NeuroRegulation

A Review of qEEG-Guided Neurofeedback

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Abstract

While there are literature reviews and meta-analytic coverage of neurofeedback (NF) studies that focus on traditional amplitude NF and slow cortical potential NF, the same is not true for quantitative electroencephalographic (qEEG)-guided NF (qNF). To that end, this is a literature review of several qNF research articles. Generally, most are found in clinical settings, address a wide variety of symptoms and diagnoses, use clinical assessments as outcome measures, employ individualized NF protocols based on qEEG findings, and define efficacy in terms of improvement on pre-post outcome measures. However, few report pre-post qEEG metrics as outcome measures. Suggestions for future research are presented.

Keywords: qEEG-guided NF; neurofeedback; qEEG; EEG biofeedback

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Introduction

In recent years there has been a rapid surge of articles focused on neurofeedback (NF) in the literature. In this landscape, there exist reviews and meta-analysis studies on traditional amplitude-based NF (Arns, de Ridder, Strehl, Breteler, & Coenen, 2009; Arns, Heinrich, & Strehl, 2014; Brandeis, 2011; Gevensleben, Rothenberger, Moll, & Heinrich, 2012; Lofthouse, Arnold, Hersch, Hurt, & DeBeus, 2012; Niv, 2013; Pigott, De Biase, Bodenhamer-Davis, & Davis, 2013) and a meta-analytic style review of slow cortical potential NF (Mayer, Wyckoff, & Strehl, 2013). In regards to the recent *z*-score NF modalities, a few studies with a quantitative analytic focus have begun to emerge (such as, Hammer, Colbert, Brown, & Ilioi, 2011; Krigbaum & Wigton, 2015; Wigton & Krigbaum, 2015); yet, there are too few to expect a meta-analysis or review summaries. However, to date no meta-analysis or comprehensive review has been found of quantitative electroencephalographic (qEEG)-guided NF (qNF), in spite of its origins dating back to the 1990s.

Even so, that is not to say that qNF is devoid of research. In fact, from 2002 to 2015 there are numerous studies in peer-reviewed literature addressing the qNF model. Unique to this genre of studies, though, is great diversity in the different conditions treated, as well as a greater use of individualized, custom-designed protocols; thus, making meta-analysis of this collection of research less feasible (Krigbaum & Wigton, 2014). Nonetheless, these studies do represent a body of research pointing to the efficacy of qNF. This, then, is intended to review qNF as represented in the literature. While this is not intended to be an exhaustive review of all qNF studies, it is believed to be a representative sample of the literature coverage of this particular NF modality.

Background Information

Historical Perspectives

While understanding of the multiple components to the EEG signal was evident as early as the 1930s, the advent of computer technology was necessary for qEEG advances (Collura, 1995); for example, the incorporation of normative databases in conjunction

with qEEG analysis. Early implementations of qEEG normative database applications date back to the 1970s with the work of Matousek and Petersen (1973) as well as John (1977; Pizzagalli, 2007; Thatcher & Lubar, 2009). However, while work exploring NF applications with qEEG began in the 1970s, its wider acceptance and use in the NF field was not until closer to the mid-1990s (Hughes & John, 1999; Thatcher & Lubar, 2009). Here too, advances in computer technology, whereby personal computers were able to process more data in less time, made way for advances in the clinical applications of NF. As a result, the 1990s brought forth a wider acceptance of qEEG technology in the NF community, for the purpose of guiding the development of protocols for NF (Johnstone & Gunkelman, 2003).

The use of normative referenced databases has been an accepted practice in the medical and scientific community, and the advantage it brings to NF is the comparison of an individual to a norm-referenced population, in terms of *z*-scores, to identify measures of aberrant EEG activity (Thatcher & Lubar, 2009). This brought forth the development of models, which focused more on the individualized and unique needs of the client rather than a one-size-fits-all model. Consequently, during the ensuing decade, the qNF model began taking hold in the NF industry.

Theoretical Foundations

Hughes and John (1999) discussed a decade-long history, inclusive of over 500 EEG- and qEEG-related reports, the findings of which indicate that cortical homeostatic systems underlie the regulation of the EEG power spectrum, that there is a stable characteristic in healthy humans (both for age and cross-culturally), and that the EEG/qEEG measures are sensitive to psychiatric disorders. These factors led to the application of Gaussian-derived normative data to the qEEG metrics such that these measures are independent of ethnic or cultural factors, which allow objective brain function assessment in humans of any background, origin, or age. As a result, Hughes and John assert when using artifact-free qEEG data, the probability of false positive findings are below that which would be expected by chance at a *p* value of .0025. Thus, changes in qEEG values would not be expected to occur by chance, nor is there a likelihood of a regression to the mean of qEEG derived *z*-scores because EEG measures, and the corresponding qEEG values, are not random. Since the work of Hughes and John, well over a decade ago, there have been numerous studies published in the literature further demonstrating the reliability and validity of qEEGs (Cannon et al., 2012; Corsi-Cabrera, Galindo-Vilchis, del-Río-Portilla, Arce, & Ramos-Loyo, 2007; Hammond, 2010; Thatcher, 2012; Thatcher & Lubar, 2009).

Normalization Model of qNF

A key focus of qNF is precisely tailoring the NF protocol, based on the individual EEG baseline and symptom status of the client, as determined by the qEEG, in conjunction with clinical history and presenting symptoms (Arns, Drinkenburg, & Kenemans, 2012). The primary premise of this approach is that localized cortical dysfunctions, or dysfunctional connectivity between localized cortical areas, correspond with a variety of mental disorders and presenting symptoms (Coben & Myers, 2010; Collura, 2010; Walker, 2010). When the EEG record of an individual is then compared to a normative database representing a sample of healthy individuals, the resulting outlier data (deviations of *z*-scores from the mean) help link clinical symptoms to brain dysregulation (Thatcher, 2013). For example, when an excess of higher beta frequencies are found, the typical associated symptoms include irritability, anxiety, and a lowered frustration/stress tolerance (Walker, 2010).

The conceptual framework of the stability of qEEG, as noted above, applies to qNF in that a stable EEG is not expected to change without any intervention, thus the changes seen as a result of qNF are not occurring by chance, but due to the training of the brainwaves as a result of the NF process (Thatcher, 2012). Therefore, in the example of excess beta frequencies, when the symptoms of anxiety and irritability are resolved after qNF, and the post qEEG shows the beta frequencies to be reduced (closer to the mean), it is assumed the improvement in symptoms is due to the change in the qEEG; thus representing improved electrocortical functioning (Arns et al., 2012; Walker, 2010). The term for this process, which has arisen secondary to qNF, is generally referred to as normalization of the qEEG, or simply normalization (Collura, 2008; Sürmeli & Ertem, 2009; Walker, 2010). Consequently, the concept of normalization is generally accepted to be when the *z*-scores of the qEEG move towards the mean (i.e., $z = 0$).

It is also important to note that the qNF model, with its reliance on the qEEG to guide the NF protocol, embraces the heterogeneity of qEEG patterns as discussed by Hammond (2010). In understanding that a particular clinical symptom presentation may be related to varied deviations in the qEEG, it

quickly becomes apparent that each NF protocol needs to be personalized to the client; as well as monitored and modified for maximum treatment effect (Sürmeli, Ertem, Eralp, & Kos, 2012). This, then, results in different electrophysiological presentations being treated differently, even if the overarching diagnosis is the same. This clinical approach is supported through multiple reports in the literature discussing how training the deviant *z*-scores towards the mean (i.e., normalize the qEEG) in qNF results in the greatest clinical benefit (Arns et al., 2012; Breteler, Arns, Peters, Giepmans, & Verhoeven, 2010; Collura, 2008; Sürmeli et al., 2012; Sürmeli & Ertem, 2009, 2010; Walker, 2009, 2010, 2011, 2012a).

In summary then, in the normalization model of qNF, when the qEEG data show excessive deviations of *z*-scores, and those deviations correspond to the clinical picture, the NF protocol is targeted to train the amplitude of the frequency in the direction of the mean (i.e., create more or less energy within a specified frequency band). In other words, if the qEEG indicates an excess of a beta frequency (i.e., high *z*-scores), and the presenting symptoms are expected with that pattern (i.e., anxiety), the protocol would be designed to decrease the amplitude of that beta frequency. Conversely, if the qEEG indicates a deficit of an alpha frequency, with corresponding symptoms, the protocol would be designed to increase the amplitude of the alpha frequency. The qNF model then, is simply traditional amplitude based NF using the qEEG to guide the protocol development for the NF sessions.

qNF in the Literature

Arns et al. (2012) conducted a well-designed open-label study of 21 attention deficit/hyperactivity disorder (ADHD) participants using the qNF model, incorporating pre-post outcome measures and qEEG data. The purpose was to investigate if the personalized medicine approach of qNF was more efficacious (as defined by effect size) for ADHD than the traditional theta/beta or slow cortical potential models, as reported in his meta-analysis 3 years earlier (Arns et al., 2009). The outcome measures incorporated were a self-report scale based on the Diagnostic and Statistical Manual-IV (APA, 2000) list of symptoms and the Beck Depression Inventory (Beck, Steer, & Garbin, 1988). The findings of the study were statistically significant improvements ($p \leq .003$) in both the attention (ATT) and hyperactivity (HI) subtypes of ADHD symptoms as well as depression symptoms. In this study, the mean number of sessions was 33.6 (*SD* 16.09), and the effect size was 1.8 for the ATT subtype, and 1.2 for the HI subtype; this was a substantial increase over the traditional model effect sizes of 1.0 (ATT) and 0.7 (HI) respectively. This suggests the qNF model is more efficacious (i.e., effect size of clinical improvements) than the older traditional theta/beta or slow cortical potential models. Furthermore, in this study, non-*z*-score EEG microvolt data was reported for only nine frontal and central region electrode sites, and three frequency bands, on a pre-post basis. Additionally, the protocols employed are described as a selection of one of five standard protocols, with qEEG informed modifications. The limitations of this study were few but include a lack of a control group, a fairly small sample size, and that some outcome measures were collected on only a sub-group of participants (thus reducing net sample size). Moreover the pre-post qEEG data analysis was limited in scope.

Koberda, Hillier, Jones, Moses, and Koberda (2012) reported on the use of qNF in a clinical setting of a neurology private practice. All 25 participants were treated with at least 20 sessions of a single-channel traditional NF protocol, which was guided by qEEG data and symptoms, with a goal to improve symptoms and normalize the qEEG. Clinical improvement was measured by subjective reports from the participants in the categories of not sure (*n* = 4), mild if any (*n* = 1), mild improvement (*n* = 3), improved/improvement (*n* = 13), much improved (*n* = 2), and major improvement (*n* = 2); with a total of 84% (*n* = 21) reporting some degree of improvement. The qEEG change was reported as a clinical subjective estimation (based on visual inspection of the qEEG topographic images) of change in the targeted frequencies, in the categories of no major change/no improvement (*n* = 6), mild improvement (*n* = 9), improvement (*n* = 8), or marked improvement (*n* = 1), and one participant not interested in post-qEEG; with a total of 75% (*n* = 18) showing estimation of improvement in the qEEG. Of note with this study was the heterogeneous collection of symptoms treated which included ADD/ADHD, anxiety, autism spectrum, behavior symptoms, cognitive symptoms, depression, fibromyalgia, headaches, major traumatic brain injury, pain, seizures, stroke, and tremor, in varying degrees of comorbidity per case. However, the primary limitation of this study was the loosely defined subjective estimations of improvement for both clinical symptoms and qEEG outcomes.

In their randomized control study, Breteler et al. (2010) evaluated qNF as an additional treatment with a linguistic education program. From the total

sample of 19, ten participants were in the NF group and nine were in the control group. Individual NF protocols were based on qEEG results and four rules, with a generally (though not strictly adhered to) 1.5 *z*-score cutoff; which resulted in the use of eight personalized protocols. Improvement was determined by results of outcome measures of various reading and spelling tests, as well as computerized neuropsychological tests. Paired *t*-tests were applied for analysis of the difference values between the pre- and post-scores. The reported findings showed the NF group improved spelling scores with a very large Cohen's *d* effect size of 3; however no improvement in reading or neuropsychological scores. The qEEG data was reported, in terms of pre-post *z*-scores, on an individual basis (i.e., per each case) for a limited number of targeted sites, frequencies, and coherence pairs; with most showing statistically significant normalization.

In a retrospective study using archived clinical case files, Huang-Storms, Bodenhamer-Davis, Davis, and Dunn (2006) evaluated the efficacy of qNF for 20 adopted children with a history of abuse who also had behavioral, emotional, social, and cognitive problems. The children all received 30 sessions of NF (from a private practice setting) with qNF protocols, which were individualized based on the qEEG profiles. Data from the files of 20 participants were collected to include pre- and post-scores for outcome measures from a behavioral rating scale (Child Behavior Checklist; CBCL; Achenbach, 1991), and a computerized performance test (Test of Variables of Attention; TOVA; Greenberg, 1987). The findings for the CBCL were statistically significant ($p < .05$) for most scales and the TOVA findings were statistically significant ($p < .05$) for three scales, thus demonstrating qNF efficacy for the participants in this study. There was no quantified qEEG reported; only observations of general trends in the pretreatment qEEG findings, such as excess slow waves in frontal and/or central areas.

Two researchers are most notable for several published studies evaluating the qNF model, that being Walker and then Sürmeli and colleagues. Each has a particular consistent style in structuring their studies; and both have reported on the use of qNF with a wide variety of clinical conditions. Therefore their works will be reviewed in a grouping format and encompass a timeframe from 2002 to 2015.

Walker has reported on mild closed head injury (Walker, Norman, & Weber, 2002), anxiety associated with posttraumatic stress (Walker, 2009), migraine headaches (Walker, 2011), enuresis (Walker, 2012a), dysgraphia (Walker, 2012b), and anger control issues (Walker, 2013). His qNF protocol development centers on tailoring the protocol to the individual clinical and qEEG data, with some restrictions of either increasing or decreasing the amplitude of certain frequency ranges. For example, the protocols for the anger outburst study restricted the target range to decrease only excess *z*-scores of beta frequencies, combined with decreasing excess *z*-scores of 1–10 Hz frequencies. For the migraine and anxiety/posttraumatic stress studies both were based on individual excess *z*-score values found in the beta frequencies in a range of 21–30 Hz (to decrease) with an addition of increasing 10 Hz. For all studies the electrode sites selected were ones where the deviant *z*-scores in the targeted range were found. In the mild closed head injury article, the protocol was different because the study was meant to evaluate coherence training with a stated goal to normalize coherence *z*-scores. Thus, the most deviant coherence pair was selected first (for five sessions each) and, then progressed to lesser deviant pairs until the symptoms resolved or until 40 sessions were completed. None of Walker's reports declare a particular research design; still all involve pretest-posttest comparisons of various clinical outcome measures and yield benefits from qNF. The outcome measures that Walker typically employs are primarily Likert or percentage-based self-reports, except in the anger control study where the DeFoore (2002) Anger Scale self-report instrument was used to track the number of anger outbursts. However, while all protocols are personalized, and based on qEEG findings, there are no quantified pre-post qEEG data used as an outcome measure, and none are reported in his studies. Overall the findings of all of Walker's studies show improvements in the targeted clinical conditions. In the mild closed head injury study, with $n = 26$, 84% of the participants reported greater than 50% improvement in symptoms. For the anxiety/post-traumatic stress article, with $n = 19$, all improved on a Likert scale (1–10; 10 being worst) from an average rating of 6 before NF treatment to an average rating of 1 after NF treatment. With the migraine study, where 46 NF participants were compared to 25 patients who chose to remain on medication, in the NF group 54% had complete remission of headaches, 39% had a greater than 50% reduction, and 4% experienced less than 50% reduction in migraines; while in the medication

group, 84% had no change in migraines and only 8% had a greater than 50% reduction in headaches. In three of his more recent studies, for the enuresis (n = 11), dysgraphia (n = 24), and anger control research (n = 46), Walker reported all findings for all participants (in all three studies) showed statistically significant improvement at $p < .001$.

Sürmeli and colleagues reported on Down syndrome (Sürmeli & Ertem, 2007), personality disorders (Sürmeli & Ertem, 2009), intellectual disability (mental retardation; Sürmeli & Ertem, 2010), obsessive-compulsive disorder (Sürmeli & Ertem, 2011), schizophrenia (Sürmeli et al., 2012), and dementia (Sürmeli et al., 2015). Notable in this collection of work are conditions previously not known to respond to NF, such as personality disorders, intellectual disability, Down syndrome, and schizophrenia. All of these studies report the qNF protocol as being individualized, as informed by a combination of the qEEG findings and clinical judgment; with an overall goal to normalize the qEEG patterns. Notable for most of Sürmeli et al. studies are a high number of sessions reported for the cases; ranging from an average of 45 to an average of 120 sessions. No particular research design is declared in the Sürmeli et al. studies, but here too, comparisons of pretest-posttest outcome measures are reported, indicating qNF brings about improvements in outcome measures. These studies generally make use of clinical assessment instruments designed to measure the symptoms targeted for the qNF treatment. For example, the schizophrenia study employed the Positive and Negative Syndrome Scale (PANSS; Kay, Fiszbein, & Opler, 1987), for the obsessive compulsive disorder research they incorporated the Yale-Brown Obsessive-Compulsive Scale (Y-BOCS; Goodman et al., 1989), and for the dementia study the Mini Mental Status Examination (MMSE; Folstein, Folstein, & McHugh, 1975) was the primary outcome measure. For many studies, the computerized performance TOVA was used. Yet, as with Walker's work, in spite of all protocols being individually qEEG-guided, qEEG data is infrequently used or reported as an outcome measure; typically, only observations of general trends of the changes in qEEGs are discussed. However, the targeted clinical symptoms, as measured by the clinical assessments, were reported as having statistically significant improvement in all studies. For the personality disorder study, with n = 13, 12 were significantly improved on all outcome measures; with the Symptom Assessment-45 Questionnaire (Riverside Publishing; Rolling Meadows, IL) at p = .002, the Minnesota Multiphasic Personality Inventory (MMPI; University of Minnesota Press; Minneapolis, MN) Psychopathy scale at p = .000, and the TOVA at $p < .05$ on the visual and auditory impulsivity scales. With the article focusing on participants with intellectual disability, including n = 23, for 19 there was improvement on the Wechsler Intelligence Scale for Children-Revised (Wechsler, 1974; Verbal scale, p = .034; Performance scale, p = .000; Total scale, p = .000) and the TOVA (Auditory and Visual Omission scale, $p < .02$; Auditory and Visual Commission scale, $p < .03$; Auditory and Visual Response Time Variability scale, $p < .03$). In the study evaluating participants with Down syndrome, while the outcome measure was not a commercialized assessment, they did develop a questionnaire formulated to evaluate symptoms associated with Down syndrome. The findings were that all participants in the study (n = 7) showed improvement at $p < .02$ on all questionnaire scales. With qNF for obsessive compulsive disorder, with n = 36, 33 showed improvement on the Y-BOCS (Obsession subscale, Compulsion subscale, and Total score all $p < .01$). In the schizophrenia study, with n = 51, 47 out of 48 patients who completed pre- and post-PANSS improved on all scales at $p < .01$. Moreover of the 33 who were able to complete the MMPI, findings showed significant improvements ($p < .01$) on the scales of Schizophrenia, Paranoia, Psychopathic Deviation, and Depression. Finally, in the dementia study, with n = 20, all participants' MMSE scores improved with an increase of six points on average ($p < .01$), regardless of dementia type (Alzheimer's disease or Vascular dementia); also qEEG improvements were reported as theta activity decreasing overall ($p < .01$) and a decrease in interhemispheric coherence ($p < .01$).

Conclusion

In summary, studies evaluating qNF typically focus on a wide variety of clinical symptoms and/or mental health diagnoses, and frequently have relatively small sample sizes. With few exceptions, literature presented on qNF comes from research conducted in clinical settings. As a result, given the ethical constraints of conducting research in clinical settings (e.g., asking clients to accept sham or placebo conditions; Gevensleben et al., 2012) few are blinded and/or randomized-controlled studies. Moreover, the NF protocols employed typically are tailored to the individual, informed by qEEG, with a goal to normalize the qEEG. The overwhelming majority of clinical qNF research employs retrospective pre-post comparison research designs and the outcome measures used are tied to the

symptoms of investigation. Yet, few report pre-post qEEG metrics, and only three (Arns et al., 2012; Breteler et al., 2010; Sürmeli et al., 2015) incorporated statistical analysis of qEEG metrics as an outcome measure (and that was to a limited degree). More so, none report a measure of overall normalization of the qEEG. Therefore, in the qNF literature, it has become an accepted practice to define efficacy in terms of measuring symptom improvement with various clinical assessments (both commercially and informally developed). Nevertheless, clearly there is a gap in the reporting of qEEG *z*-score mean data in the present qNF research. Therefore, it is important for future qNF studies to incorporate qEEG metrics as outcome measures. Methodologies developed by Krigbaum and Wigton (2015) in a single-subject design, and Wigton and Krigbaum (2015) with group means data, while implemented with the 19-channel *z*-score NF modality, are similarly applicable to qNF studies data as a means of measuring overall normalization of the qEEG.

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