Neurofeedback for Cognitive Enhancement, Intervention and Brain Plasticity

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Abstract–Neurofeedback has been employed in recent years as a cognitive learning approach to enhance brain processes for therapeutic or recreational reasons. It involves teaching people to monitor their own brain activity and adjust it in the ways they see fit. The central idea is that by exerting this kind of command over a particular form of brain activity, one can improve the cognitive abilities that are normally associated with it, and one can also cause certain functional and structural transformations in the brain system, assisted by the neuronal plasticity and learning effects. Herein, we discuss the theoretical underpinnings of neurofeedback and outline the practical applications of this technique in clinical and experimental settings. Here, we take a look at the alterations in reinforcement learning cortical networks that have occurred as a result of neurofeedback training, as well as the more general impacts of neurofeedback on certain regions of the brain. Finally, we discuss the current obstacles that neurofeedback research must overcome, such as the need to quantify the temporal neorofeedback dynamics and effects, relate its behavioral patterns to daily life routines, formulate effective controls to differential placebo from actual neurofeedbackimapcts, and enhance the processing of cortical signal to attain fine-grained real-time modeling of cognitive functionalities.

Keywords – Neurofeedback, Attention Deficit Hyperactivity Disorder, Transcranial Magnetic Stimulation, Deep Brain Stimulation.

I. INTRODUCTION

While neural plasticity reaches its peak during the fetal and postnatal period and persists through adolescence and young adulthood, the human brain retains its capacity to adapt and learn to its constantly-changing environment far into maturity and old age. This is made feasible by unique brain processes that reprogram neuronal and network activities. Transformations in the grey matter volume and white matter myelination are some of the examples of structural alterations that occur during brain plasticity. Functional alterations include the formation of new synapses and the strengthening or weakening of preexisting ones. Neuronal plasticity is maintained throughout life, even though it is greatest before puberty, particularly during important stages of brain development. Learning and development depend on plasticity in the brain. Reading, playing music, creating art, doing sports, studying, and other mentally taxing pursuits all help. Specific trainings comprising the repetitive execution of carefully defined behavioural protocols might further stimulate or increase the brain's capacity to acquire new contexts, in comparison to more conventional ways, especially in therapeutic settings. These behavioral procedures originate in the lab, but serious games and other forms of fun learning have been shown to boost their transferability to the real world.

Several of these behavioral protocols use real-time, directed control over physiological markers like heart rate (biofeedback) or cortically produced signals (neurofeedback) to teach participants to correlate this information with their actions. Neurofeedback is one such technique; it involves giving people, sick or healthy volunteers alike, data about how their brains are working when they produce a certain behavior (see **Fig 1**). This feedback to the participant may take the form of direct activation level of certain brain areas causally linked to the behaviors of interest, or it can take the shape of more in-depth data reflecting more real brain functionalities like functional connectivity measures, which represent a decoded brain condition or cognitive data. Reducing aversive feelings or enhancing a selected set of cognitive abilities are only two examples of the beneficial behavioral effects that have been linked to neurofeedback. Positive behavioral outcomes depend on brain plasticity processes and the capacity for lifelong learning. Neurofeedback is widely regarded as an effective tool for promoting brain plasticity by causing targeted alterations in brain function, such as transformations in the greay and white matter microscale alterations and characteristics (weakening or increase) of functional connections.

In this article, we take look back at the most common methodsneurofeedback has been administered, and in Section II, we talk about the principles of these methods, which affect the behavior of people with and without impairments. In Section III, the behavioral impacts of neurofeedback and its clinical application is discussed. Next, in Section IV, we discuss the neurophysiological impacts of neurofeedback, and present a discussion of neurofeedback for plasticity training in Section V. Lastly, a concluding remark is provided in Section VI.

II. GENERAL NEUROFEEDBACK METHODOLOGICAL PRINCIPLES

Neurofeedback: modus operandi and conceptual underpinnings

Neurofeedback (NF) [1] could be visualized as a non-invasive brain simulation technique with close-looped control mechanisms, wherein previously invisible information on the dynamics is made visible to participants, who can then utilize it to drive it and retroact on it to operationally desired target conditions. In NF, three things need to be determined: i) the overarching objective, ii) a neuronal targets as features, and iii) a considerable schedule of stimulation. These procedures are based on a different set of assumptions (sometimes implicit) and have far-reaching theoretical consequences for our knowledge of basic brain systems at work in health and disease.

To encourage healthy brain function via operant training, neurofeedback (NFB), also known as neurotherapy, provides real-time feedback on one's brain's activity. Electroencephalography (EEG) integrates including sensors onto scalps to record electrical activity in the brain and providing visual or auditory feedback. There is some debate about whether or not neurofeedback really works. While neurofeedback therapy has been demonstrated to have positive benefits on patients in studies and reviews, it has not yet been shown that these results are produced by the neurofeedback method itself. In placebo-controlled studies, the control group has frequently shown the same degree of enhancement as the group getting true neurofeedback therapy, suggesting that these benefits may be produced by side effects rather than the treatment itself.

Despite the criticism, it has been used for over 40 years. It just hasn't caught on in the mainstream of medicine. NFB is a long-term therapy option that is quite painless and takes around a month to complete. Sessions of neurofeedback typically last between 30 and 60 minutes. There are a number of different neurofeedback protocols available today (see **Table 1**), and the use of QEEG or fMRI to localize and customize therapy may improve outcomes even further. Neurofeedback using functional near-infrared spectroscopy (fNIRS) [2], biofeedback using hemoencephalography (HEG) [3], and biofeedback using functional magnetic resonance imaging (fMRI) [4] are all related technologies.

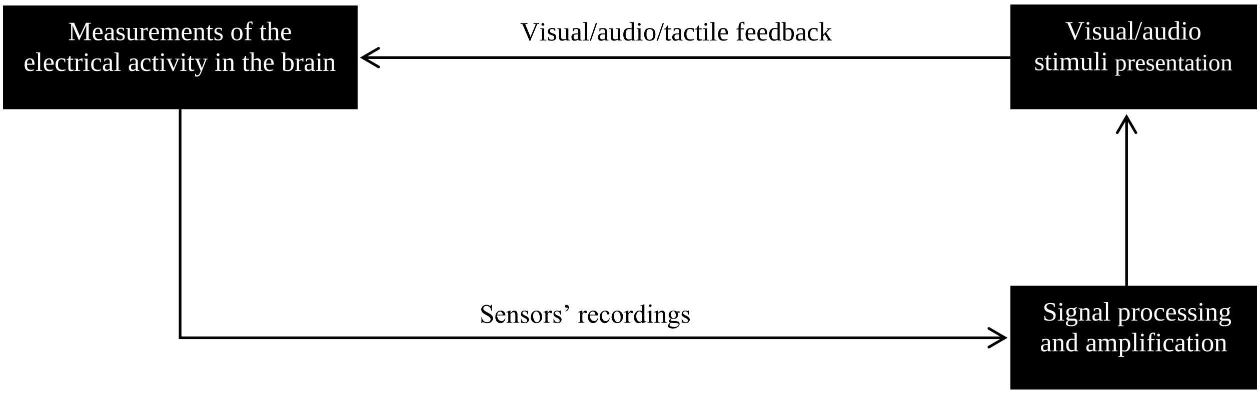

Fig 1. A representation of the neurofeedback learning process

In neurofeedback, there are two primary trajectories. Either high frequencies (beta or low beta) are emphasized to enhance activation, organization, and suppression of distractibility, or low frequencies (theta, alpha) are emphasized to strengthen attention and relaxation. Protocols for neurofeedback therapy, as shown in **Table 1**, often target specific brainwave states or a ratio between states, such as alpha/theta, beta/theta, etc.

Identifying objectives: resting state-based vs. task-induced neurofeedback

What are the main objectives of neurofeedback? The fact that neurofeedback is, in some forms, a neuromimtic process provides a flavor of the spectrum of attainable outcomes. It has been known for some time that the brain operates according to the idea of closed feedback loops. To estimate the sensory effects of a motor order, for instance, the brain is assumed to employ a forward internal model in the form of expected sensory feedback. When contrasted with the discharge that occurred as a result of the predicted action, this tells the brain how well the expected action and the external one line up. In this context, task-specific optimization becomes a natural objective for NF protocols operating at the short time-scales characteristic of sensory-motor objectives.

Table 1. Neurofeedback treatment protocols

Alpha protocol	The alpha protocol has been the subject of several scientific investigations. The brain's alpha wave often signifies a state of alert relaxation. To be in an alpha state of mind is to be in a relaxed and happy state of mind. All alpha waves are employed to characterize the brain's creative activity, which is then put to use in the relaxation (muscle) process that leads to sleep.
SMR protocol	In order to enhance concentration and focus, SMR training is a frequent regimen. In the SMR frequency range (12-15Hz), one is likely to be in a state of heightened awareness while engaging in quiet or unobtrusive motor tasks. By reducing the mind-wandering, and sleepy Theta waves, including the High Beta waves, and boosting the concentrated SMR waves, SMR learning enhances concentration and attention. Training using SMR has been shown to improve motor control, equilibrium, and stress tolerance.
Beta protocol	A person's beta activity is a reliable predictor of how well their brain is functioning, and abnormal beta activity is indicative of mental and physical illnesses such as anxiety, attention deficit hyperactivity disorder, and sleeplessness. Brain waves in the beta range are related with clear thinking, intense concentration, and the capacity to find solutions to difficulties. Beta brainwaves are also produced by the brain when taking stimulants like Ritalin and Adderall, which are intended to increase alertness and focus.
Theta protocol	Memory, creativity, emotion, sleep, hypnosis, and meditation are all linked to theta brain waves, among others. The light, easily-revived slumber of the first stages of sleep is also connected with the presence of these waves. Anxiety, sadness, daydreaming, distractibility, emotional problems, and ADHD may all be alleviated with the use of theta brainwave therapy.
Theta/beta ratio protocol	Theta-beta ratio (TBR) is a measure of communication between the brain's subcortical and prefrontal cortical regions. Core components of cognitive performance anxiety (CPA), phenomena described as when worries undermine an individual's competence to execute a task, including decreased self-reported attentional control and a sharper loss in attentional control following stress-induction.
Alpha/theta protocol	The ratio of alpha to theta brain waves reveals our level of alertness or drowsiness. Many people who use neurofeedback to learn to relax find that alpha/theta training is the most effective. Not only can this method improve creative output, relaxation, musical proficiency, and trauma recovery, but it is also utilized to cure severe cases of depression, addiction, and anxiety.
Delta protocol	The slowest waves produced by the brain, delta waves, occur during the third and fourth phases of sleep. They stand for relief from discomfort, rest, and relaxation. As a result, they are used in the treatment of severe and sporadic muscular contractions, as well as the alleviation of headaches, TBI, and learning difficulties (by simulation of 1 Hz to 3 Hz delta wave). As a bonus, they help ease anxiety and promote restful sleep.
Gamma protocol	The highest frequency electromagnetic radiation, gamma waves are linked to brain activity related to learning and memory. A quicker rate of memory recall follows from a faster frequency of these waves. Fast oscillations called gamma waves facilitate communication between neurons and the rest of the brain. They are most often found in the hippocampus, the part of the brain that helps us remember things for the long term.

Using cognitive activities, in which a specific participant or demographic is known to score badly, as well as for healthy participants, in which case neurofeedback could be employed, as the brainimprovement approach, actual-time decoding and brain activity mapping to behavior is required. How, however, can NF function in settings when stimulus discrimination isn't a primary concern, such as in NF for attention deficit hyperactivity disorder (ADHD)? However, unlike in the case of maximizing performance on a single activity, the necessary intervention aims to normalize a full repertory of reactions or symptoms, much as a standard pharmaceutical intervention would. If NF is effective, the dynamics will shift from the abnormal to the general features of a health brain system. In turn, the abnormalities could be illustrated on the basis on how they are dissimilar from the typical characteristics of brain activity that occur regardless of the specific mental job at hand. This brings up the topic of identifying the neurophysiological objective of the resting brain activities and the need of defining its features.

Brain dynamics operation

Next phases in the NF process include determining what element of brain activities to focus on and where within the brain system to do it. Due to the lack of a comprehensive model for NF, it often resorts to targeting dynamics in neuronal activity. If you have attention deficit hyperactivity disorder (ADHD), neurofeedback (NF) may help by encouraging your brain to generate more beta waves and fewer slower ones. Considering that rhythmic activity in neural networks at certain frequencies bands is considered to assist in data processing and transit in the brain, this is completely reasonable. The amplitude of the BOLD signal in discrete brain areas is often the focus of fMRI-guided NF procedures. Target characteristics are often described as a scalar in the right space, although in theory they might be any function of potentially non-local dynamics in both space and time. In a broader sense, features may be seen as behavioural control factors that, in theory, should map onto a trajectory from a given initial state to a desired final state. The topic of whether or not widely employed targets reflect true control parameters is therefore an essential one, and one that has received little attention from researchers. The manner in which cognitive demands and, in some sense similarly, psychiatric or neurological disorders are known to operate on brain activity are reflected implicitly in NF targets. For instance, conventional targets represent the notion that cognition regulates the tempo or volume of neural activity in a certain region. They also fit in with the idea that neurological and mental diseases may be treated in the same way by stimulating specific brain areas, which are engaged in abnormal activities.

Activating or stimulating the collection of areas generally involved for the correct execution of a certain cognitive objective or suppressing the abnormally active in a certain illness should restore healthy behavior or functionality, according to this theory. The fundamental notion is that there is a clear mapping between diseased and healthy dynamics in the control parametric spaces, with the system being either under- or over-activated depending on the nature of the underlying pathological state. Whilst cognitive demands are often seen as affecting the amplitude or frequency of dynamic brain fields, they may be better understood as influencing the functional shape of these fields. And although dynamics is usually what can be seen with the naked eye, the NF target may in theory take on a whole other shape (information content; thermodynamic function, etc.). It seems sense to look for the anatomical area on which a neuro-intervention should have an impact when selecting neural targets.

As neuro-stimulation procedures like DBS include a surgical process where equipment is integrated in a well-designed location, anatomical localization is definitely a critical concern for these treatment types. In NF, the location affected by the direct neural targets where information is supplied (such as major auditory or visual locations, since the signals could be as modest as the audible beeps or as sophisticated as video games) could be differentiated from the physical locations to be modulated by it; however, in TMS or DBS, the targets are anatomically localized (albeit diffused) (such as amygdala). Although it could be possible to predict the general implication of operating on localized targets within anatomical spaces, doing this is typically non-trivial and complex. Connectivity between brain regions, on one hand, is a key component of normal brain operation that regulates brain dynamics.

In contrast, abnormal connection, whether decreased or enhanced, is linked to a variety of diseases. The connection between brain regions, both static and dynamic, may be seen as a complex network with non-trivial topological features. One of the defining characteristics of networks is their susceptibility to external influences that may alter their structure, dynamics, and ultimately their behavior. Hence, the effects of focusing on a small area in the body may have far-reaching, far-from-local, and multi-scale repercussions elsewhere in the body. Examples of non-target areas regularly engaged during NF learning include the striatum and anterior insula. The identification of neuronal target is effectively conceived of as a localization procedure in some locations, such as temporal, anatomical, phase, or frequency spaces, and localization is a far broader problem than anatomical localization.

Brain intervention techniques need an action plan after the relevant target subspace has been identified (i.e. where to intervene) (i.e. how to operate on the selected target). Both stimulation regimens and objectives could be scale-reliant, therefore the time scales at which target activity occurs are an essential representation of this. Where do we want stimulation to work and be effective is the important issue here. By building a statistical framework to differentiate the patterns of brain activities in response to particular stimuli, decoding objective/task-based transformations to these patterns, modifying the stimulus based on the novel brain condition, and having subject repeat the mental process, process, it is possible to optimize task-specific performance at short time scales.

After some delay proportional to the gap between the present state and the goal pattern, the difficulty of the task may be adjusted. Assuming temporal (and frequently geographical) localization of the dynamics of the functional brain, an assumption that could be acknowledged at a shorter timeframe stimulus-based activity scales, a precise read-out of brain activities may in theory achieve this aim. The feedback loop's scale may be similar to that of the desired feature, or it may be many orders of magnitude larger or smaller. When normal, task-independent brain activity needs to be restored, this may occur. Neuro-intervention efforts in this context need to be guided by broad categories of brain function.

Generic glassy qualities such as anomalous scaling, weak ergodicity breakdown, long-range temporal correlations, and aging are seen in brain activity over long time scales, indicating that interventions could be temporally non-localised and that global (other) features could be applied as targets. DBS for PD is an example of how it's important to consider the spatial and temporal multiscale nature of brain activity. Despite its evident effectiveness, DBS has not yet succeeded in restoring in patients the normal dynamic repertoire indicative of healthier behaviors. The spatially-confined features of the complex system activation, the general effects of which is challenging to fine-tune, and the relatively incapability of prevailing stimulation plans to duplicate dynamical regimes stimulated by tonic and phasic activities of dopamine are two potential explanations for the limitations of this neuro-stimulation method. The stimulation is not only closed but also has a rather limited time scale.

Steering dynamics

For the most part, NF can be viewed as a classical control problem, where some aspect of brain dynamics deviates from an optimal (desired) regime or trajectory, and one must determine how to nudge the system so as to close in on the target dynamical trajectory or attractor. This is especially true when the feature time of target features is longer compared to the mean duration of the closed-loop. By using concepts from control and graph theory, we may get insight into how brain dynamics can be guided in a manner that promotes optimal function, which is key to solving the NF issue. The answers to the following questions are obvious in this setting: Is there a set of attainable dynamical states? Is it possible to reach a desired state or regime in a sustainable manner? How few nodes (or connections) must be changed in order to get the desired dynamics? From what beginning conditions might a set of dynamical states be reached?

The first step in resolving these issues is to determine whether or not brain activity can be seen, that is, whether or not the dynamics could be restructured by maintaining tabs on its time-based output. Achieving command would thus be as simple as introducing minute changes to the system. To do this, one might use one of two heuristic approaches, which entail tweaking the system's dynamical equations or starting point to get the system closer to the attractor of interest. These techniques have the potential to be used for network reprogramming and crisis rescue, such as in the case of epileptic dynamics, or for engineering a specific behavior of the system through the process of targeting, where the dynamics are guided towards a trajectory that is consistent with the natural dynamics of the system but comes from a distinct initial condition.

Nevertheless, this kind of analysis often requires detailed information on the state space and, in some cases, the dynamics of the system, which is not readily accessible for system-level cognition. The lack of complete information might lead to a control approach that leads the system into the trap of an unfavorable dynamics. Target observability is an approach that is more practical since it focuses on finding the appropriate sensors to infer the system's state. It is fundamental to consider that theoretically chosen NF targets may not necessarily match with the ideal sensors for network state reconstruction. In addition, determining both the global impacts of anatomically localized stimulation and the amounts of coarse graining, which might generate the best control objectives is very non-trivial due to heterogeneity, spatial extension, and principally multi-scaled condition of the brain dynamics. Analyzing the accessibility of the system, or the ability to attain an open subset of the state spaces from a particular starting state, is another fundamental consideration. Controllability means that the system could be shifted from any initial state to any postulated state in a limited amount of time. These fundamental theoretical findings may first seem to be relevant to the regulation of brain activity. There has been some application of the theoretical network control framework to neurology.

Nevertheless, these studies make certain unreasonable assumptions about brain activity, such as describing brain resting dynamics as a linearized differential equation set centered on a dominating fixed point, a hypothesis that may only account for a small subset of the dimensional space, and assuming that connection dynamics is linear and time-invariant. Despite the success of numerical control in theory, it has been indicated to fail in actuality, even for the linear modes. This is because control trajectories are nonlocal within the phase spaces, implying that the state path length is on mean independent of the distance between beginning and final conditions. In addition, below a certain control input number, numerical controls often fails due to a negative correlation between the state trajectory length and the success rate of the control algorithm. Only the linearized system has had any potential remedies to this apparently basic constraint offered.

On the other hand, adaptive networks in general and large networks with nonlinear dynamics in particular are still relatively unexplored areas of study. Evaluations of the system's observability and controllability are quite difficult. Since the order parameter, which describes the collective behavior of the system, could feed back to the control factors in adaptive systems like the brain, restrictions on network topology or dynamics may severely limit the system's controllability. Last but not least, the cost of controlling a networked dynamical system is a critical factor. How much "resistance" does one face? What kind of power would be required to control a gadget, and is it even possible? Would the necessary power cause any safety issues? Although most approaches to network management attempt to achieve this goal with a minimum number of nodes or connections, this might come at a significant energy cost if the number of nodes or links is made too small.

Indirectly affecting NF, this problem may have significant ramifications for the identification of neuronal targets and, more precisely, for the anatomical localization of targets. Interestingly, a recent research revealed that while brain networks can theoretically be physically controlled, the energy needed to operate systems could be disproportionately higher in practice, contradicting prior results that claimed resting brain activity might be controllable using a single node signifying a certain brain area. To sum up, network control techniques may represent a promising path toward better theoretical underpinnings of NF techniques and the realization of multiple potentially significant goals, though additional theoretical advancements appear required for control theoretical framework to plausibly accomplish clinical objectives

Brain function operation

Along with more conventional methods of brain stimulation such as transcranial magnetic stimulation (TMS) [5] and deep brain stimulation (DBS) [6], NF manipulates a dynamical feature of the brain to move about in the functional space, as shown by the patient's behavior. The most important aspect of NF is the process of identifying and defining cognitive processes both at the behavioral-cognitive level and in terms of matching neurophysiological mechanisms. Although cognitive and behavioral measures are used to evaluate the effects of NF, goal states are first specified in terms of brain dynamics. A functional shift in the strict sense is not necessitated simply because a particular field alters some aspect of brain activity, such as some topological network attribute. Such alterations may have significant dynamic importance but have little practical effect. Consequently, it is not dynamics in and of itself that has to be defined, but rather its functional features. So how can we define useful brain activity? This topic is more difficult to answer than it would first seem since it necessitates specifying the structure generated by a dynamics-to-function map, as well as assigning structure to the cognitive and dynamical spaces. When both individual and group variables in the mental space are supplied with explicit differentiable analytical expressions, a smooth dynamics-to-behavior map becomes possible.

However, the dynamic-to-function mapping is typically non-trivial due to the fact that it is challenging to think of the functional spaces as an easy manifold and define it on the basis of a differential equation. Hence, projections onto a suitable auxiliary space are required to disclose the functional space's structure. In a similar vein, knowing the accessibility of the associated dynamical regimes and creating functionally relevant phase space partitions are prerequisites for managing function rather than merely dynamics. The capacity to answer queries like "how distant is an observed behavioral state from some reference one?" depends on the resolution of the dynamic-to-function mapping in a particular experimental environment. Is it possible to go to a certain state in the functional space from where we are now? How broad is the spectrum of brain dynamics that don't impact function?

In the end, describing the dynamics-to-function map requires answering basic issues like, what are the impacts of a cognitive demand on the brain dynamics? What effects do dynamics have on behavior? How may brain activity be used to characterize behavior, and what, more ontologically, types of brain activity do behaviors ultimately come from? Cognitive demands, for instance, may be seen as operators operating on brain activity symmetries, and the observable behavior can be seen as a macroscopic characteristic originating from microscopic renormalization of the brain fluctuations and the breakdown of symmetries in network connection.

Neurofeedback mechanisms

When it comes to the brain, how exactly is NF working? If NF operates in the brain, how does it do so? When NF is activated, what kind of mental processes are triggered? The answers to such problems are important for things like device creation and optimization; therefore they are of much significance for the various brain stimulation approaches from both a fundamental science and a technology perspective. Both computational and experimental studies have looked at the processes by which DBS employs its impacts, for instance in the Parkinson's disease treatment. While the fundamental physics of DBS are well understood, it has been proposed that activating efferent fibers, altering oscillatory activity, or decoupling oscillation in the basal ganglia may alleviate motor symptoms.

But, our knowledge of the physical mechanisms at work in NF and how they are implemented in the brain is far more limited. The cerebral circuitry required to learn how to manipulate brain dynamics in a functionally beneficial manner is an essential feature that has been studied in the literature. It has been hypothesized that the method by which people learn to control their own brain activity is reinforcement learning, the same mechanism that underlies the acquisition of any other skill. Yet, there is still a lack of clarity on the following: How does NF affect the dynamics of the neural network? Specifically, how can NF direct brain dynamics toward more optimal phases? In the realm of algorithms, there are many different outcomes that might be achieved. One possible mechanism by which NF accomplishes its functional impacts is through the enforcement of continuous transformations between symmetry phases or groups, given that NF typically produces connectivity and maybe even topological alterations. Nevertheless, the neurophysiology that really carries out NF is still mostly understood at the implementation level.

Several types of information about the subject's brain activity are sent back to them. The strength of the participant's brain signal is instantly converted into an audio signal, allowing them to "hear" their brain activity (or a quantitative representation of this activity). Instead, the subject's brain activity may be represented in the form of virtual reality ball circumnavigating away or toward the goal, a disc contrasting or expanding in size, or gauge filed up at varied rates of speed. The difficulty of a task may also be adjusted during a trial based on data collected from the participant's brain. All of these forms of neurofeedback operate by associating the user's brain activity with either an overt (sound, ball) or covert (task difficulty) stimulus.

EEG, ECoG, MEG, and fMRI recordings are often used as driving signals in non-invasive neurofeedback methods. Participants in early neurofeedback research are given data on baseline brain activities. With fMRI-based (functional magnetic resonance imaging) neurofeedback, for instance, individuals get information on their BOLD (blood oxygen level dependent) activity with the brain ROI (region-of-interest), in contrast to the reference timeframe in the objective/task. Typically, people are instructed to raise or decrease the disk size or the gauge height to implicitly control the degree of BOLD activity in this ROI. Pre-processed EEG recordings are shown to patients undergoing neurofeedback based on electroencephalography (EEG), such as the oscillatory strength of EEG signals in alpha, gamma, or beta bands. Functional connectivity measurements between task-related cortical areas may be employed as feedback in fMRI or MEG-based neurofeedback.

Additionally, a visual feedback is often used in such methods, with a height or size representing the neurofeedback metrics. Participants have to actively (albeit not essentially consciously) regulate the volume of brain-based measure upon which neurofeedbacks are based in order to increase or decrease the intensity of the visual feedback. Using methods that a use raw or slightly modified signal has the benefit of requiring fewer (and hence faster) processing stages (**Fig. 2**). EEG

ERPs (event-related potentials), such as those identified in protocols utilizing the P300 spellers or their derivatives, may also be utilized to offer neurofeedback. By teaching participants to increase attention-based visual ERPs modulation, selective attention may be honed in on the premise that this will have an effect on attentional processes outside of the immediate activity at hand.

The lack of functional specificity in the feedback supplied by these methods is a key drawback. In order to provide more accurate and targeted feedbacks, sophisticated neural information processing techniques might be used. Specifically, recent developments in machine learning techniques have made it possible to infer the brain control signal participants in a more illuminating manner. It was shown in 2012 that a tetraplegic patient could utilize EcoG recordings to infer accurate motor instructions and so operate a robotic arm. Since the patient had complete command over the robotic arm's range of motion, this method was seen to be very illuminating. In functional magnetic resonance imaging (fMRI), neurofeedback on a high-order attention-based cognitive task has been attained by decoding the scenes against the face-based brain activation.

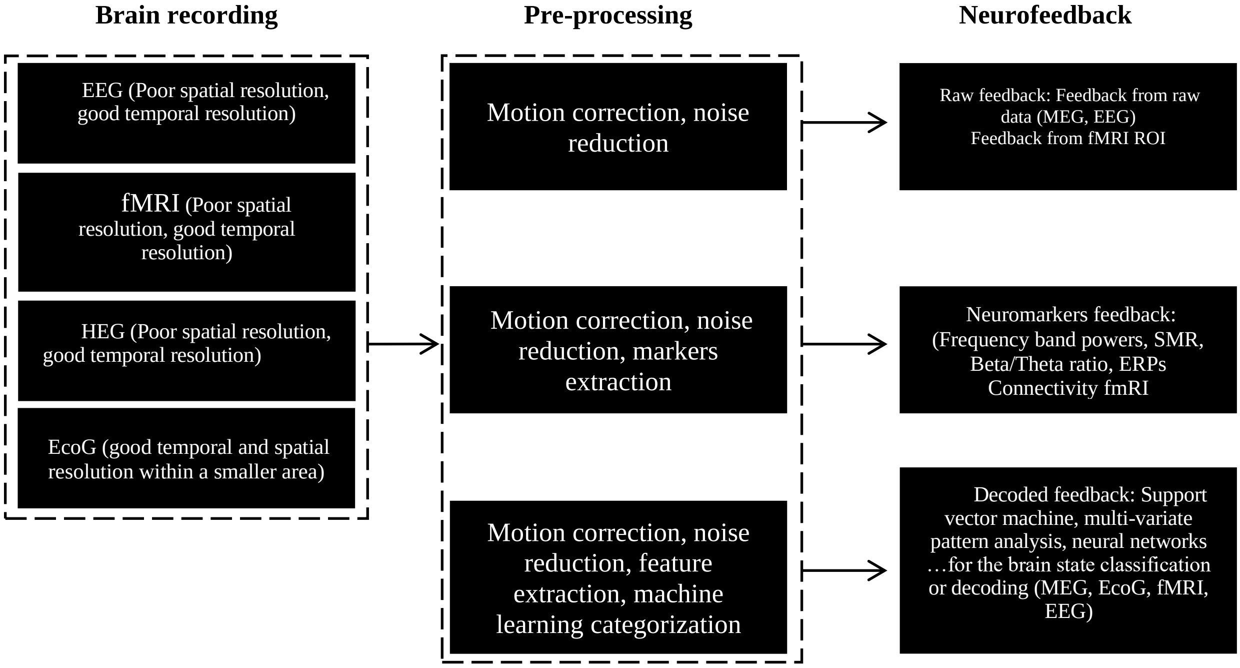

Fig 2. The present neurofeedback application phases

Fig 2 shows the present neurofeedback application phases, from the first captured brain signals, to the preprocessing phases and real neurofeedback metric. To gauge a participant's confidence in his or her ability to complete the job, other methods have used BOLD decoding techniques. Decoded neurofeedbacks could be more appealing on the subject's unique neural nuances than raw data, and the latter procedure for decoding could provide more nuanced data concerning cortical procedures. For instance, in the work of Foster and Drago [7], participants were shown images that contained both people and landscapes and were asked to choose which one they wanted to focus on. They were then given feedback based on the decoder's estimation of how well they had focused on the people or the landscapes. Subjects were prompted to concentrate their efforts by receiving feedback in the form of an increase or reduction in the task's difficulty. The participants will have access to highly nuanced data via the use of this decoded neurofeedback (DecNef) technique. The complexity of the pre-processing pipeline, however, may make it difficult to implement.

Although the later methods, which depend on real-time, sophisticated decoding of neural signals, hold great promise for improving cognitive abilities, they are currently constrained by their reliance on just two categories of decoding. Yet, new work by Garcia Pimenta, Brown, Arns, and Enriquez-Geppert [8]shows that it is feasible to accurately monitor spatial case in one of the 8 spaces, and that this tracking may be used to predict behavioral performance. In that it allows for more nuanced neurofeedback treatments addressing the precise neural computations underpinning a given cognitive function, this is a significant step forward. The following example will help to illustrate this notion. In the beginning, brain-machine interfaces (BCIs) that let people direct robotic arms with their thoughts had only limited degrees of freedom and extremely poor spatial control. In recent years, motor BCIs have advanced to the point that they are competitive with human arm motions. Cognitive neurofeedback methods are still using broad strokes to target mental processes. We may thus anticipate a significant change in the cognitive effects of neurofeedback with the implementation of finer-grained accessibility to cognitive data, as in [9] or as is now consummate with more intrusive techniques.

Hence, neurofeedback may be used to enhance, restore, or replace a particular cognitive functionality via the process of training. Humans' adaptability and capacity to learn are essential to its success. Neurofeedback has been found to increase plasticity by energizing established networks involved in reinforcement learning. We then go on to a discussion of how neurofeedback changes behavior and the brain itself.

III. BEHAVIOURAL IMPACTS OF NEUROFEEDBACK AND CLINICAL APPLICATION

Neurofeedback may be utilized for rehabilitative and therapeutic purposes, or it can be employed as a technique for pure cognitive training in healthy participants. Neurofeedback has seen extensive clinical application for the diagnosis of different psychiatric conditions, including but not limited to anxiety, addition, post-traumatic stress disorder, and schizophrenia. Research has demonstrated that neurofeedbackin accordance to alpha activities from different EEG recordings may effectively treat depression. The biomarker for depression, a drop in worldwide alpha activities within the left hemisphere, is directly linked to this impact. The therapeutic effects of fMRI neurofeedback for depression and anxiety have been promising. Research on EEG-based neurofeedback for PTSD has demonstrated beneficial benefits on stress, sadness, and self-harm. Finally, clinical results for the use of neurofeedback to treat addiction symptoms using EEG and fMRI have been encouraging. Neurofeedback using functional magnetic resonance imaging to decrease activities within the ventral anterior cingulate cortex has been demonstrated to be effective in treating nicotine dependence.

To train and cure certain cognitive deficiencies, neurofeedbackhas also been employed as a neuro-rehabilitation therapy. Most prominent among these uses is the improvement of focus in those with ADHD (attention deficit hyperactivity disorder). Both cognitive therapy and medications like methylphenidate are effective ways to deal with ADHD. Patients and their families may be hesitant to depend on cognitive rehabilitation or medication due to the former's limited effectiveness in certain cases and the latter's sometimes severe adverse effects. Because of this, many different types of cognitive neurofeedback-based trainings have been developed, all of which are safe, effective, and easily integrated into the treatment of individual patients.

Biomarkers used in ADHD neurofeedback include TBR (theta/beta ratio), the ratio between alpha and beta power in EEG recording, SMR (sensorimotor rhythm), the wave that could be captured on electrode proximals to the sensorimeter cortex, in 13 Hz and 15 Hz frequency ranges, and SCP (show cortical potential), the slow electric transformations (negative to positive) during the process of EEG recording. While it is already common knowledge that neurofeedback may assist patients with ADHD, the behavioral results, on markers like inattention signs and symptoms and impulsive and hyperactivity symptoms, remain lower compared to those attained after pharmaceutical treatment.

Patients in good mental health may also benefit from neurofeedback's ability to train healthy cognitive processes. DecNef, which employs fMRI, has been shown to enhance visual perception and category attention. DecNef utilizing fMRI affects self-confidence in healthy volunteers as they do a discrimination task, but has no effect on their discrimination performance. The fMRI DecNef protocol has also been proven to improve participants' perception to color of achromatic visual stimuli through repetition-oriented training.

According to the results of these more recent investigations, neurofeedback does indeed result in short-term behavioral alterations in task-specific areas. It is not yet known, however, whether the resulting behavioral changes are transferable to tasks other than the one that participants were trained on during neurofeedback, or if they can be maintained over time when individuals are no longer receiving neurofeedback. Indeed, very few research have been able to evaluate the long-term effects of neurofeedback training. The benefits of neurofeedback for ADHD have been shown to extend for up to a year after treatment has ended. The beneficial effects of color neurofeedback on achromatic stimuli have been seen to last for as long as five months. This provides more evidence that neurofeedback techniques have practical use in the clinic.

PTSD patients may benefit from neurofeedback. Therapists in the field of mental health now have easy access to a novel therapy for PTSD called neurofeedback. PTSD is a common mental health issue that may have serious long-term effects on a person's ability to interact socially and even their brain's biophysiological functions. The neurological effects of PTSD have been demonstrated to be treatable, and neurofeedback has showed promise in reducing both the symptoms and their causes. Clients with PTSD who did not respond to standard treatments showed positive outcomes. Intervention researchers on neurofeedback have been criticized for their deficiency of poor and rigor methodological designs; however, there is a substantial domain of case studies and clinical anecdotes supporting its effectiveness in PTSD treatment.

Neurofeedback has been shown to be beneficial in treating post-traumatic stress disorder, according to a recent comprehensive assessment of the literature. This research, prepared specifically for the mental health psychoanalyst, focuses entirely on behavioral results, as opposed to neurobiological alterations, as shown in previous evaluations. Ten papers fulfilled the inclusion criteria for this meta-analysis. The majority of study participants reported positive outcomes from neurofeedback on at least one outcome measure. Wide variations in sample sizes, research methods, end measures, and the breadth of published findings make it difficult to draw meaningful conclusions. Random controlled researches with longitudinal follow-up outcomes as well as larger sample numbers outcomes should be prioritized for future research in this field.

IV. NEUROPHYSIOLOGICAL IMPACTS OF NEUROFEEDBACK

Improved therapeutic outcomes in patients and improved behavioral performance in healthy individuals are the results of neurofeedback-based cognitive training. The capacity of the brain to learn during one's life, also known as brain plasticity, is crucial to the maintenance of these effects for up to a year. Several reports have shown that neurofeedback training may induce tangible changes in subject's neurophysiology. Functionally specific alterations related with the neuromarkers employed during the neurofeedback method, or more generalized alterations to the learning networks, account for the majority of these alterations.

Researches integrating fMRI imaging, and EEG neurofeedvack, for instance, showing that effective neurofeedback is linked with enhanced activities within that thalamus showing that neurofeedback tends to induce brain plasticity, and reinforcement learningThe striatum is also critically important in reinforcement learning, and a meta-analysis demonstrates that it is activated more strongly by almost all neurofeedback techniques. That is to say, the observable behavioral impacts of neurofeedback depend on the degree to which individuals are able to learn to regulate their own brain activity in response to a specific success signal (task difficulty transformation, gauge filling up, and ball positioning). On the basis of these findings, Schmidt et al. [10]found that participants' putamen volumes predicted whether or not they would benefit from neurofeedback, suggesting that a person's innate capacity for learning (as measured using putamen volumetric units) is an metric for how well they will incorporate and reap the benefits of neurofeedback. Hence, the structural and functional changes brought about by neurofeedback training of the brain's cognitive processes depend on a variety of preexisting variables.

Changes in neuro-biomarkers that are utilized to drive neurofeedback are, unsurprisingly, also observable in cases where neurofeedback has been shown to generate plasticity in the brain's learning network. ADHD patients, for instance, benefit from neurofeedback by increasing grey matter volume and white matter myelinisation within the functional system related to sustainable attention. These transformations may take place after just a single, lengthy session of neurofeedback. Transformations in the functional connections within the brain system after fMRI neurofeedbackhave also been reported in many studies. Even with the protocols ofneurofeedback protocols, which are not directly stimulated by functional connections, these alterations are localized to the functional network that is the focus of the neurofeedback.

An fMRI neurofeedback program based on the BOLD fMRI signals from the correct inferior frontal cortex has been shown to improve functional connectivity in individuals with attention deficit hyperactivity disorder. These alterations are associated with an increase in dorsal caudate and inferior cingulate connections and a reduction in frontal cortical connectivity to the default mode network (DMN) (salience network). The most essential point is that these alterations are associated with a more positive pattern of behavior. Similarly, after completing an EEG neurofeeback exercise stimulated by the alpha oscillatory power, individuals showcase an enhanced functional connection in the salience networks and diminished functional connection in default mode networks. For instance, the theta/beta EEG oscillatory power ration has been shown to induce profound brain reorganizations in clinical settings such as after EEG-based neurofeedback in individuals with an ADHD.

The power of the theta frequency diminishes in the cingulate regions, frontal, and left temporal regions, which the alpha frequency power diminishes in the right temporal lobe, and the right frontal region, and beta frequency power increases in the cingulate regions, frontal, and left temporal regions. The patient with post-traumatic stress disorders who engage in EEG-based neurofeedback with a focus on alpha power amplitude also show changes in long-ranged temporal correction in the amplitude envelope of wide-band signals and in the alpha and theta band oscillation from the various brain regions. These modifications are linked to diminished symptoms, calling into doubt the presumed connection between oscillatory alpha power, and long-range correlations.

Even after a few sessions of neurofeedback, changes in brain structure and function have been seen, leading some to speculattions that neurofeedback relies on conventional Hebbian plasticity processes, the goal of which is to optimize trial reinforcement result. While the particular neural processes are just beginning to be uncovered, this phenomenon is not without its mysteries. Being an ecologically unrealistic life experience, neurofeedback raises the question of whether it just recruits the pre-existing network and neural loops or if it tends to stimulate novel computational cortical capability, which cannot be reactivated by environmental circumstances.

V. NEUROFEEDBACK FOR PLASTICITY TRAINING

By learning to monitor and control their own brain activity, neurofeedback trainees may improve their overall quality of life. Participants get information about their brain functions based on fMRI or EEG readings. It is expected that providing participants with immediate feedback on potentially harmful brain processes may help them guide their own brain activity in a therapeutic manner, ultimately alleviating their symptoms. Neurofeedback training may be used on its own to alter faulty brain activation patterns without any direct teaching or as a supplement to the acquisition of new cognitive and behavioral skills. Since neurofeedback feedback is based on the individual's own brain activity, it may be tailored to the needs of the trainee. Neurofeedback training using fMRI scanners has yet to be rigorously investigated for its therapeutic value in the treatment of addiction, despite the fact that there is some evidence that using EEG scanners may be helpful.

It is thus clear that neurofeedback may induce behavioral and cortical plasticity transformations, which amounted to enhanced cognitive functionality in both healthy and impaired individuals. However, it might a challenge to make an assumption that neurofeedback techniques have universally proven useful. There are a number of restrictions associated with these techniques that must be taken into account in future experiments. Most of these problems are shared by all methods of cognitive training and are not unique to neurofeedback. To begin, it is not yet known if all neurofeedback methods provide the same long-term behavioral effects, even though some studies have shown them. Hence, it is important to organize a systematic assessment of the effects of neurofeedback at a range from interventions, which may help shed light on the structural and functional predictors of longer-term retention of neurofeedback training benefits.

Second, training generalization is the Holy Grail of cognitive learning protocols, and particularly neurofeedback, since it ensures that the improved cognitive skills shown in the primary training protocol will also be seen in real-world settings. The key issue of the therapeutic and behavioral relevance of neurofeedback beyond research setting is raised by the lack of testing of the transfer of behavioural impacts outside laboratory settings. Finally, it's important to stress that neurofeedback often leads to 70-85% of participants (termed responders) being able to self-regulate their brain activities. Approximately 25% to 30%, however, do not profit from these methods. The term "non-responders" is used to describe these individuals. This is a serious problem since it implies that as many as one-third of a group of trained patients or volunteers may be immune to the therapy. The flexibility of neurofeedback training to patients and volunteers, one of its main benefits over other cognitive training approaches, is diminished as a result.

Several studies have been undertaken to figure out why some people just do not improve after neurofeedback training, or receiving self-regulation. This would make it possible to effectively screen the priori individuals to the neurofeedback protocols and, perhaps, overcome neurofeedback resistance with individualized training plans. Rather than establishing a single predictor of non-respondence, these studies have found a variety of markers, such as putamen volume, resting state brain activity, and confidence in and familiarity with the technology of the neurofeedback protocol. Nonetheless, further research in this area is necessary, and these results imply that tailoring neurofeedback techniques to participants' individual features at the outset might help reduce the number of non-responders.

The functional specificity of the claimed benefits is another major challenge in neurofeedback research. Why wouldn't a sophisticated function be beyond the scope of a basic alpha wave's feedback to fix or improve upon it? How may altering the ratio of alpha to theta oscillatory power on a global scale have targeted impacts on a variety of functions? As a first step toward solving this problem, researchers have begun using multivariate fMRI-based neurofeedback, which takes into account the fact that the signals recorded from neurons at any given time do not reflect just one function but rather a number of them, each with their own set of complex interactions. As a whole, this has allowed for more specific manipulation of mental processes. When it comes to manipulating the linked cognitive function, for instance, in [11], scientists show that they may do so with a high degree of specificity by targeting participants' levels of confidence in the task in both directions.

In addition, sophisticated methods of targeting cognitive processes utilizing invasive recording techniques are being developed for use in animal models. As people are engaged in complicated cognitive tasks, for instance, the location of attentional spotlights could be tracked with temporal resolutions (50 ms) and fine-tuned spatial (below the 1°) utilizing state-of-the-art machine learning methods. Using these cutting-edge techniques, Posner, Sheese, Odludaş, and Tang [12]showed that processes of attentional neural networks undergo ultra-slow oscillations at a rate of around 4 to 5 cycles in every hours, alternative between different periods of low efficiency, and high efficiency. Min, Maoquan, Xiaojun, Kui, and Xiao [13]demonstrate independently that multivariate modeling of sources of noise that are attention-independent in the recorded neuronal population may further improve access to spatial attention. These researches, which use real-time signal processing, are considered to fundamentally enhance neuro-feedback methods. These methods are not only intended to shed new light on cognitive functioning, but also to be immediately transferable to human patients having ECoG electrode implants. More recently, the basic technology has been extended to include human fMRI records obtained via a noninvasive technique. As a result, the door is now open for considerably more nuanced and data-rich neurofeedback protocols to be used in the realm of cognitive training.

Perhaps most crucially, recent critical assessments of neurofeedback research findings have pointed out that many research findings lack enough experimental controls. As a result, it's possible that some of the observed benefits are "mere" placebo effects. In order to determine the efficacy of neurofeedback for treating insomnia, Snyder, Quintana, Sexson, Knott, Haque, and Reynolds [14]undertook a randomized, double-blinded EEG research. Remarkably, patients who were given either the active treatment or the placebo showed signs of improvement. They reasoned that the positive results shown in certain trials of neurofeedback may be attributable to a placebo effect caused by factors such as the subjects' belief in the efficacy of the therapy or the experimenters' compassion. As a consequence of this research, there is now a lively discussion about the potential pitfalls of financial biases, and ideological stances in neurofeedback researches, demonstrated the necessity of the placebo-controlled and double-blind trials.

VI. CONCLUSION

Brain wave training (also known as electroencephalogram (EEG) biofeedback or simply "neurofeedback") is a kind of biofeedback used to enhance cognitive performance. Promising results have been found in scientific experimentations for a variety of illnesses, including attention deficit hyperactivity disorder (ADHD), epilepsy, chronic pain, insomnia, depression, anxiety, traumatic brain injury, and addiction. Evidence-based therapeutic treatment and the fields of fundamental and applied neuroscience provide the basis for neurofeedback (NFB). Sensors are used in neurofeedback, just as they are in other types of biofeedback, to measure the body's physiological responses. So, in neurofeedback, tiny sensors are affixed to the head in order to monitor the subject's brainwave activity and provide visual feedback on any changes. Brainwave activity may be detected and processed in real time by a computer, which then displays visual and auditory data depending on the brain's performance. Individuals may learn to self-regulate or self-control their brain states with the help of this feedback. Insights like these are useful since a person's mental health profoundly affects their behavior, emotions, and physical well-being. The American Psychological Association (APA) identifies evidence-based interventions as one that combines professional competence with the best research to enhance subjective, behavioural, and cognitive processes linked to the brain activity. Neurofeedback is a long-term treatment option that does not need surgery or medicine, is neither unpleasant nor unsightly, and produces noticeable improvements.

Data Availability
No data was used to support this study.

Conflicts of Interests
The author(s) declare(s) that they have no conflicts of interest.

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