J. Indian Inst. Sci.
A Multidisciplinary Reviews Journal
ISSN: 0970-4140 Coden-JIISAD

CrossMark

REVIEW ARTICLE

Control of Alpha Rhythm (8–13 Hz) Using Neurofeedback

Ankan Biswas and Supratim Ray*

Abstract | Alpha is a prominent rhythm occurring between 8 and 13 Hz in brain signals that is often linked to a relaxed mental state. Some studies have shown that individuals can learn to control their own alpha rhythm if provided with a contingent feedback. However, investigations till date in alpha neurofeedback have provided contrasting views regarding the enhancement of alpha power. In this review, we discuss various aspects of this controversy and highlight some issues with past approaches of neurofeedback driven alpha enhancement. In particular, we discuss possible modifications in future investigations which would address some of the concerns.

1 Introduction

The technique of recording brain signals by placing electrodes on the scalp of a subject is known as electroencephalography (EEG). A hallmark of EEG signals is the presence of oscillations at various frequencies, which are better observed after transforming the EEG signal to frequency domain. A prominent rhythm between 8 and 13 Hz is known as alpha[3,6,9,] which has been considered as an idling rhythm since it is observed more prominently when the subject is in an awake but relaxed state with eyes closed[1,6]. Even though alpha rhythm has been studied for almost 90 years now, its functional role is still disputed[3,13,] with recent work linking alpha with attentional mechanisms and information retrieval[26] and creativity[12].

The process of providing individuals with a feedback that reflects their own brain activity is referred to as neurofeedback. Alpha neurofeedback refers to feedback (typically visual or auditory) about the frequency or amplitude of the generated alpha rhythm. This type of neurofeedback is also known as "surface neurofeedback", since alpha is typically obtained from EEG recordings using 2–4 scalp electrodes[31]. The altered conscious state of the subject who has undergone alpha feedback training is known as "alpha state" or "alpha experience"[22–24,] which has been correlated with a perceived relaxed mental state[8,23].

Here we discuss the controversy regarding the control of alpha activity through feedback and its behavioral consequences. Then we discuss some modifications in the experimental design that could potentially address some of the concerns.

1.1 Evidence of Enhancement of Alpha Activity in EEG

Kamiya was one of the first investigators to test whether individuals can control their alpha rhythm through operant conditioning where the subjects received feedback about their own alpha activity[22,23]. He provided a binary audio feedback to the participants in which a tone was played during alpha wave activity that was switched off when alpha activity disappeared. With this experimental paradigm he observed that subjects were able to enhance or reduce their alpha activity[32]. Similar results were reported in a follow-up study where individuals were presented with visual feedback (a blue light) instead of a tone[8]. In contrast to Kamiya's experiments, here subjects kept their eyes open throughout the experimental and rest periods. It was observed that alpha activity increased over time and exceeded the alpha activity during rest periods (baseline). Hord and Barber[21] reported that both voluntary increase and decrease in alpha activity is possible even without feedback signal once subjects had undergone initial alpha feedback training. Kamiya et al.[23,32]

Centre for Neuroscience, Indian Institute of Science, Bangalore 560012, India.
*sray@iisc.ac.in

Springer IISc Press

further proposed that by alpha feedback training, subjects were able to experience a relaxed and pleasant state ("letting go" effect). The term "alpha state" or "alpha experience" was used to describe such a heightened state of consciousness. Brown[8] also reported that the enhanced alpha activity was associated with pleasant positive mood state. Wallace[44] reported that subjects who practiced transcendental meditation had prominent alpha activity that increased in amplitude and decreased in frequency with meditation. Together, these studies provided evidence that alpha can be increased with feedback or practice, and high alpha is positively correlated with a relaxed, pleasant and positive mental state.

1.2 Is Alpha Enhancement Really due to the Feedback?

Some of the claims made by earlier studies, in particular the increase in alpha power and the relaxation effects produced by feedback were subsequently challenged by several follow-up reports (for reviews, see[29,37]. The argument was that alpha activity depended on many constitutional, physiological and cognitive-attention factors, and these factors could vary during the course of the feedback training. For example, subjects may be anxious and attentive during the start of the session, and subsequently get more relaxed as they became familiar with the surroundings. They would, therefore, show an increase in alpha power with time, but it would be observed even if no feedback was provided. Katkin and Murray[25] even questioned whether alpha feedback fell within an operant conditioning paradigm, and proposed two factors to conclude that conditioning had indeed occurred. First, increase in the activity should be above the level observed during baseline period. Second, appropriate controls should be included to demonstrate an increase in experimental groups in comparison to control groups.

Studies with appropriate controls provided conflicting results, with some studies showing no increase in alpha activity without contingent feedback[4,5,] while others showed an increase in alpha even with no or false feedback[19,27,30,41]. However, even after appropriate feedback, alpha amplitude did not increase above the baseline resting state levels obtained with eyes closed[30,36]. The increase in alpha appeared to depend on a variety of factors, such as the type of instruction[45,] presence of ambient light[34], initial level of alpha[41,] type of feedback (auditory versus visual;[30]), type of tone used in auditory feedback[42], and oculomotor activity[35]. Further, no intrinsic or direct relationship between alpha enhancement and "alpha experience" was found (for a review, see[37]. For example, Orne and Paskewitz[33] showed that anticipation of electric shock, although causing heightened arousal and anxiety, failed to depress alpha power. Similarly, when presented with an aversive situation (fingertip electric shock) followed by neurofeedback (which was either contingent, non-contingent or absent), alpha suppression was not found to be systematically related to self-reported reductions in situational reactivity[10]. Other studies also showed that "alpha experience" was independent of the strength of the EEG alpha activity[27,30,35,] even after extensive training[36]. Based on these, Plotkin[37] suggested eight factors which might be causing the perceived alpha experience, namely: sensory deprivation, sustained alertness, concentration/meditation, introspective sensitization, expectation, perceived success at the feedback task, attribution process and individual differences.

Ancoli and Kamiya[2] suggested that such conflicting results could be due to methodological difference among different studies. They suggested three critical factors in the methodology, namely (a) training for at least four sessions, (b) using continuous tone for feedback along with periodic scores of progress, and (c) using training trials of at least 10 min of duration to see positive effects of alpha feedback. Use of integrated amplitude instead of percent time was also recommended[17]. However, follow-up studies that incorporated these recommendations failed to observe the desired enhancement of the alpha activity over the eyes closed baseline alpha activity[36,37]. Similarly, while Hardt and Kamiya[18] showed beneficial effects of alpha training in control of anxiety, but a later study showed that the anxiety reduction was correlated with the subjects' rating of perceived success at the feedback, but not with the alpha activity itself[38].

Irrespective of whether neurofeedback is genuine[18] or acts like a placebo[38,] the fact remains that administering this feedback helps in reducing anxiety. In subsequent years, a plethora of feedback training protocols targeting alpha, beta, theta, delta, gamma, alpha/theta, etc., bands have been used for treatment of clinical disorders such as attention deficit hyperactivity disorder (ADHD), depression, epilepsy, insomnia, drug addiction, learning disabilities, dyslexia and dyscalculia, schizophrenia and autistic spectrum disorders (for a detailed review, see[31], and also to improve performance and creativity[14,15,43]. In a recent study, Cho et al.[11] have shown that alpha neurofeedback enhances the ability of alpha activity to maintain itself during a session, which is maintained until the next session. However, in this study no controls were used. Similarly, in a double blinded and placebo-controlled study where subjects got either alpha or random beta training, and both the experimenter and the participants were uninformed about the particular experimental setting, relative alpha power increased during training period (24 min of training for 24 consecutive working days) compared to pre-training period, which was maintained even after 3 months[7]. Further, about twice as many subjects reported that the experience was relaxing as compared to the control group who had undergone random beta training[7]. In line with these reports, alpha neurofeedback has been shown to increase the connectivity within regions of the salience network that is involved in intrinsic alertness (dorsal anterior cingulate cortex), even at 30 min after training was terminated[40]. Overall, there has been a revival of interest in neurofeedback in the recent years[14,15]. However, more carefully designed controls are required to resolve some of the issues regarding this approach[16,28], as discussed below.

2 Requirement of a Stringent Control

As discussed earlier, the need of proper controls have been emphasized from the very beginning of neurofeedback research[25,29,37]. Earlier studies used a yoked control design where individuals of control group were paired with individuals of experimental group, and received taped feedback of the experimental group who underwent contingent alpha feedback training[4,5,10,30]. Training paradigm where control groups which received feedback from frequency ranges other than the target band has also been used by some groups[7,20]. However, if the aim is to study whether neurofeedback can actually enhance alpha power, we argue that even these types of controls are not enough. This is because the confidence in the feedback, the attention that is paid to the feedback, as well as the associated mental processes with the processing of this feedback may change, depending on whether the feedback is contingent or false.

Some of these concerns can be addressed in a design in which the subjects serve as their own control. This can be achieved through a task that is similar to the Posner cuing paradigm, which has been used extensively in the study of attentional mechanisms[39]. In such a design, the feedback could be made contingent on most of the trials (say 75%), but then, unknown to the subject's knowledge and at random trials, the feedback could be false (ideally, the subject's own record from a previous contingent trial). Because only a small fraction of trials are not contingent, and the subject is unaware of the existence of such trials, they would provide the ideal control condition.

There are some limitations to such a design. First, to ensure that there is no learning within each trial about the type of feedback, the duration of a particular trial should be short, say 1–2 min. Given that the effect of feedback is more pronounced when trial duration is long (Ancoli and Kamiya[2] recommended at least 10 min long trials), we expect only a small difference in alpha power between contingent and false feedback trials in such a design. A large number of trials may be needed to see significant differences. Second, it is not possible to relate changes in alpha power to changes in behavioral states ("alpha experience"), because the subject will experience both types of feedback in the same experimental session. On the other hand, if any differences are indeed observed in alpha power between contingent and false feedback, this would be perhaps the most well controlled test of the original hypothesis of alpha enhancement induced by contingent feedback.

Received: 22 September 2017 Accepted: 24 October 2017
Published online: 22 November 2017

References

1. Adrian ED, Matthews BHC (1934) The Berger rhythm: potential changes from the occipital lobes in man. Brain 57:355–385
2. Ancoli S, Kamiya J (1978) Methodological issues in alpha biofeedback training. Biofeedback Self Regul 3:159–183
3. Bazanova OM, Vernon D (2014) Interpreting EEG alpha activity. Neurosci Biobehav Rev 44:94–110
4. Beatty J (1971) Effects of initial alpha wave abundance and operant training procedures on occipital alpha and beta wave activity. Psychon Sci 23:197–199
5. Beatty J (1972) Similar effects of feedback signals and instructional information on EEG activity. Physiol Behav 9:151–154
6. Berger H (1929) Über das Elektrenkephalogramm des Menschen. Arch Für Psychiatr Nervenkrankh 87:527–570
7. van Boxtel GJM, Denissen AJM, Jäger M, Vernon D, Dekker MKJ, Mihajlović V, Sitskoorn MM (2012) A novel self-guided approach to alpha activity training. Int J Psychophysiol 83:282–294
8. Brown BB (1970) Recognition of aspects of consciousness through association with EEG alpha activity represented by a light signal. Psychophysiology 6:442–452
9. Buzsaki G (2006) Rhythms of the brain. Oxford University Press, Oxford

10. Chisholm RC, DeGood DE, Hartz MA (1977) Effects of alpha feedback training on occipital EEG, heart rate, and experiential reactivity to a laboratory stressor. Psychophysiology 14:157–163
11. Cho MK, Jang HS, Jeong S-H, Jang I-S, Choi B-J, Lee M-GT (2008) Alpha neurofeedback improves the maintaining ability of alpha activity. NeuroReport 19:315–317
12. Fink A, Benedek M (2014) EEG alpha power and creative ideation. Neurosci Biobehav Rev 44:111–123
13. Goldman RI, Stern JM, Engel J, Cohen MS (2002) Simultaneous EEG and fMRI of the alpha rhythm. NeuroReport 13:2487–2492
14. Gruzelier JH (2014) EEG-neurofeedback for optimising performance. I: a review of cognitive and affective outcome in healthy participants. Neurosci Biobehav Rev 44:124–141
15. Gruzelier JH (2014) EEG-neurofeedback for optimising performance. II: creativity, the performing arts and ecological validity. Neurosci Biobehav Rev 44:142–158
16. Gruzelier JH (2014) EEG-neurofeedback for optimising performance. III: a review of methodological and theoretical considerations. Neurosci Biobehav Rev 44:159–182
17. Hardt JV, Kamiya J (1976) Conflicting results in EEG alpha feedback studies: why amplitude integration should replace percent time. Biofeedback Self Regul 1:63–75
18. Hardt JV, Kamiya J (1978) Anxiety change through electroencephalographic alpha feedback seen only in high anxiety subjects. Science 201:79–81
19. Hart JT (1968) Autocontrol of EEG alpha. Psychophysiology 4:506
20. Hoedlmoser K, Pecherstorfer T, Gruber G, Anderer P, Doppelmayr M, Klimesch W, Schabus M (2008) Instrumental conditioning of human sensorimotor rhythm (12–15 Hz) and its impact on sleep as well as declarative learning. Sleep 31:1401–1408
21. Hord D, Barber J (1971) Alpha control: effectiveness of two kinds of feedback. Psychon Sci 25:151–154
22. Kamiya J (1968) Conscious control of brain waves. Psychol Today 1:56–60
23. Kamiya J (1969) Operant control of the EEG alpha rhythm and some of its reported effects on consciousness. Alerted States Conscious 489–501
24. Kamiya J (2011) The first communications about operant conditioning of the EEG. J Neurother 15:65–73
25. Katkin ES, Murray EN (1968) Instrumental conditioning of autonomically mediated behavior: theoretical and methodological issues. Psychol Bull 70:52–68
26. Klimesch W (2012) Alpha-band oscillations, attention, and controlled access to stored information. Trends Cogn Sci 16:606–617
27. Lindholm E, Lowry S (1978) Alpha production in humans under conditions of false feedback. Bull Psychon Soc 11:106–108
28. Lofthouse N, Arnold LE, Hurt E (2012) Current status of neurofeedback for attention-deficit/hyperactivity disorder. Curr Psychiatry Rep 14:536–542
29. Lynch JJ, Paskewitz DA (1971) On the mechanisms of the feedback control of human brain wave activity. J Nerv Ment Dis 153:205–217
30. Lynch JJ, Paskewitz DA, Orne MT (1974) Some factors in the feedback control of human alpha rhythm. Psychosom Med 36:399–410
31. Marzbani H, Marateb HR, Mansourian M (2016) Neurofeedback: a comprehensive review on system design, methodology and clinical applications. Basic Clin Neurosci 7:143–158
32. Nowlis DP, Kamiya J (1970) The control of electroencephalographic alpha rhythms through auditory feedback and the associated mental activity. Psychophysiology 6:476–484
33. Orne MT, Paskewitz DA (1974) Aversive situational effects on alpha feedback training. Science 186:458–460
34. Paskewitz DA, Orne MT (1973) Visual effects on alpha feedback training. Science 181:360–363
35. Plotkin WB (1976) On the self-regulation of the occipital alpha rhythm: control strategies, states of consciousness, and the role of physiological feedback. J Exp Psychol Gen 105:66–99
36. Plotkin WB (1978) Long-term eyes-closed alpha-enhancement training: effects on alpha amplitudes and on experiential state. Psychophysiology 15:40–52
37. Plotkin WB (1979) The alpha experience revisited: biofeedback in the transformation of psychological state. Psychol Bull 86:1132–1148
38. Plotkin WP, Rice KM (1981) Biofeedback as a placebo: anxiety reduction facilitated by training in either suppression or enhancement of alpha brainwaves. J Consult Clin Psychol 49:590–596
39. Posner MI (1980) Orienting of attention. Q J Exp Psychol 32:3–25
40. Ros T, Théberge J, Frewen PA, Kluetsch R, Densmore M, Calhoun VD, Lanius RA (2013) Mind over chatter: plastic up-regulation of the fMRI salience network directly after EEG neurofeedback. NeuroImage 65:324–335
41. Strayer F, Scott WB, Baken P (1973) A re-examination of alpha feedback training: operant conditioning or perceptual differentiation? Can J Psychol 27:247–253
42. Tyson PD (1982) The choice of feedback stimulus can determine the success of alpha feedback training. Psychophysiology 19:218–230
43. Vernon D, Dempster T, Bazanova O, Rutterford N, Pasqualini M, Andersen S (2009) Alpha neurofeedback training for performance enhancement: reviewing the methodology. J Neurother 13:214–227
44. Wallace RK (1970) Physiological effects of transcendental meditation. Science 167:1751–1754
45. Walsh DH (1974) Interactive effects of alpha feedback and instructional set on subjective state. Psychophysiology 11:428–435

Ankan Biswas is a Master's student at the Indian Institute of Science pursuing his research project in Centre for Neuroscience (CNS). He received Bachelor of Science (Research) in Biological Sciences from Indian Institute of Science in 2017. His research interest lies in understanding brain oscillations, formation and storage of long-term memory. Besides science, he is passionate about Rabindra Sangeet, recitation and playing volleyball.

Supratim Ray received B.Tech in Electrical Engineering from IIT Kanpur and Ph.D. in Biomedical Engineering from the Johns Hopkins University. His postdoctoral training was in the department of Neurobiology at Harvard Medical School. He joined Center for Neuroscience in June 2011 and is an Associate Faculty in the Electrical Engineering Department since 2012. His lab studies the mechanisms of attention, i.e., our ability to focus on behaviorally interesting and relevant stimuli while ignoring others. In particular, he is interested in particular brain rhythms thought to be associated with higher order cognitive functions such as attention.