When Discussing Neurofeedback, Does Modality Matter?

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Abstract

Over the years, several new models and variations of neurofeedback (NF) have been developed. As such, NF has grown from traditional amplitude based modalities to now include slow cortical potential NF, as well as various approaches grounded in QEEG technology, including *z*-score NF models. These differing modalities have important implications in terms of outcomes, the number of sessions required, and treatment specificity. This, in turn, impacts clinical practice, research, and marketing considerations. In an effort to gain some perspective for where the field is today, a comparative review is presented to illustrate the importance of noting what particular modality is being referenced when discussing NF.

Keywords: neurofeedback, traditional NF, slow cortical potential NF, QEEG-guided NF, *z*-score NF

Introduction

If evaluating neurofeedback (NF) from an evidence-based perspective is important, and we propose that it is, then distinguishing between modalities is an essential component of that process. Over the years, several new models and variations of NF have been developed, which directly impacts practice implications in terms of outcomes, the number of sessions required, and treatment specificity. Thus, noting which modality of NF is being implemented is a necessary step in discussing any NF intervention.

In the 1970s, when NF was first being developed by the likes of Joe Kamiya, Barry Sterman, and Joel Lubar, the approach was generally the same, that of targeting amplitudes of specific frequency bands. However, since then, many other models, and variations of models, have been developed. While the standard for much of the history of NF was the use of only one or two electrode sites to train various EEG frequencies, today there are new models which use as many as 19 electrodes while incorporating real-time database metrics and targeting cortical regions of interest. Therefore, the current range of NF modalities include traditional amplitude-based NF (Theta-Beta, Sensory-Motor Rhythm [SMR], Alpha-Theta), slow cortical potential (SCP) NF, quantitative EEG (QEEG) guided NF (QNF), and *z*-score NF (ZNF) models including 4-channel, 19-channel surface, and l*ow resolution* brain electromagnetic tomography (LORETA) ZNF (also see Figure 1, which presents a graphic of this collection of models, in timeline format, to provide a better context for the development of these models over time).
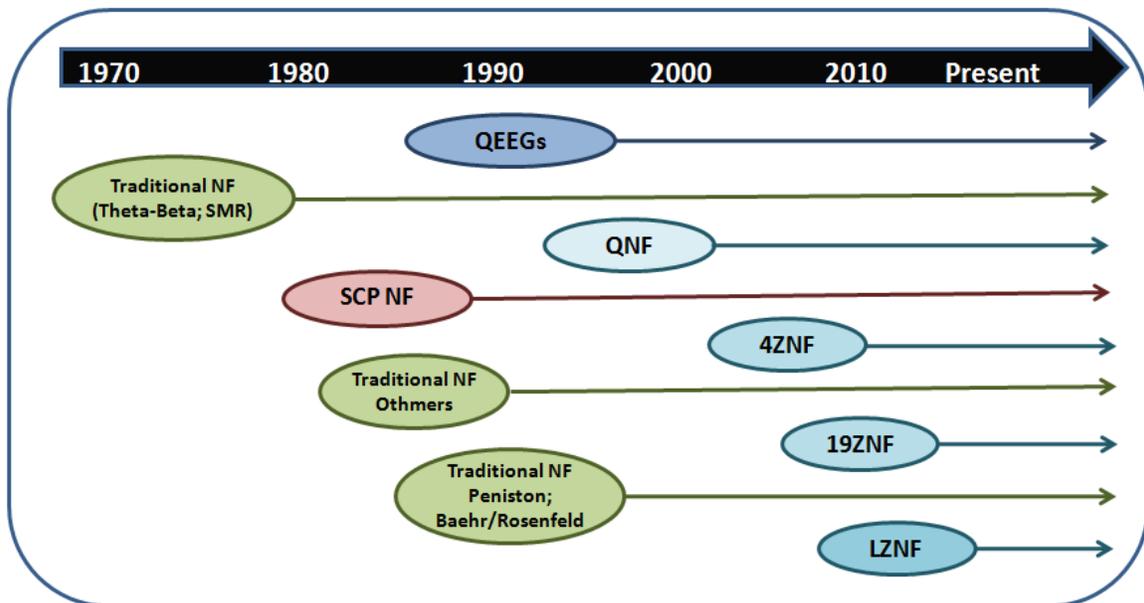

Figure 1. Timeline of when various neurofeedback modalities emerged.

NF models based on Theta-Beta bands and SCP have robust evidence-based research support; however, treatment sessions number from thirty to over forty and the specificity is limited to surface neuroregulation. In contrast, the evidence-based research is limited in newer models, such as the 19-channel and LORETA *z*-score models, which have been around since 2006 when the NF *landscape* changed to include ZNF. Yet, treatment outcome reports of the 19-channel and LORETA *z*-score models indicate that treatment goals can be achieved in fewer sessions, as more networks and deeper structures can be targeted (Thatcher, 2013; Wigton, 2013). Hence, depending on the modality, the amount of treatment sessions and specificity will make a difference in how NF is understood and/or is identified as a choice of treatment. For this reason, when addressing NF, the length of treatment and specificity are important in order to identify what modality of NF is being referenced. This is also important in terms of being an informed consumer of NF research in the literature (scientific).

In 2012, the American Academy of Pediatrics (AAP) elevated biofeedback (to include NF) to a *Level 1/Best Support* recommended intervention. However, the three NF studies evaluated to make this determination (PracticeWise, 2012) only included Theta-Beta and SCP NF (Beauregard & Levesque, 2006; Gevensleben et al., 2009; Levesque, Beauregard, & Mensour, 2006), and did not include newer models (i.e., QNF or ZNF). As a result, it is important to be aware of the scope of this recommendation. Moreover, the non-inclusion of newer models (such as QNF or ZNF) may highlight the need for further empirical support, with solid methodologies, so as to elevate the evidence-based support matching that of Theta-Beta and SCP models; because the modality of NF used guides the treatment outcome, specificity and the number of sessions, which may vary between modalities.

Although all NF is informed by a basic framework of operant conditioning and learning theory (Sherlin et al., 2011), the variation in the application of that framework presents the NF clinician and researcher with many choices. Consequently, this comparative review is presented to gain some perspective of where the field is today with respect to the traditional NF, SCP NF, QNF, and ZNF models.

It is important to note there are other neuroregulation applications, which are also frequently referred to as NF, and are beyond the scope of this article. These include hemoencephalography (HEG), *low-energy neurofeedback system* (*LENS*), low intensity pulsed electromagnetic field (pEMF) stimulation, audio-visual entrainment (AVE), and real-time functional magnetic resonance imaging (fMRI) feedback, some of which may be considered adjuncts to NF treatment. So, due to the growing variety of neuroregulation techniques included under the overarching umbrella of NF, with differences in treatment outcome, number of sessions, and specificity, it is critical to be clear about which modality is being referred to when discussing NF.

Synopsis of NF Modalities, Treatment Outcomes, Number of Sessions, and Specificity.

Traditional NF. In the context of this review, the term *traditional* is used to describe the models that are primarily amplitude based. These are the longest standing iterations of NF and can be traced back to the original founders of the field (Kamiya, 1968; Sterman & Friar, 1972; Lubar & Shouse, 1976), including models where the targeted frequencies are Theta-Beta, SMR, or Alpha-Theta. While most NF practitioners who have been in the field for more than a decade are likely to be familiar with these models, newer entrants who may start with learning more recent NF models may not. Therefore, those not familiar with the historical aspects of NF are encouraged to acquaint themselves with the beginning works in the NF field (see Budzynski, 1999; Evans & Abarbanel, 1999; Robbins, 2000; Thatcher & Lubar, 2009). Other models, which have developed from this perspective, are symptom-based approaches such as the earlier Othmer models (Othmer, Othmer, & Kaiser, 1999) where, generally, one frequency band is rewarded (either 12–15 Hz or 15–18Hz), while two other frequencies (Theta and High Beta) are inhibited. Still other models, which can be traced back to Kamiya's work, target parietal Alpha and/or Theta frequencies to enhance relaxation and creativity states (Budzynski, 1999), which Peniston and Kullkosky (1990, 1991) developed further, leading to treatment models for post-traumatic stress disorders and alcoholism. Finally, Baehr, Rosenfeld, and Baehr (1997) created protocols with the goal of balancing frontal alpha as a treatment for depression.

Slow Cortical Potential (SCP) NF. As described by Mayer, Wyckoff, and Strehl (2013), SCPs are very slow brain activation electrical shifts, generated subcortically and cortically, which alternate between being electrically negative or positive. Further, central to this model is an event related potential termed the contingent negative variation (CNV), such that

reduced CNVs have been found to be associated with attention deficit hyperactivity disorder (ADHD) symptoms; and SCP feedback has been shown to lead to an increased CNV. Therefore, in SCP NF, with an active electrode at Cz, the training goal is to generate shifts between surface-positive and surface-negative SCPs. The sessions typically consist of two to four runs made up of approximately 40 trials in each run. SCP NF is different from many traditional NF models in that there is only a single protocol used, with only slight variants, and has been designated by Mayer et al. as a *one size fits all* approach. Reports investigating the self-regulation of SCPs date back to the mid to late 1980s (Roberts, Rockstroh, Lutzenberger, Elbert, & Birbaumer, 1989; Rockstroh, Birbaumer, Elbert, & Lutzenberger, 1984; Rockstroh et al., 1993).

Traditional NF and SCP NF treatment outcomes, number of sessions, and specificity.
Over time, the Theta-Beta and SMR variations of traditional NF, together with SCP NF, have come to be some of the most researched, specifically for the condition of ADHD (Arns, Heinrich, & Strehl, 2014). This is further demonstrated by many reviews and meta-analyses available (Arns, de Ridder**,** Strehl, Breteler, & Coenen, 2009; Arns et al., 2014; Brandeis, 2011; Gevensleben, Rothenberger, Moll, & Heinrich, 2012; Lofthouse, Arnold, Hersch, Hurt, & DeBeus, 2012; Mayer et al., 2013; Niv, 2013; Pigott, De Biase, Bodenhamer-Davis, & Davis, 2013). Overall, this collection of literature provides strong support for NF being considered efficacious for ADHD.

While the traditional NF models may vary with respect to which EEG frequencies are trained, elements common to them are targeting amplitudes and a need for 40+ sessions, on average, for successful clinical outcomes. Regarding SCP, in their review of SCP NF studies for ADHD, Mayer et al. (2013) report the number of sessions ranged from 25 to 35. Thus, while SCP NF is frequently investigated and reported alongside traditional NF, it is possible that SCP NF may require somewhat fewer sessions that traditional NF.

However, with a reliance on only one or two electrode placements, specificity in traditional and SCP NF is limited. At any individual electrode location, the EEG recording includes diffuse sources (both close and distant) that are picked up from other brain areas (Thatcher, 2013). Thus, with traditional NF, EEG recordings from an electrode at Cz will actually include a blend of the EEG signal from all other areas of the scalp, to varying degrees. Yet, traditional NF still employs choices of different frequencies at varying sites, depending on the particular symptoms or case presentation. However, with SCP NF, generally there is a single electrode on the central strip, typically at Cz, with a singular protocol applied to all clients (Mayer et al., 2013).

QEEG-guided NF (QNF). In their recent review of NF for ADHD, Arns et al. (2014) suggest that research efforts should focus on NF protocols that are tailored to the individual, as many studies have suggested clinical outcomes can be improved with a personalized approach to NF. QNF allows for a tailored approach to individual treatment. QNF is grounded in QEEG technology dating back to the late 1980s; it has been improved through the years, so that the treatment can be tailored given the particular QEEG baseline, clinical status, and history of the client (Arns, Drinkenburg, & Kenemans, 2012). This then allows for individualized treatments of differing electrocortical presentations, even with the same or similar overarching diagnoses (Hammond, 2010). Multiple reports in the literature support this clinical approach indicating how training the deviant *z*-scores towards the mean (i.e., normalize the QEEG) yields clinical benefit (Arns et al., 2012; Breteler, Arns, Peters, Giepmans, & Verhoeven, 2010; Collura, 2008a; Orgim & Kestad, 2013; Surmeli, Ertem, Eralp, & Kos, 2012; Surmeli & Ertem, 2009, 2010; Walker, 2009, 2010a, 2011, 2012a). Therefore, QNF still targets amplitudes of frequency bands, but does so in an effort to

normalize the excessive *z*-score deviations shown in the QEEG that correspond to the overall clinical picture.

QNF treatment outcomes, number of sessions, and specificity. QNF studies are well represented in peer-reviewed literature; however, no meta-analysis of QNF has been identified to-date. Yet, the current QNF studies in the literature do report positive treatment outcomes. Moreover, while traditional and SCP NF mostly focus on ADHD symptoms, QNF studies report covering a wider range of symptoms, syndromes and disorders that include, behavior aspects, mood, cognitive dysfunction, epilepsy, head injuries, autism spectrum, migraines, learning disorders, schizophrenia, post-traumatic stress disorder, Down syndrome, and intellectual disability (Arns et al., 2012; Breteler et al., 2010; Coben & Myers, 2010; Huang-Storms, Bodenhamer-Davis, Davis, & Dunn, 2006; Koberda, Hillier, Jones, Moses, & Koberda 2012; Surmeli et al., 2012; Surmeli & Ertem, 2007, 2009, 2010, 2011; Walker, 2009, 2010b, 2011, 2012b, 2013). This literature collection largely represents retrospective investigations from clinical settings.

While some QNF studies provide results from research where the number of sessions was in the range of around 20 sessions (Breteler et al., 2010; Walker, 2009) others have reported as many as 50 or 100 sessions (Surmeli & Ertem, 2009, 2011). However, as with traditional NF, the number of sessions for QNF typically remains on an average of 40 (Thatcher, 2013; Wigton, 2013).

Specificity with QNF, however, improves by being able to individually tailor the protocol to the needs of the client as directed by the QEEG findings and clinical assessment. This is accomplished with protocols that target specified sites with a goal of normalizing identified deviant *z*-scores. Thus, this NF modality takes into account the heterogeneity of QEEG patterns, more so leveraging the sensitivity, reliability, and specificity of the QEEG, as discussed by Hammond (2010).

Z-Score NF (ZNF). Rather than targeting frequency amplitudes, as with traditional NF or QNF, in ZNF, the training targets are the calculated real-time QEEG *z*-scores integrated into the NF software. As a result, real-time QEEG assessment metrics can be paired with operant conditioning and incorporated into the NF session (Collura, 2014; Thatcher, 2013). Thus, ZNF capitalizes on the statistical foundation for a normal distribution, where a value converted to a *z*-score is a measure of the distance from the mean of a population, such that the mean represents a range considered to be typical (Collura, 2014). This brings a new dynamic to the NF process. The focus is no longer on making more or less of a particular frequency, but rather moving excessive live (i.e., real-time) *z*-score metrics towards the mean (i.e., *z* = 0), thereby placing more emphases on normalizing the QEEG values. ZNF allows for more metrics to be targeted in a NF protocol as active training components — up to ten frequency bands, both absolute and relative power, frequency power ratios, and the connectivity metrics of asymmetry, coherence, and phase lag. Yet, consistent with being an outgrowth of the QNF model, normalization goals are still governed by the presenting clinical picture. ZNF is one of the newest models, but even within this category, three distinctions can be made to include 4-channel ZNF, surface 19-channel ZNF, and LORETA ZNF; each are discussed as follows:

4-Channel ZNF (4ZNF). The 4ZNF model was the first iteration and was introduced in 2006, with the total number of metrics available to train being 248 (Collura, 2014). However, while the reference to *4-channel* implies only four channels can be trained, there are also options for one or two channel ZNF training as well; thus this can be considered an *up to* 4 channel

model. Here the *z*-scores are calculated from the surface recordings; yet, there is still access to all metrics/components as described above (i.e., power, connectivity, etc.).

19-Channel ZNF (19ZNF). 19ZNF was made available as an outgrowth from 4ZNF in 2009, and the total number of metrics for protocol selection is 5700 (Collura, Thatcher, Smith, Lambos, & Stark, 2009). Again, in 19ZNF, the surface EEG recording is the source for the real-time *z*-score calculations. However, unique to 19ZNF, in addition to the linked-ears montage, is the availability to directly train the Laplacian montage. Yet, as with 4ZNF, so long as the linked-ears montage is applied, any number of channels up to 19 can be included in a protocol, thus allowing the use of any number of electrodes from one to 19.

LORETA ZNF (LZNF). While there have been investigations of non-*z*-score LORETA NF (examples include Cannon, Lubar, Sokhaze, & Baldwin, 2008; Cannon, Congedo, Lubar, & Hutchens, 2009; Cannon, Baldwin, Diloreto, Phillips, Shaw, & Levy, 2014), LZNF was first introduced in 2010. Even though similar in many respects, there is a fundamental difference between surface ZNF and LZNF. Surface ZNF calculates the *z*-score of identified EEG metrics at various 10-20 electrode sites, whereas with LZNF, the *z*-score is calculated for a particular collection of current source density (CSD) voxels. This makes it possible to conduct NF with the *z*-scores of the calculated location of deeper cortical dipole generating regions or structures (i.e., Brodmann areas, cingulate gyrus, precuneus, etc.). Consequently, isolated cortical regions of interest can be identified for normalization with this modality.

ZNF treatment outcomes, number of sessions, and specificity. Currently, case reviews, technical reports, and discussion about ZNF can be found in books (Collura, 2014; Thatcher, 2012), and publications such as that of Collura (2008b), Genardi (2012), Koberda (2012), Thatcher (2008, 2013), and Wigton (2013). Additionally, there have been conference presentations such as Koberda, Moses, Koberda, and Koberda (2012a), Rutter (2011), and Wigton (2010). Nevertheless, while it is hoped there are more studies in preparation, currently, there are few examples of *empirical investigations* of ZNF in *peer-reviewed* literature evaluating the outcomes of ZNF. There are two such publications that investigate 4ZNF, the first of which is a study by Collura, Guan, Tarrant, Bailey, and Starr (2010) that presented a collection of clinical reports from six clinicians covering 24 successful cases, with an average of 21 sessions per case, and all clients reported clinical improvement. The second publication, by Hammer, Colbert, Brown, and Ilioi (2011), is a randomized, controlled, single-blind study with small sample size ($n = 3$ and $n = 5$) that suggests 4ZNF is beneficial for insomnia. For 19ZNF, examples include two single case study evaluations: Hallman (2012) described a case of a child with fetal alcohol syndrome where 80 sessions of 19ZNF brought about remarkable improvements and QEEG normalization; then, Koberda, Moses, Koberda, and Koberda (2012b) described a case where both 19ZNF and LZNF were used with a 23-year-old male, where improvements in cognitive and QEEG assessments were achieved in 15 sessions. For LZNF, one study presented a review of four cases: Koberda, Koberda, Bienkiewicz, Moses, and Koberda (2013) applied LZNF to treat chronic pain and all cases reported improvement.

In terms of number of sessions, ZNF employs simultaneous training of multiple *z*-score metrics (i.e., power, connectivity) at many more electrode sites (up to 19), within either surface or LORETA frameworks. This allows for more neuroregulation and enhanced QEEG normalization. Consequently, in clinical reports of ZNF it is suggested that positive clinical outcomes can be achieved in an average of 10 to 20 sessions (Collura et al., 2010; Koberda et al., 2012b; Wigton, 2013).

The available *z*-score metrics and multiple channels of the ZNF modalities greatly enhance NF specificity. With surface 4ZNF and 19ZNF, the dysregulated areas and rhythms can be isolated for normalization, and even more so with the Laplacian montage (Thatcher, 2013). With LZNF, brain networks and hubs can be identified and targeted as regions of interest for training. By directly targeting these regions of interest, in a *z*-score framework, it is reported that LZNF allows for specificity and localization similar to that of fMRI methods (Thatcher, 2013). This allows for the linkage of functional systems with the presenting clinical symptoms, such as when identified brain regions (with deviant *z*-scores) are being reinforced towards the mean (i.e., $z = 0$) to promote increased stability and homeostasis in brain function (Koberda et al., 2013).

Conclusion

In sum, while all NF is grounded in operant conditioning, it is clear there is a wide range of approaches today. As a result, misunderstandings and misinterpretations can happen if the modality being addressed is not noted. This can have implications for clinical practice, research, and marketing, as has been addressed through this review. For instance, although the AAP recommended that biofeedback/NF be elevated to a *Best Support* intervention, would all NF modalities be paid if NF is accounted for as a managed care paid intervention (even though the decision seems to be based on traditional NF)? In research, each NF modality may have different levels of efficacy, number of sessions, and treatment specificity, which directly impacts methodology and implications. And, in marketing, a frequent question of NF consumers is how long does the treatment take or how many sessions are needed? In answering these questions, it is clear that the treatment and amount of sessions is guided by the NF modality utilized. Thus, when discussing NF, does modality matter? Yes, it does matter.

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