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Towards Efficacy of EEG Neuro Feedback from Traditional to Advanced Approach: A Review

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One of the major tasks in the society is theenhancement of the cognitive functions, to improve intellectualdeficiencies or psychosomatic ailments, hence, improving the quality of life. This new period of therapeuticadvances uses various treatments using various sub-disciplines of biomedical engineering and psychology. Neurofeedback (NF) based operant conditioning is one of them. Up till now, many reports have focused on efficacy of NF in context of clinical and non-clinical applications. New advances in cognitive neuroscience and imaging methods have made neurofeedback training (NFT) more efficient. So, there have recently been further developments in traditional NF procedures. A comprehensive review on the recent advancements with major issues and challenges are tabulated. Even though a number of reviews have been proposed in the literature, but not any of the study has executed analysis of the recent advances.

Keywords: EEG, neurofeedback, inverse problem, tomography.

What is neuro feedback

NFT is state of art training that is based on principle of operant learning. NF accounts for permitting the individuals change their cortical activity based on the biofeedback, defined on the particular features of brain cortical action, so that the behavior should be influenced potentially. Subjects change their electrical activities such as amplitude, frequency or the coherency[1].

It has been widely used for enhancement of sporting skills, cognitive skills, artistic and music performance as connections have been acknowledged among cognitive functioning and brain cortical activity[2]. NFT is being examined as potential treatment candidate in recent years[3]. It is learnt as to how to regulate EEG rhythms in a way to regulate cortical levels. EEG data is described by delta, theta, alpha, beta, and gamma bands. A comprehensive depiction of allocated EEG bands has been specified in[4].

First of all, this review will start with introduction to neurofeedback. Since past 40 years, many traditional neurofeedback studies have been proposed. But since last decade, new advances in cognitive neuroscience and imaging methods have made neurofeedback training (NFT) more efficient. So, there have recently been further developments in traditional NF procedures. In the present article, a special emphasis is given to the discussion of novel developments.

Scientific Basis (History)

NF field started in 1960s with experiment conducted by Kamiya who proposed the possibility of learning brain activity controls with the help of feedback in the form of EEG based frequency power, ERP (Event Related Potential) and SCP (Slow Cortical Potential) protocols. Sterman invented that NF training has effect on cats where preclusion of seizure in cats was observed after SMR (Sensory Motor Rhythm) augmentation. This finding supported its efficacy for neurogenetic disorder and stress related disorders.

Then Twelow and Bomen in 1976, invented alpha and theta training for alcoholism but first controlled study came into scene after 13 years by Peniston. Also in this period, direction of training and alpha training were correlated. Alpha enhancement was found to reduce test anxiety. Alpha and alpha- theta NF was administered at Cz site. Even neurofeedback was linked with pseudo-science, but SAN (Society of Neuroscience) had stimulated resurgence of attention in investigating NF on the basis of scientific assessment and verifications.So in 1990s again it took off. In recent years, the field has changed in many respects. New advances have contributed to the NFT significantly[1, 3, 5-6].

Related Work

Neurofeedback has been used for treating wide variety of neurological and psychological disorders and for cognitive enhanced performance in healthy individuals. All the approaches have been classified into traditional, tomographic and others as shown in figure 1.

Afterwardrevisingprevailing surveys in this field, we recognized that there is no review that concludes the recent advances in EEG neurofeedback along with traditional NF. Many advanced approaches are missed in these works. More significantly, the new EEG neuroimaging techniques based NF has not been covered. This inspired us to accomplish this review paper to target more approaches that conclude the recent advancements in NF.This work is focused to review various NF improvements on the basis of EEG that have been on the basis of methods referring to biomagnetic source localization problems, a latest advancement in digital signal processing.

Multichannel Tomographic NF

Within past 40 years, even though extensive amount of research on NF has been accumulated but still lot of broad features have been ignored. One such aspect is that according to sensory information provided by feedback, an electromagnetic signal is linked to create NF loop. But still it is not known as to how physiological activity is derived by brain by using this sensory information. Another fact is to check for learning, linked with NF as volitional process or not. These days, EEG neuroimaging biofeedback is a new knowledge in the field of neuroscience. EEG/MEG are one of the best imaging techniques of brain that has incomparable time resolution as compared to fMRI (functional Magnetic Resonance Imaging), PET (Positron Emission Tomography) that are based on measuring slow metabolic changes. Hamalainen *et al*[6] described measurable EEG signal having resolution to be 1 out of 1000 concurrently active synapses in cortex of area forty square mm approximately. But the disadvantages of poor spatial resolution due to inverse problem and increased distance between source and the sensor[6- 7]. Such points account for limitations of traditional NF. Traditional and tomographic NF has been shown in the figure 2, where, the spatial unspecificity of target signal (TS) has been signified by a question mark below the active electrode site[6].

Spatial non- specificity of particular electrode site results in little spatial information from single channel EEG. This limitation can be improved by involving information that is more spatially specific and that can be achieved through electromagnetic tomographic method that is, an inverse solution method. So, major limitations of traditional method are poor spatial resolution and spatial unspecificity. If particular site's voltage function is under training, there is effect of whole brain training as gray matter adds to scalp voltage.

Inverse Problem- The Physiology

The neocortical cells, especially, pyramidal cells generate postsynaptic potentials that create electric fields which are measurable on the scalp. Scalp potentials are recorded according to number of pyramidal cells that are fired synchronously and simultaneously. Infinite number of current source combinations could produce same scalp potential distribution. So this inverse problem (mathematical solution) has no unique solution. That is, in inverse problem, sources are not known and are determined using scalp distribution of electrical potentials. It can be inferred as a filtering problem.

If N_v numbers of voxels (volume elements represented by cubic areas) are placed in rectangular grid over the gray matter region of cortex then, local 3D current vector is assumed to be defined at each of the voxel as

$$J\,(v,t) \;=\; (j_x\,(v,t), j_y\,(v,t), j_z\,(v,\,t))$$

...(1)

Here, v is denoting the voxel label, t is the time and † is matrix transportation.

Column vector of current sources corresponding to all voxels can be denoted as

$$J\,(t) \;=\; (j(1,t)^{\dagger}\,, j\,(2,t)^{\dagger}\, \ldots.\, j\,(N_v,t)^{\dagger})$$

...(2)

This equation represents whole system's vigorous status variable. EEG measures these currents. Corresponding to individual electrode, EEG is s(i,t) with i representing electrode label.

$$S(t) \;=\; (s(1,t), s(2,t), \ldots.\, s\,(n_c,t))$$

...(3)

Equation (3) represents column vector of n_c dimensions for all electrodes' electric potential. General model is generated expressing the experiential EEG data *S (t)* as linear function of BES (Brain Electrical Sources) j(t) according to quasi- static approximation of Maxwell's equation.

$$S\,(t) \;=\; G\,J\,(t) \,+\, E$$

...(4)

This is the branch of EEG inverse problem typical formulation[8- 10]. So, the inverse problem deals with dilemma of estimating the distribution of BES (factors such as orientation, position and the magnitude) from measurements of EEG that is noisy. In equation (4), *G* is gain matrix of lead fields of dipole sources and this transfer matrix is denoted as lead field matrix. *E* is additive noise. G matrix can be calculated using multiple head model and using electrode positions for example, boundary element method (BEM) can be used to calculate this matrix roughly corresponding to three shell model and for particular position of electrodes. Finding a consistent approximation of this matrix is the crucial prerequisite for any technique to inverse solution.

Also, this estimation problem is very exigent because j(t) is dimensionally much bigger than S(t). Nonetheless, fairly accurate guess of is possible to acquire. Also, silent BES which generates fields on scalp that are not measurable makes infinite solutions to EEG inverse problem. These silent EEG get added to inverse solution exclusive of disturbing measurements. So, inverse problem is *ill- posed* and *uncertain*. Two most important categories of inverse solvers for EEG/MEG source estimation are: discrete parametric solvers, well-known as dipole fitting and the distributed inverse solvers.

Discrete parametric method: These are the standard algorithms of estimating parameters like orientation, amplitude and location of dipoles of predetermined number of dipoles known as dipole fitting methods. Examples of these parametric approaches are spatio- temporal dipole methods - Multiple Signal Classification (MUSIC), and its advanced versions, beamforming, computer intelligence algorithms and Brain Electric Source Analysis (BESA) etc[11- 14].

Distributed inverse solvers: The distributed inverse solver takes into account discrete source space locations from the cortical surface exclusive of clear control of the number of current dipoles. The required result is calculated by diminishing a cost function depending on sources in the source space. The non-parametric methods include MNE (Minimum Norm Estimate), LORETA (Low Resolution Electromagnetic Tomography), sLORETA (standardized Low Resolution Electromagnetic Tomography), Shrinking LORETA FOCUSS (SLF) and Bayesian approach etc. These are also called imaging methods[15- 16]. Based on these methods, advanced neurofeedback approaches have been presented and studied in detail as described in the following section.

Neurofeedback Tomographic NF

These days, EEG neuroimaging biofeedback is a new knowledge in the field of neuroscience. Tomographic neurofeedback provides spatially more specific feedback than traditional approaches.Table 1 gives a general overview of classification of traditional protocols on the basis of applications.

Current source localization based neurofeedback

Much is to be discovered about the underlying complex system under EEG recordings. To conquer such troubles, solution is to include studies based on source current densities from EEG signals. LORETA and sLORETA based NF is such source current judgment solution.

LORETA

Congedo *et al*[17] amalgamated two techniques of neurofeedback and electromagnetic tomography that is, LORETA, as an aim to enhance more self-regulated brain electrical activity. It was the first investigational support of learning on the basis of intracranial current density feedback. LORETA estimates current source density (CSD) to provide direct three dimensional solutions.

The basic principle behind its operation is the hypothesis that voltage spatial gradient changes steadily and only maximally even distribution of source magnitude will be selected. The methods are implemented on basis of 3D shell spherical model that has co- registration to MRI atlas. LORETA is compilation of various independent sections that transforms raw EEG into images of LORETA by running procedure in explicit sequence[17-18].

Compared to PET and fMRI, LORETA exhibits better temporal resolution but inferior spatial resolution. Also, economically it is more advantageous than fMRI. Various studies have validated LORETA proving mathematical proofs as combining with fMRI, PET and other recognized localization methods and it has been proved to suitably work with larger volumes of brodmann areas (BA).

Mathematical Approach

A discrete spatial Laplacian operator is used to enforce a smoothness constraint on *J(t)* estimation as defined by

$$L = (I_{N_V} - \frac{1}{6}N) \otimes I_3 \qquad ...(5)$$

Where, N denoted NV × NV matrix as defined in[9]. * is matrices Kronecker multiplication. LORETA approaches to find minimization of objective function as a solution to inverse problem defined as

$$E(J) = \| (S - GJ) \|^2 + \lambda^2 \| LJ \|^2 \qquad ...(6)$$

||.|| represents Euclidean norm. ë hyper parameter represents equilibrium among observation filling and constraint of smoothness. Regularization for solution is provided by non- zero ë value. If second term mentioned above could be chosen properly, not only spatial smoothness constraint is forced but other constraints like anatomical constraints and inverse problem sparseness are also strained. Minimization of this equation is solved by least square solution as

$$\hat{J} = (G^{\dagger}G + \lambda^2 L^{\dagger}L)^{-1}G^{\dagger}S \qquad ...(7)$$

Here, $\hat{J}$ is estimation of J state vector which is independent of selection of references for measuring EEG data S. This is one of the advantages of converting EEG into source CD (Current Density) estimation as reference independent solution is provided. The major problem is to choose proper ë for making efficient LORETA which is a difficult task [9, 28- 30]. The reliability measure of qEEG and LORETA calculations is of great significance. QEEG can be considered as a straight signature quantifying mental activity with a temporal resolution in milliseconds ideally. So considering the importance in milliseconds reliability analysis of phase, absolute power and LORETA CSD was conducted [17]. Summarizing, LORETA is linear, distinct and 3D distributed inverse problem that grants low localization errors but with low spatial resolution.

SLORETA

The sLORETA is based on least square (min two norms) solution which is discrete, distributed, linear and instantaneous solution of inverse problem. MNE can be changed to noise-normalized methods like sLORETA by conversion to statistical parametric maps considering the noise. It regiments the source distribution a posteriori by taking variance of each projected source,

$$\hat{J}_{sLORETA} = \hat{J}^T_{MNE,l}\left\{ | V_{\hat{J}} |_{ll} \right\}^{-1} \qquad ...(8)$$

$\hat{J}_{MNE,l}$ is the density estimate of current density of l^{th} voxel as defined by MNE. $V_{\hat{J}}$ is variance of current density estimate and $\{| V_{\hat{J}} |_{ll}\}$ is diagonal block at position l of resolution matrix. It can be defined as . SLORETA is not the estimation of intensity of source but its probability to reveal high amplitude compared to others. LORETA is intensity approach and sLORETA is probability approach[9]. SLORETA based learning is based on combination of CSD voxels in defined region of training. The solution provided by sLORETA works on taking central voxel based on particular remote generator but in other voxels also it does not show zero values within the solution space. The target ROT changes are effected by outside ROT changes also. So, even though it is a smooth and simple method of low localization errors having high-quality stiffness to noise but it has spatial blurring of reconstructed current density. More number of electrodes may give more improved spatial resolution. Its limitations are requirement of noise free environment, appropriate head models and poor spatial resolution.

Z- score training

Various new methods are rising for enhancing the training designs and also it is possible in present time to identify definite brain procedures which lie beneath behavior and symptomatology so that targeted feedback can be directly provided like live z- scores. The live z- score training is based on the normal equation given as,

$$z = \frac{x-\bar{x}}{\sigma} \qquad ...(9)$$

Where, x is current sample, is the mean reference value and ó is the standard deviation[31-33]. The amalgamating rationale of z-score biofeedback is to emphasize extreme scores (outliers) in the direction of Z=0, which is arithmetical center of a group of healthy normals. This set point has been taken ideally where balanced structures swing around perfect z=0. Unstable neuronal states having outsized z-scores (5 SD to 3 SD) are de- emphasized, while stable states (< 2 SD) are emphasized[33]. Or, brain is made aware of the variables to be within a definite range of normal (e.g., +/- 1.0 SD), making simultaneous training of variables across several brain positions.

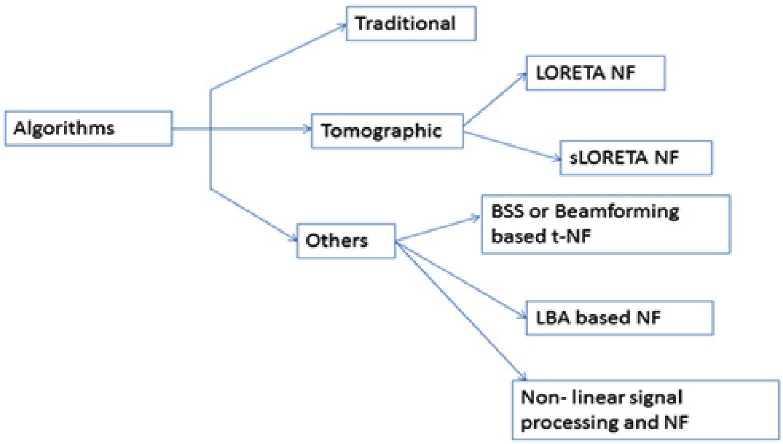

Fig. 1. Classification of NF approaches

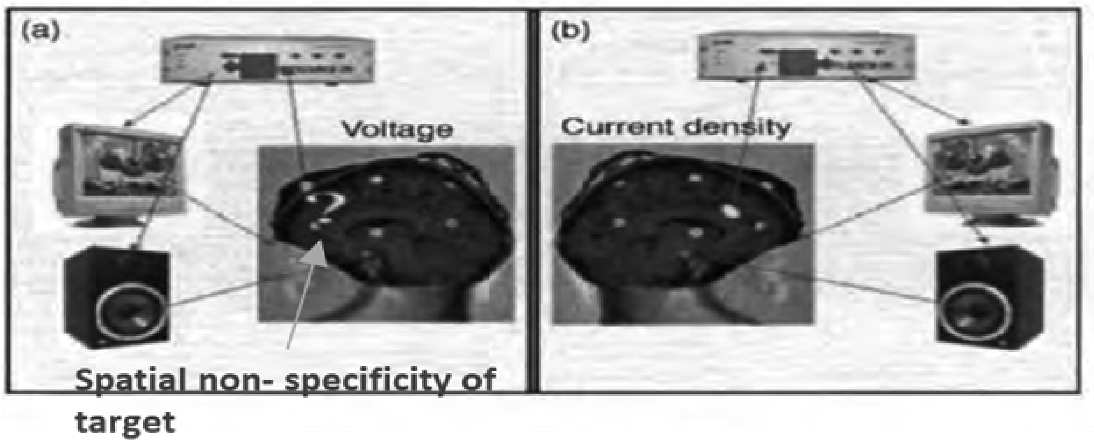

Fig. 2. Traditional and tomographic neurofeedback graphic demonstration [6]

Table 1. Comprehensive analysis of advanced NF approaches

NF approach	Applica- tions	Data Analysis	Significance	· Challenges
LORETA	ADHD, Healthy, Chronic Pain	ϕ^1 function, ERPContingent negative variation (CNV) mappings, Z- scores	• Congedo*et al.* amalgamated two techniques of neurofeedback and electromagnetic tomography [17]. • Alpha based tomographic NF . (t- NF) with closed eyes in Precuneus with a significant total relative power increase at the Precuneus than the control group [18] • Two studies showed enhanced integration process in terms of processing speed, working memory in ACC and dorsolateral prefrontal cortices by increasing 14- 18 Hz by LORETA NF training (LNFT) [18- 19]. • Diminishing pain effects of z- score training [21].	• Spatial smearing effect that is, stronger current density in neighbor voxel can alter estimation of current density within ROT [17]. • Multivariate autoregressive analysis or joint time-frequency-space correlation for future studies [17]. • More exploring and larger studies required [18- 21]. •Future studies on circumstances for successful training and more advanced techniques need to be proposed [20].
sLORETA	ADHD, Major Depress-ive Disorder (MDD)	ERP & CNV using t- maps, z- scores, power analysis	• Concluded important aspects of sLORETA t- NF albeit partial improvement in ROI [22] • Escolano studied effect of upper alpha on MDD patients [23] • Tomographic neurofeedback has greater impact on depression [24- 25]	• Small sample size [4, 22- 24] • No sham group [22- 25] • Partial improvement observed in the ROI [22] .
BSS (Blind Source Separation) and Beamforming for t-NF	Cognition Enhancement	-	• Learned augmentation of peak theta and volitional self-control of feedback signal [26] • Best results can be achieved if BSS can be applied before source localization [26] • Online Linearly Constrained Minimum Variance beamformer can assist NF in real time [25]	• Fluctuations in band beyond target frequency band, small sample size, and limited protocol design. • More controlled studies required [25- 26]
Non- linear signal processing and NF	Healthy	TOVA (Test of Variables of Attention) and Reaction Time	• Important results for FD [27]	• EEG analysis not done • Small sample size • More controlled studies required
LBA (Local Brain Activity) feedback	Healthy	ERP	• Learning observed [34- 36]	• Small sample size • No CG, sham group • Use of standard head models • Additional EEG analysis measures required

Solution to spatial resolution- LBA and IFC techniques

Local Brain Activity (LBA) based feedback

Faster learning by cheaper EEG based NF can be impelled if such method can be developed that trains particular areas in brain. rtfMRI is limited in terms of speed. To counterpart these limitations, multichannel t- NF was offered. But again, in t- NF, there is spatial blurring effect of signals in LORETA or sLORETA based NF. Then to counterpart, spatial filter was used along with sLORETA. Corresponding to MEG/EEG topography, a study was offered by Congedo to use spatial filter (to reduce spatial blurring of ROT) and one more filter (to increase SNR of input signal) and sLORETA technique, but this has not been used for NF applications although has been tested on simulated data. To overcome these limitations, a technique using only local maxima of estimated neural activity has been proposed called LBA feedback by Bauer in 2011. Combination of IHMs, proper localizer technique (improving spatial accuracy) and electrode coordinates specific to sessions allow LBA feedback comparable to rtfMRI. Further this technique requires examination so as to well adjust ingredients of tNF[34- 36].

IFC

A new method called Intracerebral Functional Connectivity (IFC) has been proposed to provide good spatial resolution. This study concluded results for dyslexia treatment where feedback was lagged phased synchrony. Narrative mathematical representations have made the possibility of calculating scalp signals intracerebral origin. The rationale behind this method was that various neuronal systems can be mathematically modeled using graph theories thus providing disseminated and focused information processing. IFC systems can be estimated using current or spectral power density information for voxels, region of interest or BA from the observed EEG signal. Phase information is preserved. One study using EEG and IFC analyses for musicians showed increased phase synchronization between right and left ARC (Auditory Related Cortex). This paper has discussed that IFC based NF may possibly improve auditory related dysfunction. No completed claims have been dealt with. This area needs strict future studies on the basis of given protocols[37].

DISCUSSION

Current piece of effort evaluates the rudiments and present position of neurofeedback training (NFT) the detailed overview of the existing tomographic approaches. The current information that has been explored using a number of studies have interpreted that NF has been established to be useful in modifying the mind arrays in the field of sports, music, cognitive enhancement and for various neurological applications but still optimum performance is well ahead of recording confirmations of learning. The future directions and challenges have been hypothesized for newer source localization techniques which need strict future studies on the basis of given protocols.

CONCLUSION

In recent years there has been a great deal on gaining knowledge of neuronal underpinnings of cognitive abilities as revealed by functional correlates of cortical oscillations. NF uses the fact of training subjects to achieve cortical oscillation modulations, which in the past has been extensively explored for treatment of conditions correlated with altered cortical oscillations. The present article reviews the literature focusing on tomographic EEG NF, its applications, benefits and limitations.

In this review, a discussion has been put for the case studies and examples to illustrate the fact that NF could have greater impact. This information presents a credible motivation for using NF training for performance augmentation. Various studies are examining efficacy for each of the area of creativity, sports and cognition. In terms of data of specificity, NF has been found to be helpful in altering mind patterns. In terms of security issues, it can be endured and established. So, it can be said that NF is effective but additional studies should be carried out to direct its accurate use. This work is focused to review various NF improvements on the basis of EEG that have been on the basis of methods referring to biomagnetic source localization problems, a latest advancement in digital signal processing. Future is better for NF as newer qEEG and strategical NF developments are being offered like live z- score training. There is urgent need of scientific research in this field to be planned and carefully executed considering the fact that it is being used on a large scale for treatment proposes.

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