Live Z-Score training (LZT) neurofeedback is described. Its theoretical underpinnings, technical foundations, and relationship to brain operant learning are described. LZT is an outgrowth of both neurofeedback and quantitative electroencephalography (QEEG) and is consistent with previous QEEG-based neurofeedback methods. In addition, it incorporates elements of self-regulation that allow the client’s brain to become part of the decision-making process, providing an important aspect of individualized treatment. LZT encourages flexibility and appropriateness of brain activation and connectivity and is adaptable to a wide range of clients and training needs.

Live Z-Score training (LZT) is a form of neurofeedback that incorporates real-time quantitative electroencephalography (QEEG) information in the form of Z-Scores, as a component in the feedback control mechanism. The Z-Score is a statistic that indicates how many standard deviations the current signal is from the mean on some specific parameter, such as amplitude, power, or coherence. Beyond this one basic principle, there is considerable latitude and variation in precisely how these values are used. It is generally true that the client receives information related to these scores, but further assumptions are not generally valid, without considering the details of a specific method and system. The variations in approaches include whether and how QEEG assessment data are considered, which Z-Scores are selected for training, how Z-Score ranges or windows are defined, what type of algorithm is used to convert Z-Scores into feedback signals, and whether and how outliers are handled.

The essential element of LZT is that the EEG is processed to produce estimates of Z-Scores in real time, and these Z-Scores are used to create feedback. The principles were described by Collura and Thatcher (2006). LZT provides a bridge to QEEG and is consistent with other types of QEEG-informed neurofeedback. One key aspect is that deviations from typical EEG activity may be chosen for operant training in the direction of being more typical. For reasons to be explained, we use the concept of typical rather than normal in referring to our reference database population. Unlike traditional neurofeedback in which the QEEG may be used to help to design the training protocol, LZT has the unique advantage of reflecting changes in QEEG information in real time, as training proceeds. It is thus more adaptable and flexible than previous approaches. It is rather like the difference between first reading a map and then undertaking a journey, compared with having a live global positioning system (GPS) system available to monitor and possibly control travel to a designated location.

There are many ways to use Z-Scores in neurofeedback, and Z-Scores can be computed for a wide range of EEG parameters. The most common ones include absolute power, relative power, power ratios, asymmetry, coherence, and phase. More recently, with the use of inverse methods to estimate regional brain activity, parameters based on current-source density (CSD) are possible. CSD-based LZT makes possible the ability to train, as well as image, localized brain activity in three dimensions. In addition to metrics related to brain activity (power), it is possible to compute metrics that reflect the connections between specific brain regions, rather than simply between scalp locations. When the connections between two or more regions are measured, we become able to define combinations of regions in the form of networks. Specific networks that serve identifiable tasks are also referred to as hubs, reflecting their functional roles.

Because LZT can use many parameters at once, it is intrinsically a multivariate method. Therefore, it can address complex sets of brain activation information in pursuit of directed goals. Rather than simply training “Theta amplitude down” or “to increase Sensorimotor rhythm,” LZT can address more functionally rich states. When, for example, one trains multiple connectivity metrics at once, in a directed fashion, whole brain function can be managed. To make another analogy, it is like the difference between “pumping iron” and “riding a bicycle.” Like bike riding, LZT appears to incorporate multiple sets of basic brain skills that can be learned and retained in the interest of overall brain efficiency and flexibility.

It may be helpful at the outset to define what LZT neurofeedback is not. It is not a “one size fits all” method of treating every client in the same manner. It is also not intended to “train everyone the same,” and it does not “dumb people down” by reducing everyone to a lowest
The equation for a Z-Score is as follows:

\[ Z = \frac{(current\ value - reference\ mean)}{reference\ standard\ deviation} \]

When a single Z-Score is used for neurofeedback, the result will be equivalent to neurofeedback using the raw value, because the Z-Score translates directly to the original data using a simple formula. If, for example, the Alpha amplitude at Cz is being measured, an eyes-closed value of 10 microvolts might produce a Z-Score near zero. As this amplitude increases, the Z-Score will increase, according to a direct relationship, so that 15 microvolts might be 1 or 2 standard deviations high, producing a Z-Score of 1 or 2. Similarly, a lower value such as 5 might produce a Z-Score of −1 or −2. Therefore, if we place a threshold at \( z = 0 \), and reward when the Alpha Z-Score is above this, we are simply up-training Alpha with a threshold of 10 microvolts. While this example is simple and potentially useful, it does not take advantage of the strength of LZT neurofeedback.

One important capability of LZT training is that we can not only set a single threshold but we can also define a window of acceptance, so that, for example, the client is reinforced when the Z-Score is between +1 and −1. This window need not be symmetrical and could have different upper and lower limits, which is in fact quite common.

**Why Is \( Z = 0 \) Beneficial?**

A Z-Score of zero, on the average, reflects the fact that the individual’s EEG is centered on a typical mean value but does not imply that the EEG remains at that value at all times. Indeed, it is by varying in time above and below this level that the brain is able to exhibit a typical mean. Indeed, it is this continual change that makes discrimination possible and that underlies healthy and flexible functioning. Neurofeedback in general, and LZT training in particular, is about behavior and operant learning, in which the EEG parameters are encoded into becoming a behavior, from which the brain learns self-regulation. This is an important concept. Electrical brain activities that have been heretofore hidden from view become evident through visual, auditory, and tactile feedback, hence literally become a behavior that can be regulated. It is through the regulation of EEG behavior that the brain changes, with resulting changes in the client’s internal world, thoughts, feelings, and external actions.

Because the brain is a biological, hence a physical, system, it has a certain range of normal operation, based on physical limits. An Alpha wave can be only so large, based on the number, orientation, and connectivity of the pyramidal cells that produce it. A key facet of the Alpha wave is that it waxes and wanes in a characteristic fashion, and this waxing and waning is important to observe. If the Alpha bursts are too persistent, or too infrequent, this will be reflected in the overall average of the Alpha activity over time. Similarly, connectivity (coherence for example) is a continually changing value that at any instant must fall between 0 and 100. Therefore, the average value of connectivity over some time period reflects the time course of the connectivity metric within this range, over the specified duration. This is a general principle. The observed measure of an EEG parameter, such as amplitude or connectivity, reflects the behavior of the parameter in time, as it fluctuates.

This can be illustrated with a simple example. Figure 1 shows that the Z-Scores that are most deviant are also the least variable. The colored bars represent the average of power across 19 sites, so that the blue and green boxes show an overall deficit of the activity (Theta). The lines with purple “caps” on them show the immediate variability of each component, over the recent past. It is evident that the boxes that are largest, hence most deviant, have the smallest variation, almost none at all in the two most deviant. On the other hand, sites that are very close to typical exhibit considerable variability, and the most variable ones are also among those that are most typical on the average.

Rather than regarding Z-Score targets as being “normal,” we prefer to consider them as “typical” and, more...
specifically, “neurotypical.” They give an indication of the average value of a parameter in an individual who is exhibiting the typical range of EEG behavior. Therefore, “Z = 0” does not reflect being “stuck” or being “dumbed down.” Rather, it reflects an optimum state of balance and flexibility, not rigidity.

There is a further significant difference between live Z-Score neurofeedback and other forms of directed training. The critical difference is that the client becomes part of the decision-making loop. In conventional forms of neurofeedback, a clinician or consulting expert will examine the clinical presentation and other factors that may include QEEG data and make a decision as to which sites and components are to be trained. The clinician further chooses specific metrics, such as absolute or relative power, coherence, or other metrics, to be incorporated into a fixed protocol. When using LZT neurofeedback, the client’s brain becomes an overt part of the decision-making control loop. Live Z-Scores offer the opportunity to present the client with a variety of information at once, allowing the client’s brain to determine its own path toward self-regulation within a wide range of possible operating modes.

Figure 2 shows the progress of a typical live Z-Score session in the form of the changes in the live Z-Scores every minute.

Figure 3 shows the same session, with the data presented in the form of raw amplitudes. It is evident that the excessive low-frequency components (Theta and Alpha) are decreasing, whereas the higher-frequency components (Beta and high Beta) are increasing over the session. Because this corresponds to each of these components becoming more neurotypical, this is an example of LZT automatically producing a training effect that might be observed if the clinician had hand designed an “enhance and inhibit”-based protocol using power training. The emphasis here is that the use of LZT is, in its simplest form, consistent with conventional power training and does not introduce excessive or insurmountable obstacles to the brain trying to figure out what is being asked of it.

How Are Live Z-Scores Used?
LZT training can be simple or complex. However, the client experience is always similar, in that visual, auditory, or tactile signals are used to inform the brain of a targeted state or of a change in state. Training protocols can range from using a single Z-Score to using hundreds or more. As more Z-Scores are combined, the information becomes more comprehensive. If a very large number is used, the relevant feedback information may become obscured in irrelevant data, so that judicious selection of Z-Scores is a good policy.

When a single Z-Score is used as a target for neurofeedback, the effect is equivalent to when training the raw value. This is because the Z-Score is really nothing more than a change in the coordinate system, replacing one set of continuous variables for another, preserving the size and direction of the difference.

From one Z-Score as a basis, more complex protocols can be created using two, four, dozens, hundreds, or even thousands of Z-Scores. There is no a priori reason to limit the types or amount of information that a brain can process to just a few parameters, as is done in traditional neurofeedback protocols. In our experience, there is an optimal range between about 50 Z-Scores and about 500 Z-Scores, which is in practical terms provides a good level of specificity as well as variability in the feedback.

LZT offers the opportunity to reward the brain for more complex states and transitions. When using a structured database of reference, these states may be relevant to information processing, communication, limit cycles, and so forth. As an example of the utility of this approach, Wigton and Krigbaum (2015) showed significant improvements in attention, executive function, and behavior, along with electrophysiological changes, when using 19-channel LZT with children with attention-deficit/hyperactivity disorder (ADHD). This is in contrast with the findings of Arn, de Ridder, Strehl, Breteler, and Coenen (2009), who reported that traditional neurofeedback had beneficial effects on inattention but much less for hyperactivity.

One of the first observations, which has been seen repeatedly in clinical settings, is that, when an observable Z-Score deviation can be correlated with clinical symptoms, and when those deviations are reduced by neurofeedback, the clinical symptoms also generally resolve. There are exceptions to this rule, which generally show up when the client has multiple symptoms and multiple Z-Score deviations.
Options for Constraining Degrees of Freedom

In some ways, LZT may be likened to the GPS now commonplace in cars and smart devices. Like GPS, LZT provides subjects with information about their location, in relation to a defined target. Also, like GPS, LZT does not compel individuals to follow any particular path. Rather, it provides suggestions that can be followed or not. Like GPS, LZT does not require everyone to arrive at the same place. It does, however, provide valuable information so that progress and changes can be experienced and visualized. It is a reference, not a hard target. To further the analogy, whereas conventional neurofeedback may be thought of as a compass, pointing in a direction, LZT provides a complex set of coordinates that can be used to navigate the inner space of brain activation and connectivity.

Early concerns regarding LZT neurofeedback referred to the role of outliers, which are the Z-Scores that are most deviant. It was evident early on that the most outlying values were not necessarily the most useful. For example, if a client produces electrical activity in the form of eye blinks, muscle activity, or other artifacts, these are not particularly relevant to brain function. One positive aspect of this fact is that LZT training provides an automatic rejection of artifact during training. Because the reference databases are constructed from EEG that has had artifacts carefully removed, the Z-Scores are intended to reflect clean brain activity. When artifacts are present due to noise, movement, eye activity, or other contamination, one or more live Z-Scores will become very large in absolute value, whether they go in a positive or negative direction. This will generally cause reinforcement to stop, so that the client is not rewarded. Indeed, it is possible to configure LZT so that, if a relatively wide Z-Score range is used, Z-Scores will exceed this range when artifacts occur. LZT used in this manner actually becomes a mechanism to create useful inhibits and can be used to augment traditional power or connectivity training by providing such an inhibit function.

Beyond the value of outliers in detecting and responding to artifact, LZT can incorporate the use of outliers as part of functional training. There are various ways to incorporate...
information relating to Z-Scores that are outside the acceptance band, and that would otherwise be ignored. For example, one approach provides additional feedback information reflecting instantaneous changes in Z-Scores outside the training band, as they move toward or away from the target range (Collura, 2012).

**How Do Z-Scores Relate to Phenotypes?**

The concept of EEG phenotypes has become a valuable means of recognizing and working with individual differences and patterns in brain function (Johnstone, Gunkelman, & Lunt, 2005). This approach can be used consistently with LZT in that it is important to incorporate these considerations into assessment and treatment planning when working with clinical populations. Many of the phenotypes have a direct relationship to QEEG parameters and hence to the LZT approach. Among the most obvious phenotypes with QEEG associations are those reflecting excess slow or fast activity of diffuse or focal origin. We note several examples of phenotypical patterns that have been shown related to deviant Z-Scores and their clinical value.

Arns, Swatzyna, Gunkelman, and Olbrich (2015) showed that when visible spindling Beta is seen in the EEG of a clinical population, the Z-Scores also show elevated levels. This is an example of the time versus space distinction; the individual Beta bursts are not excessively large per se, but their abundance and persistence reveal a characteristic dysregulation, in this case reflecting the activity of the cingulate gyrus. This population has characteristic hypoarousal, with concomitant issues with sleep and impulse control. With regard to slow activity, Arns, Drinkenberg, and Leon Kenemans (2012) showed that when a child has the excess frontal slow or the slow frontal Alpha form of attention-deficit disorder/ADHD, these characteristics show up in the Z-scores in this clinical group, which has a characteristic response to medication, in addition to responding positively to neurofeedback that targets this excess.

Jonathan Walker (2011) showed that when treating migraines in a clinical population, if excess high Beta is used as an indicator of where to train that high Beta down, then symptomatic relief can be expected. He identified the presence of excess high Beta, in the form of QEEG Z-Scores, and then designed a conventional power-based protocol based on the locations of the excesses. This is a manualized form of using Z-Scores for choosing sites and components while using raw power training as the neurofeedback method. LZT can be seen as a direct descendant of this approach, wherein the determination of which sites and which components are in excess is performed continually during the training process.

**Combining Z-Scores With LORETA/sLORETA**

Z-Score low-resolution brain electromagnetic tomography (LORETA) and its variants (standardized LORETA [sLORETA], exact LORETA, etc.) all operate by converting the surface electrical field into an estimate of the three-dimensional activity within the brain. LORETA-based neurofeedback can be done using raw values (CSD) or
using Z-Scores. The following figure shows a typical live Z-Score session incorporating sLORETA live Z-Scores as well as surface Z-Scores. This shows that the live maps provide useful summary and training information related to surface EEG, whereas the sLORETA three-dimensional imaging shows in more detail which location and component are of interest. In this case, Brodmann areas 44, 45, and 46 show a focal excess of Beta, which can be addressed with operant training. The associated trend and bar graphs on the right show the exact training parameters at that instant, and they control the animations, games, and sounds that provide operant feedback.

**Conclusions**

In summary, LZT is basically a descendant of QEEG-informed neurofeedback, in which live QEEG information is brought into the information mix provided to the client. Based on observations of the multiple scores being able to come into balance, the concepts of game theory, and Nash equilibria are relevant. This field of analysis takes into consideration the strategies that any system (the brain) will follow in achieving some payoff or goal (visual and auditory rewards). Basically, by manipulating various combinations of inputs (Z-Scores), the brain can learn which combinations provide more or less reward. The system is characterized by multiple stable attractors, so that more than one local solution exists. Therefore, a brain might be in a local optimum state but can be moved into a more globally optimal state when provided with the information. LZT informs the brain of the locations of attractors by telling clients where they are. Clients then implement individual strategies.

In summary, learning self-regulation through live Z-Score neurofeedback training can be as simple as riding a bicycle. It is designed to help the brain locate and access new states of activation that incorporate whole-brain information. Neurofeedback provides information and thus opportunities for change, but it does not “push” the brain; rather, it coaxes it, to follow its own innate tendencies to seek novelty and reward, toward beneficial goals. LZT does not expect everyone to be the same, but it does seek to empower the brain to fully explore its functional range and to be flexible and adaptable.

**References**


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