Real-Time EEG Z-Score Training – Realities and Prospects

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This paper discusses the realities and possibilities raised by the implementation of "real-time Z Score Training" as an emerging neurofeedaback paradigm. Such an approach makes it possible to compute, view, and process Z Scores as a fundamental element of a neurofeedback system. Such an approach is bound to elevate questions and concerns, as well as enthusiasm. We aim to present factual information in a systematic manner, and to help guide practitioners who wish to evaluate and possibly pursue this avenue.

The Z score design is a front-to-back design, from the properties of the amplifiers all the way through the digital processing and feedback designed as a system, and tuned to work correctly. It is the result of years of work, and it has not been rushed into the marketplace. It is, as introduced, a mature and well thought-out method.

The Z Scores are based on Applied Neuroscience, Inc. NeuroGuide data base, and computed using the same code that exists in the NeuroGuide software. It includes over 600 people, ages 2 to 82. This is a database and system that is FDA registered with a 510(K) for the intended use. Both BrainMaster and NeuroGuide have their proper 510(K)'s and this is a legitimate clinical system. The Z scores you get in real time from this system are the same ones you get post-hoc from NeuroGuide. So this is a well integrated and thought-through system.

The delay is negligible. The Z scores are computed well within the time period of each computation epoch, which is currently 33 milliseconds. The maximal delay in the overall system is no greater than this. It is simple to tune this to compute at any speed deemed necessary. The computational demand of the Z scores adds only about 5% CPU load to the BrainMaster software, which currently runs typically from 1% to 10% of the CPU, depending on the type of PC. This is a very lean, efficient system.

BrainMaster has validated their own coherence scores to match the NeuroGuide coherences, seen on www.brainm.com/software/2.5/BMrNGCoherence.pdf So not only do users get the real-time Z score values, they can know that there is a documented connection between the two coherence methods implemented in the instrument and software. Significantly, two separate (and collaborating) developers are providing concordant measures, and documenting the agreement.

We have observed the 10% variation seen in the higher frequency measurements. The difference is likely because BrainMaster is using a form of "complex demodulation" while NeuroGuide is using FFT's. In fact, NeuroGuide will also offer complex demodulation in the future, which may in fact line up the calculations even better.

The BrainMaster coherence calculation itself comes in two forms, one is a similarity measure, the other is a "pure" coherence. The graph cited shows the "pure" coherence. We calculate both types, plus phase, inside our digital filters using a proprietary "quadrature" method, some of which is published in the IEEE journal. More recently, people have tried to emulate these, and other methods, in various other software, and there have seen some scary errors and misconceptions "out there". We have published and shared sufficient information to provide confidence that our method works, and that it is faster than conventional methods. However, the proclivity to try to copy (incorrectly) our work motivates us to be more circumspect than we might have been 10 years ago. The popular "do-it-yourself" mode of development seems to do a disservice to the community at large, and is an affront to those with decades of experience in this area.

Z Score training is entirely new way to work. Imagine a protocol that simply says "normalize coherence in all bands". The "thresholding" is handled by the trainee's age, eyes-open or closed condition, and the sensor sites used. We can design many protocols simply based on normalizing, or increasing, or decreasing, any quantities we like (there are 72 Z scores available). It will take some getting used to, but it is surely an empirically based, and sound method. Theta/beta ratio training is just one of the examples built into our latest release.

Regarding the problems with ratio-based training, those that relate to numerator and denominator problems do not exist in this method. We are not computing metrics that can "blow up" when signals are small. Indeed, using Z scores provides a smooth normalization, that will, at the extremes, only to to 4 or 5 sigma. So this method deserves a new look, relative to ratio training (there are 10 such ratios in the software)

We do not seeing this all as obviating the need for a QEEG where a need exists, but Z score training is an efficient and valid way of getting the same information in a real-time form, for appropriate needs.

We personally do not see this as affecting the current role of the QEEG in any significant way. It does not replace the capabilities or information provided by a QEEG. What it provides is an additional, consistent, way of seeing what is happening. It also provides 1/30 second resolution, instead of 1-minute resolution.

We are looking at the instantaneous value of a normative variable, and interpreting it in terms of the population mean. So we have not yet really articulated the meaning of "If this were your average value, then you would be in X% of the population". We assume, and find empirically, that using Z scores as training variables is useful. How we interpret the scores and build protocols is new territory.

But, since it does provide instantaneous measures of relative and absolute amplitude, coherence, asymmetry, phase, and ratios, it should be of value during training, so that you have a multidimensional handle on the EEG criteria you are training. I agree, when doing any 2-channel work in particular, the "way to go" seems to be to acquire both channels, then perform metrics and derived computations, to emulate bipolar as well as more complex protocol arrangements

More significantly, it provides an entirely new conceptual framework for designing protocols. It amplifies the value of the QEEG, and the QEEG significantly informs the use of Z score training. Importantly, Z scores greatly simplify the process of biofeedback by reducing disparate measures such as power, coherence, phase delays and ratios to a single metric, i.e., the metric of the Z score. One no longer has to wonder whether to increase or decrease coherence or phase, etc. in a give electrode pair for a particular age or frequency, because the Z score simplifies this process by removing the guess work.

We think these advancements are here to stay.

There is a "Heisenberg" issue that enters out thinking in this field, relative to real-time systems design. This relates to making tradeoffs between response time and specificity. This is one aspect of the "art" in the design. While we describe the underlying algorithms, and the results, other elements are proprietary. Much of this relates to tuning and timing, and how you trade "time for space" or "response time for selectivity", etc. We use algorithms that push the tradeoffs right to the edge, and we also use tricks that avoid certain steps, such as the "rectify and measure the peak" step that our system avoids, thus saving 1/2 to 1 cycle of response time. It's a lot like saying we use a "dual overhead cam with advance timing compensation and a hemispherical head" so that you understand the benefits and capabilities, without revealing all the design details. We will address these and other issues in future publications. Our basic approach is to do the math the way "Mother Nature" would have wanted it and then test and verify the accuracy.

Some worry that Z score training will somehow lead to bringing novices into the field, with a simple "plug and play" strategy. We disagree that Z score training somehow brings the novice into the picture. That is like saying that adding more instrumentation or autopilot to an airplane cockpit makes it easier for an untrained person to fly the plane. Z Scores provide more information, and can automate certain aspects, but they do not take the practitioner out of the equation. To use the system intelligently, one needs to know what a Z score is, what it means, and how all the EEG criteria fit together.

Furthermore, any practitioner working in any area needs to have their own credentials. So someone using this for language problems, for example, better be credentialed to work with language problems. Neither this, nor any biofeedback system, is an instant path to the clinical sea. The practitioner must bring their skills and expertise to the biofeedback system, not the other way around.

And so on. We do not see this quite as a simple "stick it on and fix it" approach. There will be practitioners who use it that way, but they will find and use specific tried and true protocols, which will be built using Z scores, as well as other metrics and modalities. This will likely add capability, not replace it. More generally, we see the Z Score training as an additional source of information and control, that can potentially fit into any training philosophy or approach, and enhance it, not diminish it.

We agree with perspectives that are skeptical about blindly training "to the Q". The point can be made that to do so slavishly is to make "mediocrity the norm". It is also true that increased alpha coherence has long been associated with optimal functioning, from James Hardt to Les Fehmi to Adam Crane and onward. Indeed, there are individuals (some well known to us) who have shown up "abnormal" on a Q, simply because they may be meditators, or have other EEG characteristics that distinguish them from their peers. Such is not necessarily a bad thing.

To us, one of the key elements of Z-score training is that it provides a new coordinate system for training. Rather than relying on some interpretation of what needs to be larger or smaller, or what is better or worse, we have a metric that we know hovers around 0 for the general population, and that we can play with, in terms of how many standard deviations we want to work with. Keep in mind that we are using population statistics for a within-subjects training, so the interpretation must be made very carefully. The interpretation would be "if this were your average score over a minute, then you would be in X percent of the population at large". But when doing the training, we are looking at instantaneous scores, which are expected to wax and wane.

But with Z-score training we can also choose to uptrain or downtrain any components we like, including combinations of components, or relationships between components. So we can train to a Z score of -2 or -3, or +2 or +3 or even +6 if we choose. The use of Z score training does not dictate the target, rather, it casts it in a new dimension.

It is important to emphasize that using Z scores does not automatically relegate us to the domain of trying to "normalize" everyone, although we can certainly "normalize" if we choose. For example, normalizing 4 or 5 or 8 coherences in a single band between F3 and P3 is likely to be an exciting prospect for those with language challenges. At the same time, we can tweak any metrics we like up or down, based on judicious choices and stated goals. The use of Z scores really provides an alternative to the concept of thresholding, and provides us with "portals" through which we can use the metrics, based on our own needs and persuasions and the clients needs.

We further include herewith a citation to a paper that first discussed Z score biofeedback which was Thatcher, R.W. EEG Operant Conditioning (Biofeedback) and Traumatic Brain Injury. Clinical EEG, 31(1): 38-44, 2000 and a somewhat less scientific abstract "An EEG Least Action Model of Biofeedback" , R.W. Thatcher, 8th Annual ISNR conference, St. Paul, MN, September, 2000.

Around 1997 is when Dr. Thatcher gave the idea some thought and from this the dll was finally developed and tested in 2004 and then he incorporated the procedure in Neuroguide as the Dynamic JTFA in 2005. Dr. Thatcher discussed the idea initially with Lexicor in 1999 but the discussions were mostly about a multivariate feedback involving discriminant functions. Thus, there is a little bit of history to the idea in the scientific literature and, of course, the implementation and practical ideas are crucial and an important catalyst to allow professionals to make use of this new approach. The mathematics and methods for computing the dynamic JTFA and Z scores for biofeedback can be read at www.appliedneuroscience.com and click on Articles & Links > Articles and download the article "Hand Calculations of EEG Coherence and Phase Delays"

We refer the reader to the following peer reviewed journals for essential background information. The selection criteria, demographics, no. per age group and per year, I.Q. and neuropsych. tests, etc. are published in the papers below:

Thatcher, R.W., Walker, R.A. and Guidice, S. Human cerebral hemispheres develop at different rates and ages. Science, 236: 1110-1113, 1987.

Thatcher, R.W. EEG normative databases and EEG biofeedback. J. of Neurotherapy, 2(4): 8 - 39, 1998.

Thatcher, R.W. EEG database guided neurotherapy. In: J.R. Evans and A. Abarbanel Editors, Introduction to Quantitative EEG and Neurofeedback, Academic Press, San Diego, 1999.

Thatcher, R.W., Walker, R.A., Biver, C., North, D., Curtin, R., Quantitative EEG Normative databases: Validation and Clinical Correlation, J. Neurotherapy, 7 (No. ¾): 87 - 122, 2003.

Thatcher, R.W., North, D., and Biver, C. EEG and Intelligence: Univariate and Multivariate Comparisons Between EEG Coherence, EEG Phase Delay and Power. Clinical Neurophysiology, 2005, 116(9):2129-2141.

Thatcher, R.W., North, D., and Biver, C. EEG inverse solutions and parametric vs. non-parametric statistics of Low Resolution Electromagnetic Tomography (LORETA). Clin. EEG and Neuroscience, Clin. EEG and Neuroscience, 36(1), 1 - 9, 2005.

Thatcher, R.W., North, D., and Biver, C. Evaluation and Validity of a LORETA normative EEG database. Clin. EEG and Neuroscience, 2005, 36(2): 116-122.

The cross-validation accuracy of the normative database, i.e., by removing an individual subject and then re-computing the means and standard deviations and classifying the subject was > 95% accurate and the age regressions are all close to this value (Thatcher, 1998; 1999; Thatcher et al, 2003). The brain develops slow enough that samples of about 400 carefully screened individual from birth to 10 years shows dominant linear changes as a function of age, like John et al (Normative data banks and neurometrics: Basic concepts, methods and results of norm construction. In A. Remond (Ed.), *Handbook of electroencephalography and clinical neurophysiology: Vol. III. Computer analysis of the EEG and other neurophysiological signals* (pp. 449-495). Amsterdam: Elsevier, 1987); Gasser et al (Development of the EEG of school-age children and adolescents. I. Analysis of band power. EEg & Clin. Neurophysiol., 69(2): 91-99, 1988 and Matousek and Petersen (Frequency analysis of the EEG background activity by means of age dependent EEG quotients. In P. Kellaway & I. Petersen (Eds.), *Automation of clinical electroencephalography* (pp. 75-102). New York: Raven Press, 1973) and many others have published. Thus, EEG norms are very stable because brain development is a relatively slow process.