QEEG Biomarkers: Assessment and Selection of Special Operators, and Improving Individual Performance

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Abstract. Future military special operator selection and education programs will take advantage of state-of-the-art neuroimaging and normative statistical tools in the creation of a customized database of EEG patterns gathered from top performing specialists over their careers. Such a quantitative EEG Normative Database (qEND) will function as the benchmark for screening, assessment, selection and even training of targeted individuals required to work effectively as operators under extreme stresses and for extended periods. This assumption implies that an improved warfighter selection and training pedagogy will embrace the concept of a "model" brain activity pattern (BAP) that represents a warfighter at peak potential and in a highly focused and resilient state of mind. It also implies that this model BAP can be used to: 1) identify biomarkers of positive traits in candidates for specialized training programs, and 2) reduce stress and improve sleep and training performance of program selectees using guided EEG neurofeedback to maintain an optimal BAP. One such statistical qEND (NeuroGuide) is used clinically in the assessment and diagnosis of EEG imbalances specifically related to neurological and behavioral disorders, as well as for guiding individual brain pattern changes through the use of neurofeedback training (NT).

To evaluate qEEG for monitoring an individual's BAP changes and potentially improving mood and work performance, two military specialists with leadership experience underwent a program of pre- and post-EEG recordings and 20 neurofeedback training (NT) sessions. Here, the NeuroGuide database was used to determine how each participant's BAP differed from the age-matched group norms, and it was also used during the NT process to inform the software of the differences from the norms at each of the 4 training sites used to adjust the trainees EEG towards the direction of "normal".

Changes from the NT program were assessed pre- and post-intervention using seven neuropsychological assessments of mood, anxiety, sleep, work performance and life satisfaction. In addition, one subject had a series of blood draws taken over the course of the NT program to evaluate changes in his plasma Cortisol; a reliable biomarker of stress level. Both subjects reported reduced levels of anxiety, impulsivity and anger, and improved mood and life satisfaction after the 20-session NT intervention.

Keywords: Assessment and Selection, Biomarkers, Quantitative EEG, Neurofeedback, Normative Statistics, Training Technologies, Training Policy.

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1 Introduction

Adult electroencephalography (EEG) patterns are individually stable with predictable age-related patterns of change in amplitude, coherence and phase measures of resting brain wave activity (1, 2). This predictability allows the use of comparative statistics in the evaluation of an individual's BAP and its comparison against an age-matched norm of over four-thousand independent EEG measures (3). What follows from this statistical measurement capability is the development of a normative database of EEG features gathered from a large number of "normal individuals". Such a database makes it possible to quantify the statistical differences in the brain waves of one person as compared to their age-matched group averages (4). Several EEG normative database products exist today for assessing individual brain imbalances (NX Link), prescribing psycho-active medications (Reference EEG), and as a neurofeedback training modality (NeuroGuide) primarily for individuals coping with anxiety, stress, insomnia, depression, addiction, obsessive compulsive disorders, cognitive difficulties and behavioral problems.

This paper attempts to describe an analytical approach known as the quantitative EEG Normative Database (qEND) and its use in assessing brain functions and guiding neurofeedback training (NT) protocols that may be used to reduce stress and enhance mental and physical resilience in the warfighter. There is a scientific basis for use of NT as a means to help combatants maintain peak levels of performance under stress, and a strategy exists for the rapid development, validation and deployment of enhanced neurotechnologies specifically targeting rapid expert level knowledge and skills acquisition. The use of EEG neurofeedback to normalize brain wave activity has consistently been shown to improve sleep and reduce anxiety and it is widely available all over the world today (5, 6, 7).

2 The Plastic Brain

One thing we can all agree upon is that chronic stress will change your brain, particularly in areas associated with memory, sleep and emotional regulation (8). Long-term stress changes hormone levels, which in turn modulate neurotransmitter production and uptake; driving lasting changes in the EEG (9). Over time, imbalanced EEG patterns reorganize in the brain's key system-level networks, ultimately establishing a new "yet stable" brain activity pattern (BAP) (10). With reinforcement, this imbalanced BAP can stabilize through a resonant process that perpetuates the thoughts and feelings associated with prolonged exposure to high stress; like anxiety, rumination, panic, depression, and contemplating suicide. Ultimately, this highly imbalanced BAP becomes the norm and repetitive patterns of negative or self-effacing behaviors develop and become linked to this now-stable imbalanced brain state (11). NT provides a rapid way to use the EEG to redirect an imbalanced BAP back into a more normal pattern (12,13) and this reorganizing to a target capability is why the method has direct application to specialized training programs with rigorous selection and acceptance criteria and high costs of operation.

Neural plasticity is the term associated with the brain's ability to reorganize and recover lost functions after injury or illness, and it means that when one part of the brain is damaged or excessively imbalanced, after some re-connecting takes place, the brain's key systems reorganize to a new state of balance where some (or all) of the impaired cognitive or sensorimotor abilities re-emerge. (e.g. a patient regaining the ability to speak or to use his arms and legs again after a stroke). Thus, neural plasticity provides the means for accessing the brain's wiring and directly modulating it to reorganize the activity of its main cognitive and emotional systems to a new state of balance. Even without damage to the brain, it is possible with NT to induce neural plasticity through a process known as operant conditioning, where a stimulus is timed to a particular measure(s) of the participant's BAP and fed back to either reward (reinforce) or punish (extinguish) that particular pattern of brain activity.[14] Several EEG and fMRI studies have reported the use of NT protocols with an ever widening range of notable positive effects correlated with attention, memory, cognitive function and operational performance (15, 16).

3 The Quantitative EEG Normative Database (qEND)

There are a small number of qEND products used clinically for the assessment and treatment of CNS disorders, depression and stress related conditions. Some of these products provide condition-specific medication treatment plans (e.g., Reference EEG), and others are used in assessment, diagnosis and delivery of NT therapies (e.g., NXLink and NeuroGuide). These neuroimaging systems provide an output in the form of color coded maps and graphs that indicate where and by how much the first and second order amplitude and frequency-based features of the EEG differ from an age-matched normal group average; and in which direction the imbalances occur. In clinical care, this information is correlated with other neuropsychological and behavioral assessments and evaluations of the patient, and a treatment plan including neuro-cognitive and cognitive-behavioral strategies is developed to reorganize the patient's BAP and help them develop a positive "way of thinking".

4 Reorganizing Brain Connections: Z-Score Neurofeedback

From a systems perspective, when the brain activity of an individual is out of balance to the point where cognitive and behavioral problems exist, it makes sense to reorganize the connections in key executive and emotional networks to establish a more "normal" BAP. In the most advanced systems, this process uses Z-score guided neurofeedback training (zNT) where real time brain activity is measured, compared to an age-matched norm, and depending on the differences from normal, used to control how a movie is presented to the subject to either reward or punish a particular pattern of activity. For instance, if the delta and theta EEG activity in the frontal lobes of a trainee were to remain below normal, than the picture and sound would be reduced in

clarity and volume as the movie played. Then, when the brain activity moved more towards normal by increasing in delta, theta and even alpha power, the picture and sounds would play more clearly, thereby rewarding the change in his BAP. By repeating this zNT process over several weeks, the trainee's EEG can be guided into a more balanced state with respect to the normal database population used, and in this case, behaviors like impulsivity, anger, anxiety and rumination lessen in severity while mood and cognitive function improve over time (17).

5 Future Assessment, Selection and Neurotraining Pedagogy

In the clinical setting, Z-score guided NT uses software that contains an instantaneous version of the qEND containing all the normalized EEG measures, so a site-specific training protocol can be applied to target the imbalanced brain waves of the patient and move them (through temporal and frequency neuromodulation) in a direction understood to be more normal "or desired" than their current BAP. In practice, it is the average value taken from the "normal population" that becomes the target of the neurofeedback. Then, with repetition, the individual's brain waves can be influenced from an existing "imbalanced" state towards the pre-determined qEND standard BAP. Ever growing research continues to demonstrate that these directed changes in brain activity toward a target pattern of activity are associated with improved task performance, cognitive agility and perceptive functioning, all necessary to achieve persistent resilience to highly stressful situations (18, 19).

With the ability to re-connect and re-organize a trainee's brain waves towards a specific target BAP, it becomes possible to design a qEND from a population of highly experienced and trained mission specialists and then to use that qEND to help select candidates and train them toward a BAP more consistent with the target group normal. With a specifically focused "BAP++ Gold Standard" representing a large group of expert level operators (~500) throughout their career, it may be possible to identify key features of the BAP++ that correlate with reduced stress, increased cognitive agility and elevated motivation and resilience under demanding circumstances. If such a qEND is constructed, then it also becomes possible to design zNT protocols customized for each candidate selected for a specialized program (e.g., Engineer, Pilot, or Operator). In each case, key attributes of the BAP++ would be used to guide the selected trainee's EEG towards a pattern to help them better achieve their training objectives with lower levels of anxiety and negative responses to stress; ultimately leading to higher performance ratings by assessment specialists.

6 Case Study: Research Methods

Two individuals with military leadership experience signed informed consent forms and volunteered to participate in a 20-session Z-score neurofeedback training (zNT) study to evaluate the effects on their BAP as compared to the age-matched means in

the NeuroGuide qEND. These individuals were chosen because of their relevant backgrounds and experience as mission specialists. Subject 1 is a USMC Captain (Res.) with 10+ years in active and reserve service; including deployments in Afghanistan and Haiti and 2 combat tours in Iraq. Subject 2 is a US Army Sergeant Major (Ret.) with over 18 years of service in Special Forces assessment and training.

Immediately prior to and after a 20-session zNT program, 32-channel linked-ear referenced EEG recordings, plus bipolar vertical and horizontal eye, heart and neck muscle channels were recorded during 20-minute eyes-closed resting and 10-minute eyes-open resting conditions. These data were manually reviewed and edited and 2-minutes of non-contaminated EEG data were selected from each subject's EEG for use in the NeuroGuide qEND. The standard 19 channels of the International 10-20 System were submitted for each subject into the NeuroGuide database to produce the Z-scored maps and connectivity graphs displayed in Figures 1 and 2. In each figure, the summary maps on the left are from the recordings made before the intervention and those on the right provide the results immediately after the 20-session zNT trial. The qEND compares the temporal and frequency components of the EEG from all 19 sensor sites (e.g., 1st and 2nd order amplitude and frequency measures from all possible combinations of the 19 sensors) between each subject and the group of age-matched members included in the QEEG database. From those data, it computes the magnitude of the spatial-frequency EEG differences and displays the results in Z-scores, where 1 Z-score is the equivalent of 1 Standard Deviation from the mean for each of the more than 4000 EEG measures computed.

In qEND mapping, the frequency components of the EEG are separated using the FFT, averaged, and displayed in narrow bands: delta (1 – 4 Hz), theta (5 – 8 Hz), alpha (9 – 12 Hz), beta 13- 22 Hz) and high beta (23 – 40 Hz). The magnitude of the difference between a particular EEG measure and the group mean is represented by color coded Z-score maps and graphs, where activity that is -3 std. dev. below normal is shown as Dark Gray and activity +3 std. dev. above normal is Light Gray in color. Abnormal changes in the coherence and phase activity between sensor pairs is indicated by a reduction or excess (Dark Gray lines) as compared to normal, where the thickness of the line indicates the magnitude of the imbalance from +/- 1.96 to 3.09 std. dev. from the mean.

The pilot study evaluated changes in the qEND maps and connectivity graphs (Figs. 1 and 2) from before and after the zNT intervention. Self-reported assessments of anxiety, sleep, depression, job performance and life satisfaction were used to track emotional and behavioral perception. In addition the study examined changes in plasma Cortisol to assess endocrine system stress. To accomplish this, Subject 2 had serial blood draws done throughout his 2.5 week evaluation period: Pre (3 draws), Mid (2 draws) and End (2 draws) to evaluate his corresponding changes in Cortisol level and infer the results to his stress level changes. All seven blood draws were done in the A.M. within 30-minutes each other. Overall, Subject 2's average Cortisol levels went from 14.07 down to 11.45 mcg/dl a reduction of 2.62 mcg/dl (43% from the baseline average, full range = 6.1 mcg/dl).

7 Assessing Neurofeedback Training Results

Thirty-six-channel EEG recordings were made pre and post-intervention from two veterans with leadership experience to track changes in their BAP coincident with a program of 20 zNT sessions (Figures 1 and 2). Their raw EEG signals were reviewed for quality and at least 2-minutes of eyes-open and eyes-closed resting data from throughout the recordings were input to the NeuroGuide qEND to measure individual differences in BAP between each subject and their age-matched group norms.

To design a 4-channel zNT protocol specific to each subject, the results of the behavioral assessments were combined with the qEND results to inform the choice of sites for training. During zNT sessions, an elastic cap was placed on the head that carried the 4 EEG, plus reference and ground sensors, and the wires were attached to the system while the trainee sat comfortably for 30-minutes watching a DVD of their choice. As they watched and listened the trainee's brain waves were measured and used to control how the images of the movie played. The choice of movie was not important, as long as it held the subject's attention.

Figures 1 and 2 each display a pair of eyes-closed EEG Power Summary Reports generated from the Subjects immediately before (Left Report) and after (Right Report) 20 zNT sessions. Visual comparison of the pre-NT and post-NT topographic Power maps (Left vs. Right) details the spatial-frequency differences coincident with the 20 session zNT intervention. Neither of the subjects used medication before or during the evaluation periods and no traumatic events were reported. For Subject 1 (Fig. 1) differences in the Pre vs. Post-intervention Reports were primarily visible in the delta and theta bands where bilateral-frontal and temporal excesses had almost completely resolved, while at the same time the prior reduction of power in the occipital lobes had also normalized (i.e., resolved areas show as Grey in post intervention reports). Subject 2's reports (Fig. 2) indicates a different pattern of change in BAP, where in this case, the delta band shows normalization of only the left occipital lobe imbalance while the right lobe remained in a reduced power state (Note: this may be an indicator of peak performance). The higher frequency bands of beta and high-beta show the largest changes towards normal in Subject 2's BAP, primarily through the reduction of excess power in the right dorsal-medial frontal and insular cortices, all of which play an important role in prosody, empathy, socialization and approach / avoidance behaviors.

Both Subjects conveyed that they experienced improvements in anxiety, rumination, anger, frustration and job performance after 20 zNT sessions. For instance, in the overall assessment, Subject 1's report of anxiety level lowered from an initial score of 49 down to a post-intervention score of 29, a change of 41% over a period of 15 weeks. To evaluate the feasibility of a more rapid training program, Subject 2 carried out two zNT sessions a day and completed the training in 2.5 weeks. He reported a positive change in 5 out of 7 assessments: Insomnia, Depression, Life Satisfaction, and Daytime Function Positive and Negative attributes. In his case, there were no changes reported for the Anxiety or Sleep Quality assessments.

Subject 2 also volunteered to have serial blood draws done to evaluate his morning Cortisol volume changes (measured in mcg/dl). Plasma Cortisol is a biomarker

proportionally related to stress, and provides a quantitative and independent source to monitor changes over the course of the intervention.[20,21] Seven plasma Cortisol measurements were taken at key points over the course of the 2.5 week study. Initial blood draws were taken on the three days prior to the beginning of training to establish a baseline average, two blood draws after the 9th and 11th sessions gave the midpoint average, and two final draws after the 18th and 20th sessions gave the endpoint average. The results indicated a First Half increase in Cortisol from the early to midperiod of 1.28 mcg/dl (a rise of +21%) and a decrease in Cortisol of -3.9 mcg/dl over the Second Half of the intervention (a reduction of 64%). Overall, the average reduction in Cortisol level from beginning to end was 2.6 mcg/dl; a drop of 43% from the baseline. These data are consistent with the subject's reports of feeling less stressed and anxious, and not being so easily angered. This sentiment was also reflected in a relationship assessments filled out by the subject's wife.

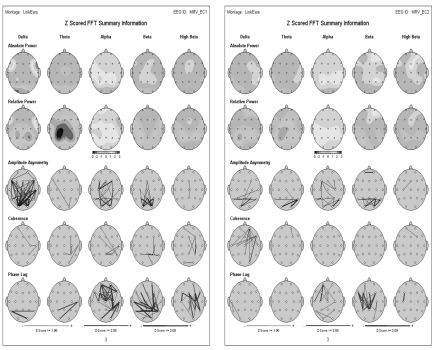

Fig. 1. 33 year old U.S. Marine Captain (Reserve): No diagnosis; high stress, obsessive about home safety. The 2 reports above indicate differences in BAP before (Left) and after 20 zNT sessions (Right) done over a period of 15 weeks. Subject reported lower levels of stress, fewer safety related concerns and improved mood and job satisfaction.

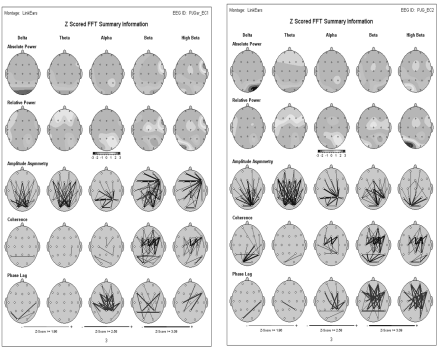

Fig. 2. 44 year old Retired U.S. Army Sgt. Major: No diagnosis; high stress, easily frustrated and angered. The 2 reports above indicate differences in BAP before (left) and after 20 zNT sessions (Right) done over a period of 2.5 weeks. Subject reported less outbursts; lower frustration level and generally improved mood and work performance.

8 Discussion

As we gain a rapidly expanding glimpse into the working brain through a plethora of modern neuroimaging and cognitive-behavioral research tools, we stand at a pinnacle, where brain-machine technologies can externally influence the dynamics and balance of that interconnected system of nervous tissue which constrains the human mind. Even as we stand at the edge, with our minimal understanding of how cells coordinate through waves of chemical and electrical interactions to process information, make decisions and think abstractly, we have made the tools! We are now able and willing to imply meaning to scant measures of mind informing us about the thoughts, moods

and feelings of that person living inside the calvarium…and in good faith we seek to improve the mind within…to make it better when emotions are askew or when one seeks a higher plane of existence or improved levels of performance.

With the infancy of our field beginning to wane, we stand on shaky legs to take those first few steps. Thus we must come together as a community to prevent missteps as we begin in earnest to test the limits of our understanding of mind and machine and develop these impressive new tools in the light of day…not in hiding for fear of public debate. Today it is possible to assess BAP imbalances in one person as compared to a known group of people, and to use the knowledge of these imbalances to redirect specific EEG activity and reorganize the connectivity within that person's brain. This process uses concepts of operant and classical conditioning, targeted neuromodulation and neuroplasticity. There are currently more than 10,000 professional providers of such NT services around the globe with limited regulation and oversight; and only a hand full of government sponsored studies. Yet the adoption of NT by mental and behavioral health professionals and use by consumers has never been at a faster pace. Many NT methods abound supporting a wide range of backgrounds and experience among the providers of clinical services.

Plischke et al.,(22) acknowledge the rapid expansion of neurotechnology businesses and growing exploitation of novice and uninformed users of games, toys, education aides and clinical services. They argue that the use of some neurotechnologies may come with the potential to do harm and call out for regulatory and peer oversight of the brain computer interface industry along with the establishment of a Clinical Field of Practice at the university level. Canli et al., (23) go on to say that it is the responsibility of the entire neuroscience research community to be open about all their endeavors with interfacing neurotechnologies, particularly those related to National Security, and they expect active peer-review and oversight by the researchers themselves, as well as administrators in the governmental funding agencies.

9 Conclusion

Brain waves are changeable towards a predetermined normal pattern of activity using Z-score neurofeedback training and undergoing this process creates a benefit to trainees by lowering their anxiety and stress and helping them better manage their daily behaviors. The zNT approach was successful in two veterans, each with different but relevant backgrounds and military experience. For each subject, the pattern of brain wave activity was different, but the general outcomes from the zNT intervention were the same; reduced stress and improved mood and performance.

Each person handles stress differently, and that difference can be identified in their BAP maps and is likely an inherited trait. Gianotti et al., (24) have identified genetic markers of EEG genotype that link to specific behaviors and they state the purpose of their work saying "it is to identify possible neural mechanisms by which the polymorphism may contribute to stable individual differences. Such neural baseline activation measures are highly heritable and stable overtime, thus an ideal endophenotype

candidate to explain how genes may influence behavior via individual differences in neural function."

Interfacing neurotechnologies are here to stay and the use of normative BAP methods provides the most logical way forward to investigate the use of brain computer systems as a means to reduce stress and improve trainee mental and emotional performance. The question still remains, however, if a customized qEND composed of high performing experts in specialized military domains can be constructed, or if it even should be constructed…but the potential remains, and the feasibility of the success of such a project is very high. Additionally, relevant to military training, it appears possible to compress NT into a shortened time span and still see positive results in stress, mood, life satisfaction and job performance on par with the longer delivery period…borne out in both self-assessments and Cortisol measures. The inexpensive and portable nature of the qEEG method and shortened time frame of a zNT training component makes it feasible as an integrated segment that can be inserted within almost any existing special missions training program.

In the right environment with SMEs experienced in training Special Forces a structured assessment, selection, and training framework combining neurocognitive, metacognitive and cognitive-behavioral methodologies may be more fully investigated. Independently or in combination the use of a BAP++ qEND along with a concomitant real time zNT training methodology provides an approach capable of improving military assessment and training technologies by reducing stress and enhancing cognitive and emotional agility of trainees so they can best process and absorb the tactics and information presented during training.

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