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SPECIAL ISSUE

Quantitative EEG and Live *Z*-Score Neurofeedback—Current Clinical and Scientific Context

Thomas F. Collura, PhD, QEEG-D, BCN, LPCC

The Brain Enrichment Center and BrainMaster Technologies, Inc., Bedford, OH

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This article discusses the relevance of quantitative EEG (QEEG) and live z-score training (LZT) to the field of mental health in general, and to neurofeedback in particular. We examine what practitioners might learn about clients when QEEG is used for assessment, and the relevance of LZT as a treatment modality. Clinicians can benefit from viewing the brain as a dynamic system, and this point of view can provide a foundation for QEEG and LZT. This approach emphasizes understanding the value of brain activation as a basis for observed symptoms and behaviors. Of paramount importance are localization and frequency information, as well as connectivity metrics. The brain can be viewed as a complex self-controlled system operating with various identifiable networks and frequencies that, when dysregulated, produce what we commonly refer to as "disorders."

The uses of quantitative EEG (QEEG) and live *z*-scores (LZT) have become established themes in neurofeedback. Their importance stems in part from the increasing use of evidence-based approaches, including the use of brain-based approaches, and the availability of normative references. Their relevance to emerging models of self-regulation and control in the brain is a second key area.

Practitioners in mental health and in general medical fields can learn from these approaches, which may not be part of a typical educational program. QEEG and related methods provide a focus on functional neuroscience, rather than diagnostic classification. Daniel Amen (2016) has opined that psychiatrists are among the few practitioners who do not study the organ that they treat. QEEG-based approaches place the emphasis on the brain and its functioning. Another important benefit is that these methods can be adapted to a wide range of situations, and are not restricted to any particular therapeutic model (Collura & Frederick, 2016).

QEEG and LZT approaches emphasize the use of brain-based assessments and treatment as a key component of modern mental health practice. When using QEEG/LZT, one is naturally led to examine carefully the observed dysregulations in a client's brain, and to correlate them with presenting problems. At the same time, individual differences and unique strengths are also revealed, and can be considered, without necessarily subjecting them to modification. As in other QEEG-based approaches, the client's brain must be carefully examined in concert with presenting problems, use of medications, exercise, diet, health history, and other factors.

Treatment Planning with Normative References

There are many possible approaches to neurofeedback treatment planning and assessment. One important direction is the use of QEEG and normative references to compare clients with typical populations. Such references are helpful when identifying dysregulations that are related to clinical issues, as well as in identifying unique individual characteristics. For example, it is apparent that combining the use of QEEG assessment with consideration of overarching factors such as phenotypes (Arns, Gunkelman, Breteler, & Spronk, 2008; Johnstone, Gunkelman, & Lunt, 2005) helps to produce an objective idea of the client's unique characteristics, and how they impact mental and emotional health, and performance.

QEEG and live *z*-scores have provided a reentry path for clinicians who have had experience in neurofeedback but discontinued it for any of a number of reasons. Existing approaches to neurofeedback have been highly varied, ranging from highly intuitive, "one size fits all" approaches, to simple selection of a protocol from among several choices, to systems that emphasize individualized assessment and the importance of neural flexibility. QEEG databases provide a uniquely objective and repeatable set of criteria. Clinicians who experienced the limitations of a particular approach and left the field often take interest when QEEG databases are presented that are published and FDA registered.

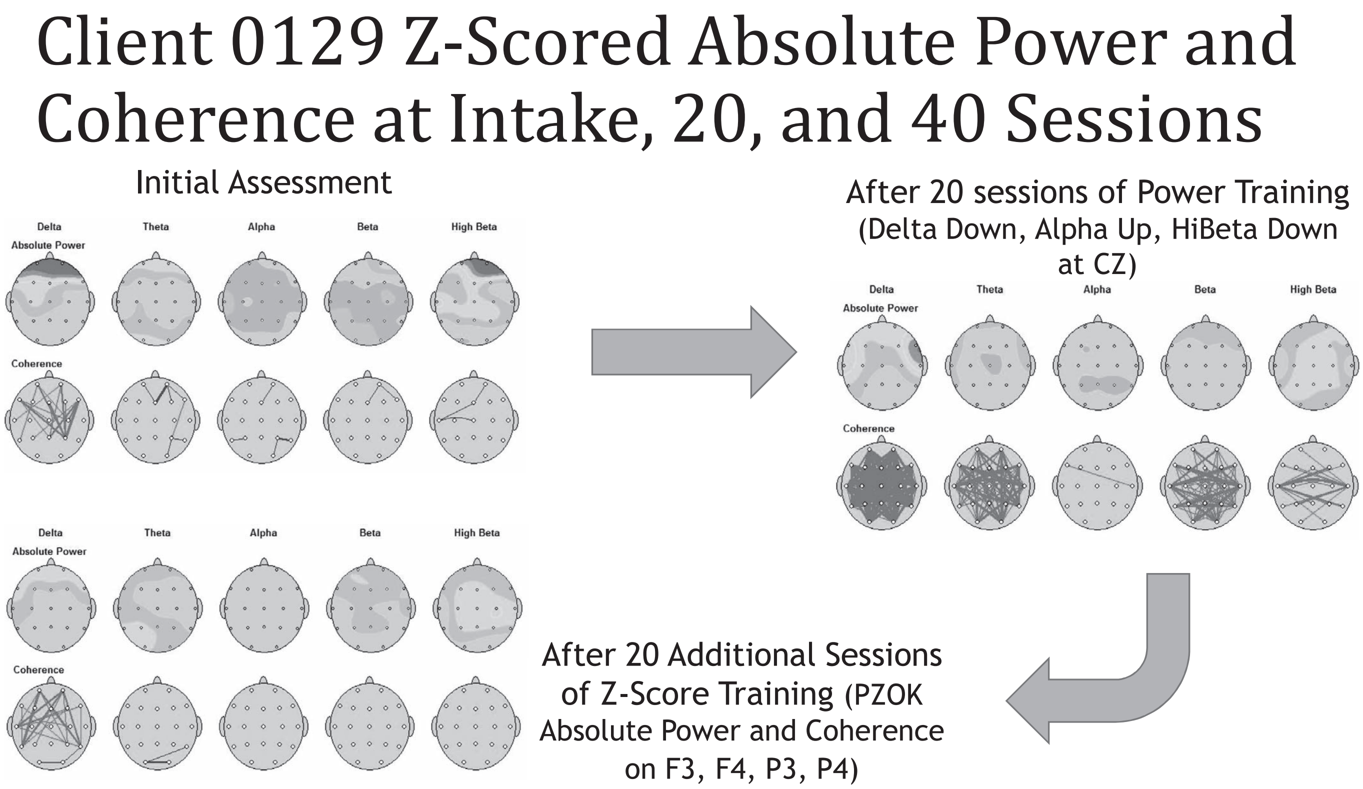


Figure 1. QEEG results from a client with autism, showing changes after 20 and 40 sessions. While power training resulted in improvement in amplitudes, a connectivity (coherence) dysregulation emerged (dark coherence lines). For color versions of figures, see http://www.brainm.com/software/zscoreimages.

LZT neurofeedback is a form of QEEG-guided neurofeedback. However, rather than using a QEEG to design a traditional protocol, LZT further employs the use of live QEEG processing, so that the neurofeedback is continually informed by how the EEG is changing moment-to-moment.

Amplitude and Connectivity

LZT neurofeedback appeals to the concepts discovered and described by Barry Sterman (1998) in his seminal work with cats and with humans. Sterman (1998) demonstrated and articulated the importance of the "concentration/relaxation" cycle in human performance. This relates to QEEG and *z*-scores as follows: A *z*-score that is consistently deviant is typically "stuck" at and near a dysregulated level, and is not able to find the set point of optimal flexibility, which is at or near $z = 0$ in a typical individual (Collura 2008, 2014, 2016).

Traditional approaches to neurofeedback tend to emphasize amplitude, rather than connectivity. This is because it is easier to work with amplitude alone, and connectivity work requires additional channels. Multichannel QEEG/LZT is uniquely able to address both brain activation and brain connectivity by overcoming these limitations. Figures 1 and 2 illustrate results with a client with autism, who initially received traditional amplitude training, and was then switched to *z*-score–based neurofeedback. EEG and cognitive results showed that, after the initial power training, certain power abnormalities were normalized. However, connectivity was not being trained, and it was seen to deviate, shown by hypercoherence. Also, there was no measurable improvement in cognitive performance. With the introduction of LZT neurofeedback, the power improvements continued, but connectivity deviations were further brought into normal ranges. At the completion of the LZT series, cognitive performance was again assessed, and found to have improved.

Brain Function Spectrum, Not Disorders

Live *z*-scores are even more important when using electrical tomography techniques such as LORETA, VARETA, sLORETA, eLORETA, and other variants, which we refer to generally as LORETA methods. The individual voxel-level current-source information can be best understood in an activation/relaxation model when *z*-scores are used to process the image. This approach amplifies an underlying concept—that of looking at brain function rather than disorders or even symptoms. When one examines the brain from this point of view, the essential functions that emerge

Client 0129 CNS-Vital Signs at Intake, 20, and 40 Sessions

Initial Assessment

Patient Profile:	Percentile Range				> 74	25 - 74	9 - 24	2 - 8	< 2
	Standard Score Range				> 109	90 - 109	80 - 89	70 - 79	< 70
Domain Scores	Subject Score	Standard Score	Percentile	VI**	Above	Average	Low Average	Low	Very Low
Neurocognition Index (NCI)	NA	59	1	No					x
Composite Memory	78	59	1	Yes					x
Verbal Memory	36	43	1	Yes					x
Visual Memory	42	86	18	Yes			x		
Processing Speed	26	72	3	Yes				x	
Reasoning	-4	74	4	No				x	
Executive Function	-1	72	3	No				x	
Psychomotor Speed	94	63	1	Yes					x
Reaction Time*	1144	36	1	Yes					x
Complex Attention*	39	68	1	No					x
Cognitive Flexibility	-6	69	2	No					x
Social Acuity	4	81	10	Yes			x		
Working Memory	-2	68	1	No					x
Sustained Attention	8	79	8	No				x	
Total Test Time (min:secs)	80:31				Total time taken to complete the tests shown.				

Above	Average	Low Average	Low	Very Low	Invalid
0	0	2	1	4	7

After 20 sessions of Power Training (Delta Down, Alpha Up, HiBeta Down at CZ)

Patient Profile:	Percentile Range				> 74	25 - 74	9 - 24	2 - 8	< 2
	Standard Score Range				> 109	90 - 109	80 - 89	70 - 79	< 70
Domain Scores	Subject Score	Standard Score	Percentile	VI**	Above	Average	Low Average	Low	Very Low
Neurocognition Index (NCI)	NA	51	1	No					x
Composite Memory	86	73	4	Yes				x	
Verbal Memory	47	80	9	Yes			x		
Visual Memory	39	77	6	Yes				x	
Processing Speed	17	60	1	Yes					x
Reasoning	-5	71	3	No				x	
Executive Function	-8	65	1	No					x
Psychomotor Speed	97	65	1	Yes					x
Reaction Time*	926	67	1	Yes					x
Complex Attention*	91	-5	1	No					x
Cognitive Flexibility	-19	58	1	No					x
Social Acuity	-16	-24	1	No					x
Working Memory	-4	62	1	No					x
Sustained Attention	3	72	3	No				x	
Total Test Time (min:secs)	57:52				Total time taken to complete the tests shown.				

Above	Average	Low Average	Low	Very Low	Invalid
0	0	1	2	3	8

After 20 Additional Sessions of Z-Score Training (PZOK Absolute Power and Coherence on F3, F4, P3, P4)

Patient Profile:	Percentile Range				> 74	25 - 74	9 - 24	2 - 8	< 2
	Standard Score Range				> 109	90 - 109	80 - 89	70 - 79	< 70
Domain Scores	Subject Score	Standard Score	Percentile	VI**	Above	Average	Low Average	Low	Very Low
Neurocognition Index (NCI)	NA	68	1	No					x
Composite Memory	92	85	16	Yes			x		
Verbal Memory	46	76	5	Yes				x	
Visual Memory	46	97	42	Yes		x			
Processing Speed	35	83	13	Yes			x		
Reasoning	-3	77	6	No				x	
Executive Function	-3	70	2	No				x	
Psychomotor Speed	117	77	6	Yes				x	
Reaction Time*	1135	37	1	Yes					x
Complex Attention*	34	75	5	No				x	
Cognitive Flexibility	-7	68	1	No					x
Social Acuity	-2	49	1	No					x
Working Memory	6	93	32	Yes		x			
Sustained Attention	19	92	30	Yes		x			
Total Test Time (min:secs)	45:38				Total time taken to complete the tests shown.				

Above	Average	Low Average	Low	Very Low	Invalid
0	3	2	3	1	6

Figure 2. CNS-VS neurocognitive test results from the client in Figure 1, showing cognitive improvement after live *z*-score (LZT) neurofeedback. For color versions of figures, see http://www.brainm.com/software/zscoreimages.

include pattern recognition, goal-setting, attentional control, mood control, decision-making, and other basic activities. These combine to produce what we recognize as thoughts, feelings, and behaviors. However, rather than classifying individuals on the basis of disorders, which can include many different combinations of functional concerns, we look at the functions themselves. To use an analogy, rather than saying that my car has "no-go" disorder, or "doesn't go but makes noise" disorder, I can say "the fuel pump is clogged with residue," which is a much more helpful diagnosis, and also leads to a useful action plan.

QEEG, when combined with neurofeedback, further takes this consideration into the therapeutic realm by giving the clinician a basis from which to effect and assess changes in the brain locations and frequencies that underlie specific functions. For example, when excess fast activity (beta or high beta) is seen in the cingulate gyrus, the resulting behaviors may include inattention, distractibility, oppositional or defiant behavior, or mood instability. Clearly, a single dysfunction can lead to any of a variety of observed outcomes, hence "disorders."

In existing QEEG-based approaches to neurofeedback, an initial QEEG is used to create an assessment and treatment plan, and then is not repeated until after a certain number of neurofeedback sessions have been completed (for example, see Walker, 2011). LZT has the potential to significantly compress the cycle of assess–treat–reassess, by incorporating all three stages in a single process.

Maximum Flexibility

QEEGs are normally taken at rest. During LZT training, the brain is actually under a task. The question arises whether an at-rest reference is appropriate as a training target. The answer lies in understanding how the brain cycles between rest and activity, and the relevance of the at-rest target in the mean, even as the brain undergoes cyclic activation and rest. A deeper understanding of LZT shows that an average of $z = 0$ is a position of maximum flexibility. There is a common misconception that LZT approaches attempt to make everyone the same, and to train the brain toward a mediocre average. The concern for "dumbing down" the brain has emerged. However, far from reducing subjects' brains to a state of mediocrity, the process actually helps to teach flexibility and adaptability. Diwadkar, Asemi, Burgess, Chowdury, and Bressler (2017) showed that brain networks at rest are in readiness for action. Clients with cognitive, emotional, and other struggles often reveal a rigidity and fixedness of response, which can be addressed using a method that inculcates flexibility and appropriateness in response actions, rather than preprogrammed, maladaptive patterns.

To use an analogy, $z = 0$ is a target, being the center of the bullseye in typical LZT training using a normative database. But we reward for "arrows" that are near the target within a range, and focus on whether, on the average, $z = 0$ is being met, knowing that sustaining an instantaneous value of $z = 0$ is likely not attainable nor is it desirable. So we always train to a range. There may be some who try to drive the instantaneous scores near zero, or to reward when all *z*-scores are within a narrow range, but this is not necessary or optimal. However, if the average is zero over time, then the brain is finding a location from which it can have optimum flexibility. Ros et al. (2016) explained how a system that self-regulates can find a state of optimum self-criticality when balanced between the extremes of order and disorder, which is analogous to finding the ability to oscillate above and below a value of $z = 0$ in the mean.

This is consistent with the principle of entropy, which determines in which conditions a system is optimally able to respond in a meaningful manner. A state of maximum entropy in a self-regulated system reflects the fact that perturbations, and connectivity in particular, are poised so that more than one response option is potentially likely. The state of optimum entropy can be defined as the condition during which an equal number of connections are above and below a particular "set point" of connectivity. In a study by Guevara Erra, Mateos, Wennberg, and Perez Velazquez (2016), this set point was derived as the mean connectivity between surface sites, when taking a Laplacian montage. When using *z*-scores, it is possible to consider the mean value of a connectivity over time ($z = 0$) as a similar set point. When doing so, we have a condition in which the number of positive *z*-scores equals the number of negative *z*-scores, disregarding their exact magnitude. It can be seen that a condition in which the *z*-scores are equally distributed around $z = 0$ is a similar condition to rewarding when an optimum number of *z*-scores are near zero in the average, as they vary. Therefore, LZT training can be interpreted as producing a similar result as would be achieved if one were to overtly train entropy. It is further possible to modify an LZT protocol so that rewards are specifically provided when *z*-scores are equally distributed as positive and negative, providing a *z*-score–based metric that is specifically traceable to entropy. The further use of LORETA-based region of interest (ROI) connectivity metrics in this regard has the potential to further the specificity of EEG-based brain network connectivity and entropy based assessment and training.

The Next Step in the Evolution of Neurofeedback

Live *z*-score training is a next step in the evolution of neurofeedback, which is itself a major step in mental and brain healthcare. Collura, Guan, Tarrant, Bailey, and Starr (2010) and Wigton and Krigbaum (2015) have shown benefits from 10 or fewer LZT sessions in cases including ADHD and autism spectrum disorder. Further studies and case histories can be found in Collura and Frederick (2016) and Thatcher and Lubar (2014). It is important to recognize that, rather than being a single fixed approach to neurofeedback, LZT training is a type of approach that has many variations and can be applied in different ways. The availability of live *z*-scores is an important breakthrough, but it does not dictate the approach, or even the philosophy surrounding training. Different systems and practitioners use differing methods, with variations in the number and type of *z*-scores used, the sites used, whether surface or LORETA-type *z*-scores are used, the algorithm used to create feedback, and the types of sound, visual, or tactile feedback used.

References

Amen, D. (2016, March). *The brain warrior's way*. Presented at the Annual Meeting of the AAPB, Chicago, IL.

Arns, M., Gunkelman, J., Breteler, M., & Spronk, D. (2008). EEG phenotypes predict treatment outcome to stimulants in children with ADHD. *Journal of Integrative Neuroscience, 7*(3), 421–438.

Collura, T. F. (2008). Neuronal dynamics in relation to normative electroencephalography assessment and training. *Biofeedback, 36*(4), 134–139.

Collura, T. F. (2014). *Technical foundations of neurofeedback*. New York: Taylor & Francis.

Collura, T. F. (2016). Live Z-score neurofeedback. *Biofeedback, 44*(4), 212–217.

Collura, T. F., & Frederick, J. (Eds.). (2016). *Handbook of clinical QEEG and neurotherapy*. New York: Taylor & Francis.

Collura, T. F., Guan, J., Tarrant, J., Bailey, J., & Starr, F. (2010). EEG biofeedback case studies using live Z-score training and a normative database. *Journal of Neurotherapy, 14*(1), 22–46.

Diwadkar, V. A., Asemi, A., Burgess, A., Chowdury, A., & Bressler, S. L. (2017). Potentiation of motor sub-networks for motor control but not working memory: Interaction of dACC and SMA revealed by resting-state directed functional connectivity. *Plos One, 12*(3), e0172531. doi:10.1371/journal.pone.0172531

Guevara Erra, R., Mateos, D. M., Wennberg, R., & Perez Velazquez, J. L. (2016). Towards a statistical mechanics of consciousness: Maximization of number of connections is associated with conscious awareness. *Physical Review E, 94*(5). doi:10.1103/PhysRevE.94.052402

Johnstone, J., Gunkelman, J., & Lunt, J. (2005). Clinical database development: Characterization of EEG phenotypes. *Clinical EEG and Neuroscience, 36*(2), 99–107.

Ros, T., Frewen, P., Théberge, J., Michela, A., Kluetsch, R., Mueller, A., Candrian, G., et al. (2016). Neurofeedback tunes scale-free dynamics in spontaneous brain activity. *Cerebral Cortex, 27*(10), 1–12. doi:10.1093/cercor/bhw285

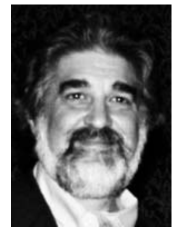
Sterman, M. B. (1998). Physiological origins and functional correlates of EEG rhythmic activities: Implications for self-regulation. *Biofeedback and Self Regulation, 21*(1) 3–33.

Thatcher, R. W., & Lubar, J. (2014). *Z-score neurofeedback* (1st ed.). New York: Academic Press.

Walker, J. E. (2011). QEEG-guided neurofeedback for recurrent migraine headaches. *Clinical EEG and Neuroscience, 42*(1), 59–61.

Wayne State University. (2017, March 12). Brain networks at rest are in readiness for action [Press release]. *Neuroscience News*. Retrieved from http://neurosciencenews.com/brain-network-action-rest-6234/

Wigton, N. L., & Krigbaum, G. (2015). Attention, executive function, behavior, and electrocortical function, significantly improved with 19-channel *z*-score neurofeedback in a clinical setting: A pilot study. *Journal of Attention Disorders*. March 30, 1–11. doi:10.1177/1087054715577135



Thomas Collura

Correspondence: Thomas F. Collura, PhD, QEEG-D, BCN, LPCC, The Brain Enrichment Center and Brain Master Technologies, Inc., 195 Willis Street, Bedford, OH 44146, email: tomc1@brainmaster.com.