing the eyes can elicit reasonably robust effects on alpha amplitude. Nevertheless, NFT has been conducted both with eyes closed (e.g., Bazanova et al., 2009; Cho et al., 2008; Fell et al., 2002; Yamaguchi, 1980) and eyes open (e.g., Angelakis et al., 2007; Hanslmayr et al., 2005; Putman, 2000). Unfortunately, it is not always made clear why one approach is selected over another.

For eyes closed there seems to be an implicit assumption that such training mirrors the relaxed approach utilized by meditators attempting to achieve a calm state of restfulness and that it may also engender an inward focus of attention (Hardt & Kamiya, 1976b). In contrast, some have suggested that NFT with eyes open provides a lower "baseline" from which to attempt to increase alpha amplitude (e.g., Travis et al., 1974) and as such is more likely to exhibit positive effects from NFT. However, not all agree with this rationale; in fact Hardt and Kamiya (1976b) criticized the idea that NFT should be conducted with eyes open because of the naturally suppressing effect this has on alpha amplitude. They argued that this represents a contradictory training regime, in the sense that opening the eyes naturally suppresses alpha amplitude, which participants then attempt to overcome by using NFT. They suggested that this is "rather like asking persons to experience a state which they are prevented from experiencing" (p. 102). Furthermore, Travis et al. (1974) suggested that eyes open alpha NFT is primarily concerned with reducing the alpha suppressing effects resulting from oculomotor processes, whereas Hardt and Kamiya (1976b) put forward the idea that eyes closed alpha NFT is influenced more by what they call "central processes" (p. 105). They argued that such central processes are more likely to determine states of consciousness than are the peripheral processes involved in eyes open NFT. The notion that eyes open compared to eyes closed NFT may rely on distinct processes gains some support from the work of Travis et al. (1974), who found that participant's ability to enhance alpha amplitude with eyes open was uncorrelated with their ability to enhance alpha amplitude when eyes were closed. They suggested that such a pattern supports the notion that the two approaches to NFT may rely on "different internal controls" (p. 680). If this is the case, then Ancoli and Kamiya (1978) may have been correct in their assertions that research utilizing an eyes open paradigm should not be compared with data obtained from eyes closed NFT. Furthermore, if eyes closed NFT does rely more predominantly on internal "central processes" it may be the case that such an approach would elicit greater changes in behavior and/or cognition, relative to an eyes open approach.

Index of Learning

It may seem obvious to suggest that the method of assessing learning can influence the perceived outcome. However, when examining the efficacy of NFT a variety of measures have been used, begging the question, Which measure(s) provides the best index, or indices, of learning and how can those that exhibit learning best be identified? The most common measures used include changes in mean amplitude or amplitude ratio (e.g., Cho et al., 2008; Fell et al., 2002; Hanslmayr et al., 2005; Putman, 2000), changes in the percentage of time alpha is evident (e.g., Angelakis et al., 2007; Nowlis & Kamiya, 1970; Peper & Mulholland, 1970; Yamaguchi, 1980) or an integrated measure combining both amplitude and time (e.g., Knox, 1982; Plotkin & Rice, 1981; Tyson, 1982). We have made a case elsewhere suggesting that both amplitude and percent time should be reported separately and that such measures need to be examined in relation to appropriate baseline levels of activity and as such do not repeat it here (see Dempster & Vernon, in press). However, no clear criteria have been proposed to help delineate learners from nonlearners. In the past, researchers have simply classified those showing some change in their EEG in the desired direction as "responders" in a post hoc fashion (e.g., Hanslmayr et al., 2005). Given that the goal of NFT is to encourage the individual to learn to alter his EEG without the need for feedback, we would suggest a more stringent criterion for classifying a participant as a learner. For example, an individual could be classified as having learned to control his EEG when he is able to enhance and inhibit it relative to an appropriate baseline with and without feedback information. The adoption of such a criterion is conservative but would provide a clear indication of the level of control achieved by the participant undergoing NFT. In addition, such a criterion, if adopted, could facilitate cross study comparisons.

SUMMARY

Given the clear associations between changes in alpha EEG and alterations in mood and/or cognition alpha NFT represents a potentially useful technique for influencing such behaviors. Unfortunately, it is not clear at present what the most effective method to achieve such changes would be. Some headway has been made in attempting to identify an optimal training paradigm; however, a review of the literature highlights that there is still some way to go. For instance, with regards to the NFT schedule it may be possible to elicit changes in the EEG and behavior following a single short duration session of 20 to 30 min. However, such changes may be short-lived and additional sessions may be required to engender long-term effects. Whether such additional sessions will be more effective if massed within a short period or spread out across a number of days/weeks remains unclear. In terms of the reward thresholds set during NFT it is not clear at present whether a variable or fixed threshold would be more effective. Nevertheless, it is likely that a threshold based on some aspect of resting EEG will be more relevant than an arbitrary level of amplitude and/or time. The feedback signal used may also influence the outcome of the NFT with pleasant sounds potentially eliciting a more positive outcome than unpleasant ones, particularly if coupled with visual feedback. However, this area needs to be explored further as it is not yet clear whether combining audio-visual feedback signals will be more effective at encouraging learning and eliciting change in the EEG than audio signals alone. Furthermore, we suggest that a bidirectional NFT regime may be more effective compared to unidirectional training. We also highlight the fact that the alpha frequency range can vary across participants, and as such NFT based on IAF ranges may be more effective compared to training regimes that utilize a traditional fixed frequency range for all. Furthermore, it is possible that eyes closed NFT may elicit distinct behavioral and/or cognitive changes relative to eyes open training. Finally, we propose a criterion of learning where the individual in question can be classified as having learned to control his EEG when he is able to enhance and inhibit the specific component relative to an appropriate baseline with and without feedback information.

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