Whole-Head Normalization using Live Z-Scores for Connectivity Training

Part 1 of a 2-Part Series
Look for part 2 in the July, 2008 issue

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This article relates some of our last 2 years of work with Live Z-score Training (LZT), and how the methods and clinical experience have evolved. Starting with the simple use of live Z-scores to view EEG parameters and do simple training, we have evolved the practice into a comprehensive multichannel whole-head approach with an underlying rationale and a growing set of advanced protocols.

We have been doing live Z-score training (LZT) with 1, 2, and 4 channels, since April, 2006. Our initial implementation gave access to any of the possible Z-scores, through a general, flexible mechanism, called the "Event Wizard." This was used to construct basic protocols using single Z-scores, Z-score range training, and combined Z-score training such as "all coherences normal." From there, we moved to "range trainin," in which one or more Z-scores can be trained within a range. These provided important starting points for clinical work, which then motivated additional developments.

The LZT DLL (Thatcher, this issue) that underlies this approach provides Z-scores for 6 important metrics: absolute power, relative power, power ratios for each channel, and coherence, phase, and asymmetry for each pair. Thus, 1 channel of EEG provides 26 Z-scores, 2 channels provide 76 Z-scores, and 4 channels provide 248 Z-scores. As we shall see, the use of 4 channels is a significant advancement, as it provides data on 6 simultaneous interconnectivity paths, not just 1, and thus provides a gateway to whole-brain training.

The simple LZT training worked well. By adding the ability to specifically target connectivity measures, clinical benefits were observed (Smith, 2008). In addition, we realized that additional power in the design of complex protocols would be of great value. For example, training a single parameter from a single component band is effective, but may not be optimal. Training all component bands in a given metric ensures a more comprehensive training for purposes of local neuronal activation

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or relaxation. Similarly, when more than 1 channel of EEG is available, it is beneficial to incorporate all channels into the training, to provide greater coverage and specificity, and to address connectivity. Multiple connectivity training is a significant capability of live Z-Score training, and may be its greatest strength.

Regardless of the number of channels used or the Z-score training strategy, feedback has generally consisted of animations, DVDs, games, sounds, music, and other typical displays. The trainees are not necessarily aware that they are using an entirely new form of training. They are only aware of the brain states into which they are being guided.

The combination of proper QEEG methods, along with a well-planned neurofeedback program of protocols based upon live Z-scores, can provide an accelerated and highly targetable regimen.

Jonathan Walker has emphasized the delicate nature of coherence training and the dangers inherent in overtraining any particular coherence. Z-scores provide an important relief of this concern, by ensuring that coherence targets are appropriate for the individual. We have found that, consistent with Walker's observations, it is generally difficult to normalize connectivity of the brain. Moreover, it is possible to cause abreactions of various types, whenever attempts are made to alter the coherence of one particular band in one particular direction.

An example of the importance of Z-scores connectivity training is presented by Smith (this issue). As experienced in this study, a single coherence between two sites was targeted for traditional neurofeedback coherence training. The band of interest was effectively altered. However, as that coherence normalized, other coherences in the brain became abnormal. Even without the trained connection moving toward hypocoherence, the rest of the brain had maladapted to the training.

When I presented this to a former physics professor who had pioneered neural network research, he replied, "I am not aware of any conservation principle that would dictate a response like this." So that got us to thinking about how and why the brain would respond in this way to the information being fed back. The brain, like any dynamical system, will seek the minimum-energy pathway to satisfy external and internal constraints. Indeed, one may posit a model of "brain hydraulics" in which various constraints are at work. These may variously be regarded as tendencies or pressures, which give rise to the flow of information and control, thus reflecting the cybernetic activity of the brain.

Robert Thatcher has proposed a predator-prey model that describes the mediation between short-range connections and long-range connections in the brain. According to his model, each neuron has a limited resource of inputs and outputs, which it must allocate between the various connections available, including both short-range and long-range connections. As the brain trades off between these connections, changes in coherence and phase metrics will reflect this dynamic reorganization.

Therefore, it is reasonable to set forth a brain model in which the response to neurofeedback training is in the form of a variety of adjustments which, through learning, tend to have a lasting nature. In the case of amplitude-based training, changes take the form of changes in cortical relaxation produced by alternating the strength of individual inhibitory connections, thus modulating cortical excitability, and thalamocortical cycling tendencies, for the affected cortical locations and pathways. Other metrics are more related to connectivity, such as coherence and phase, and the changes they introduce are different in nature. They include the structured rearrangement of the neuronal connection strengths, in order to comply with the training conditions.

When the conditions are limited, then the brain's response may be similarly limited.

This does not mean that the training effect is limited to the training area. Quite the contrary. Both beneficial as well as adverse responses may occur. Thalamic pathways, as well as various cortical interconnections are involved. Stark (2008) has used Z-scores extensively, and has learned to see patterns and time-dependent shifts in the full complement of Z-scores. He often sees phase as a primary adjuster, then wave of re-organization.

A single z score is just a target re-implemented. Especially in cases of connectivity metrics, it provides a valuable aid to determining and using target values. It can also be useful when used in a ranged fashion (high and low thresholds), to train within a range. However, as we see it, targeting a single connectivity metric, although it may be trained within a normal range, can cause other reactions in the brain, which are not necessarily beneficial.

We therefore believe it is important to use multiple channels with Z-scores, and to use the information effectively. A minimum of 2 channels are needed in order to see the pathway between them, and compute coherence, phase, and asymmetry metrics. But when 4 channels are used, the number of connections is 6, which is significantly more information.

Four channels are sufficient to ensure coverage of the basic interconnections in a given training paradigm. Examples of typical arrangements include F3-F4-P3-P4 and C3-C4-Fz-Pz. With a MINI-Q, it is possible to define predefined layouts of 4 channels that emphasize different brain connections

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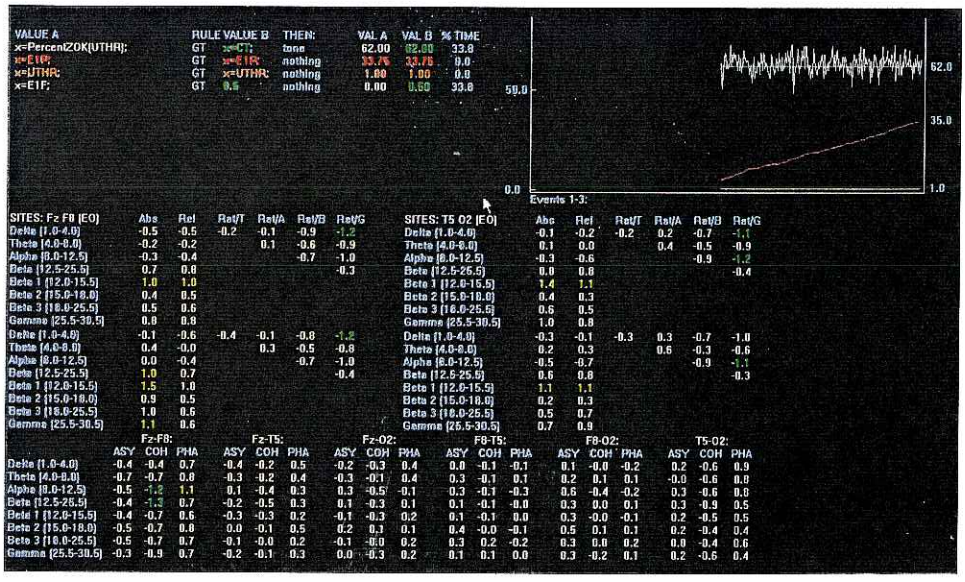

Figure 1: Typical multivariate Z-Score display using 4 channels, providing 248 Z scores. The sensors happen to be placed at O1, Pz, T4, and P4.

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and activities. Furthermore, these predefined "quads" can be used for assessment as well as training, providing a unified approach to whole-brain work.

In the case of F3-F4-P3-P4, for example, we have not only 4 important brain sites, but also 6 important connection pathways. This 4-channel montage allows us to monitor both the left and right frontal areas, and the left and right posterior areas. It also provides information relating to left intra-hemispheric function (language), right intra-hemispheric function (spatial, etc), frontal inter-hemispheric function (attention, planning), and posterior inter-hemispheric function (sensation, perception). This is a very simple, yet comprehensive way to gain access to EEG information for training purposes.

The following figure shows an example of a 4-channel Z-score display from the system. Our software automatically compiles, displays, and computes complex training statistics based on all of the available scores. There are a total of 248 Z-scores available. The indicated Z-scores are dynamically color-coded in a manner that makes it easy to spot deviations. The power-based Z-scores are clustered at the top of the display, and the connectivity metrics are shown at bottom.

It is not possible to understand the dynamics of brain response by watching a single Z-Score, or even a small number of Z-Scores. It is necessary to simultaneously monitor the full range of variables in a suitable number of sites, in order to observe the dynamical brain processes (Stark, 2008). To relieve these concerns, it is necessary to implement a comprehensive brain training method. This method needs to simultaneously address issues of activation and relaxation, connectivity in the form of communication and control, and relative activation

To this end, we have designed a series of advanced multichannel, multivariate training methods, which are collectively described as "Multivariate Proportional," or "MVP". These are comprised of algorithms that automatically incorporate all of the available Z-scores for all channels acquired, and compute continuous output values that are in essence figures of merit for the Z-score set. The MVP score is thus truly a complex measure of "how normal" the EEG is, when accounting for all available information.

This article is the first in a 2-part series that explains the theory behind the use of Z-score training with multiple sites. Look for a practical description of training protocols based upon this in your July issue of NeuroConnections (Ed.).

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