CHAPTER

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Neurofeedback's first fifty years: my story

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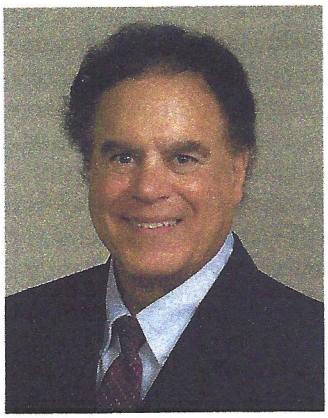

Why and how I was initially motivated to enter the neurofeedback field

Helping others was and is the most important motivation, and wanting to know why life, consciousness and the Universe exist is the second motivation. I was fortunate to have had a good 4 year education as a graduate student at the University of Waterloo (1966–1970) as I matured and gained a spiritual humility to better understand consciousness and myself and the Universe. In 1969 Steven Fox gave a series of lectures and workshops, including methods of implanting electrodes in the brain of a cat to do Neurofeedback (called EEG biofeedback in those days). He explained how he and his graduate students (Peter Rosenfeld and Alan Rudell) do EEG biofeedback and evoked potential biofeedback from implanted electrodes and scalp electrodes. In 1971, I was a postdoc at Albert Einstein College of Medicine, and I

Neurofeedback
https://doi.org/10.1016/B978-0-12-817659-7.00056-7

was introduced to Alan Rudell who was doing cat Neurofeedback training. I observed Alan preparing to do Neurofeedback with a cat moving around in a cage with electrodes implanted in the brain. I asked Alan what he was doing and he said that he was doing evoked potential biofeedback. He asked me to select a part of the cat's visual evoked potential and then he will train the cat to change the amplitude or latency or polarity. I knew that the lateral geniculate projects to cortical layer IV which determines the P-100 component, and so I selected it and asked him to reverse the polarity and make the positive P-100 a negative N-100. Alan raised his eye brow a bit and smiled – ok let's go! Initially, every now and then a negative potential would occur and immediately a milk reward was delivered to the cat through a tube in its mouth. Within 10–15 min the Cat was lapping up the milk and the P-100 became a N-100! So there you go, a convincing and eye opening firsthand experience that has been confirmed multiple times since 1969. Other motivating experiences while a young post doc included attending Eric Kandel lectures on the molecular mechanisms of EEG operant conditioning (for which he was awarded a Nobel Prize) and Dominic Purpura's influence. Alan placed electrodes everywhere in the brain and discovered that everything is modifiable, single neurons, groups of neurons, larger groups of neurons and the EEG.

In 1973, I was appointed as an assistant professor at New York Medical College in the department of Psychiatry. My office and laboratory were in the Brain Research facility with E. Roy John, a brilliant, multilingual and imaginative person with a deep passion for mankind and the clinical applications of EEG. Roy and Stephen Fox were friends as well as with Walter Freeman and many others from around the world, and he also was passionate about Neurofeedback. In 1977 I was appointed as an associate professor at NYU School of Medicine where I wrote the EEG biofeedback section of a NIH grant as a co-investigator, with E. Roy John as the PI. I was responsible for developing EEG biofeedback at a learning disabilities center in Long Island (BOCES) using one and/or two channels and reinforcing the alpha frequency. In the first year we successfully operantly conditioned children with various disorders, but after the second year the NIH grant funding was cut back and the Neurofeedback section was terminated. The focus shifted to patients with depression and aging and Alzheimer's and other psychiatric disorders. I continued to read the biofeedback scientific literature and later resumed working with EEG neurofeedback in 1994 in collaboration with Daniel Hoffman and Lexicor, Inc.

Opinion of the most important and landmark developments in the field over the fifty-year time span

I believe that the greatest contributions to the field of EEG biofeedback (Neurofeedback) were by the pioneers who laid the physiological foundations and the fundamental science in the 1960s–70s that later was buttressed by the 1970–1990s discovery of the molecular mechanisms by which operant conditioning changes the size and number of synapses. This was summarized in Eric Kandel's Nobel Prize in the year 2000. Since this time, the history of EEG Neurofeedback has been one of building on expanding computer technology coupled with the neuroscience knowledge to use EEG biofeedback to improve clinical outcome with fewer sessions and less cost. Kandel proved that neurofeedback had a bright future by demonstrating the how and why of operant conditioning at the molecular level. The single unit, multi-unit, evoked potential and EEG operant conditioning in animal studies of the 1960's by Edward Feta, Steven Fox, Alan Rudel, Peter Rosenfeld and Barry Sterman

were landmark studies. The human operant conditioning studies by Knott and Henry in 1941 and later by Joe Kamiya and Joel Lubar and Barry Sterman were also landmark studies that set the stage for the clinical applications of EEG neurofeedback. I believe that my and my colleague's implementation of normative database comparisons for assessment and protocol development, and our invention of real-time Z score neurofeedback in the 1990s–2000s were also landmark developments. I also believe that the implementation of 19 channel Neurofeedback, and especially 3-dimensional LORETA source neurofeedback in the 2000s were landmark developments. For example, since our first distribution in 2006 there are now over 7,000 clinicians using Z score Neurofeedback worldwide. This includes numerous VA medical centers and military rehabilitation facilities. Prior to 2006 there was no real-time Z score Neurofeedback – hence it was a game changer.

Another important development was the application of the physics of inverse solutions to measure the sources of the scalp EEG in the 1970s and 1980s. While working at NIH as the project manager for the development of the first 128 channel EEG, and to integrate EEG with fMRI and PET I had the opportunity to work with many brilliant scientists to cross-validate the accuracy of EEG inverse solutions. One of the inverse solutions that we tested was Low Resolution Electromagnetic Tomography (LORETA) in 1994. The use of EEG inverse solutions meant that EEG Neurofeedback of the sources of the EEG such as the amygdala, hippocampus, cingulate gyrus and all of the 88 Brodmann areas was possible. This is of huge importance. One of the principles of operant conditioning is "specificity", and by evaluating the 3-dimensional sources of the EEG in real-time one can link specific symptoms to dysregulation in specific brain networks. Very relevant to this, I and Dr. Juan Gomez published a paper on the relationship between frequency and time that furthered the understanding of exactly how to do EEG neurofeedback from Brodmann areas and network hubs and connections between hubs (Gomez and Thatcher, 2001).

In Addition to the above positive landmark developments, there have been some historical issues I consider negative. In spite of the solid physiological science underlying EEG operant conditioning (Kandel's Nobel prize and over 2,000 peer reviewed journal articles), insurance companies still fail to properly reimburse for EEG Neurofeedback. Recent specific negative developments include the insistence by certain biased individuals with competitive motives that only sham control studies and randomized control studies be used as valid science in support of the operant conditioning of the EEG. Over the last 100 years only about 5% of all clinical and/or medical publications involve sham controls of various types, and, therefore, this is a biased and unreasonable burden placed on the entire Neurofeedback field. In fact, there are numerous double-blind and various sham control published studies. However, the critics of neurofeedback demand more and more. Therefore, in my opinion a major hindrance to the development of neurofeedback is the biased and unjustified "put-down" criticism of Neurofeedback.

Author's most important personal contributions to the evolution of the field—past, present and future

I consider my most important contribution to be the 1994 introduction of a reference normative database to the field of Neurofeedback. In 1993 while working at the National Institutes of Health (NINDS) I received a call from Michael Hickey (CEO of Lexicor, Inc) who described their new 19 channel EEG amplifier and ideas for EEG neurofeedback. Michael explained

that there was no standardization of QEEG or any comparisons of patients to a reference population to help design Neurofeedback protocols and to link symptoms to dysregulation in the brain. I recommended that the reference normative database from birth to age 82 years that I developed at the University of Maryland be incorporated into the Lexicor QEEG assessment software. Michael liked the idea and invited me to travel to Boulder, Colorado (where I first met Steve Stockdale and Daniel Hoffman) to plan how to integrate the means and standard deviations of QEEG from birth to 82 years of age from my University of Maryland normative database. This we accomplished in a few months. The University of Maryland norms were first sold to clinicians by Lexicor, Inc. in June 1994. This was the first time in the history of EEG biofeedback that a normative reference database was used to assess a patient's brain before during and after neurofeedback. In 1998 I wrote an article in the Journal of Neurotherapy that described this new development in detail (Thatcher, 1998).

I consider the introduction of Z scores for assessment, protocol design and real-time Z score neurofeedback to be my second most important and enduring contributions to the field. In 1998, I also suggested to Lexicor a new form of EEG biofeedback that I called "Z Score Neurofeedback" in which real-time comparisons to an age matched reference population of healthy or normal subjects are used as a guide or "compass" to increase specificity and provide a uniform direction and threshold for the biofeedback process (Thatcher, 1998, pp. 16–21; 1999; 2000a; 2000b). At this time Lexicor was not able to implement my idea, and it was not until 2003 that I was in a position to implement Z score neurofeedback myself in the form of a distributable "dynamic link library" (DLL). In 2004, after extensive testing I distributed the DLL to Brainmaster, Inc. and Thought Technology, LLC. Brainmaster was the first to distribute the real-time Z score DLL in 2006, followed shortly by Thought Technology. Simkin, Thatcher, & Lubar, 2014 many different companies (Thought Technology, Mind Media, Neurofield, EEG Spectrum, Brain Master, Deymed, NxLink, EEGPro, and Applied Neuroscience) have distributed the real-time Z score DLL inside their respective software environments; and in 2019 there are over 7,000 users of this new invention. Since 2008 there have been over 60 scientific publications using Z score Neurofeedback (Bell et al., 2019; Kerson et al., 2008; Collura, 2008a; 2008b; 2008c; Collura., 2009; Collura et al, 2009; 2010; Decker et al., 2014; Duff, 2004; Frey and Koberda, 2015; Foster and Thatcher, 2014; Gluck, and Wand, 2014; Groeneveld et al., 2019; Guan, 2016; Hammer et al., 2011; Kaur et al., 2019; Engelbregt et al., 2016; Koberda, 2011; Koberda, 2012a; 2012b; Koberda, 2014a; 2014b; 2014c; 2014d; 2014e; 2014f; 2014g; 2014h; 2014i; Koberda, 2015a; 2015b; 2015c; Koberda et al., 2012a; 2012b; 2012c; Koberda et al., 2013a; 2013b; 2013c; Koberda et al., 2014a; 2014b; 2014c; 2014d; Koberda and Frey, 2015a; 2015b; Krigbaum and Wigton, 2014; Lambos and Williams, 2014; Little et al., 2014; Lubar, 2014; Pérez-Elvira et al., 2018; Pérez-Elvira et al., 2019; Simkin et al., 2014; Smith, 2008; Stark, 2008; Thatcher, 2000a; 2000b; 2000c; 2010a; 2010b,2010c; 2012; 2013; Thatcher et al., 2014a; 2014b; 2014c; Thompson and Thompson, 2014; 2015; Wigton, 2013; Wigton and Krigbaum, 2015.

Prior to Z score Neurofeedback clinicians had to guess about what threshold to set for a given frequency or location to trigger the feedback signal or reinforcer signal. The clinician had to ask and answer questions like: Shall I reward alpha rhythms when they exceed 10 μV? or 20 μV?, shall I inhibit theta rhythms when they exceed 5 μV or 10 μV? What threshold for coherence shall I use for a particular age or scalp location? What EEG frequency and amplitude will be the threshold for a given scalp location at a given age? Over the years different protocols had been developed where "one size fits all" were adopted independent of

age or symptoms. There was a lack of standardization and an abundance of arbitrary threshold selections prior to the advent of Z score Neurofeedback in 2006.

Z score Neurofeedback was a game changer because it greatly simplifies and standardizes EEG biofeedback by reducing many different metrics that are like apples and oranges (absolute power, relative power, ratios, coherence, phase) to a single or common metric of the Z score, i.e., the distance a given metric is with respect to the EEG from a group of age matched healthy normal subjects. Z score Neurofeedback also takes the arbitrariness and guess work out of setting a threshold to determine when to deliver a reward signal. For example, there is a unifying objective of reinforcing EEG measures of all kinds toward $Z = 0$ which is the center of the age matched normal population. This is like providing real-time feedback of a blood test for cholesterol or liver enzymes and reinforcing movement toward the standards of a normal healthy population.

In the following section I list my contributions which I consider to have had major positive influences on the field for the past twenty five years, and which, along with their continuing refinement, hold much promise for the future.

List of contributions to the field of EEG neurofeedback

1994

- First to Introduce and Implement a Normative Database for assessment prior to EEG Biofeedback (Lexicor). The goal was to use Z Scores from Norms for Assessment, Biofeedback Protocol Development & Evaluation of Treatment efficacy following Biofeedback (Thatcher, 1998).

1999

- First to publish how to compute LORETA Z scores in real-time for Neurofeedback (Gomez & Thatcher, 2001; Thatcher, 1999).

2002

- First to Produce Commercial Software that Integrates Conventional EEG with QEEG on the Same Screen at the Same Time from birth to 82 years called "NeuroGuide" that was later FDA registered in 2004.

2003

- First to Invent and Implement a "Real-Time DLL" (Dynamic Link Library) of 2 and 4 channel Z Scores ("Live Z Scores"- 1 msec time resolution) for EEG Neurofeedback that was later distributed to multiple Neurofeedback companies for usage by over 7,000 clinicians using "Real-Time" Z Score DLLs in 2018.

2004

- First to implement LORETA Z scores for Assessment and evaluation of clinical efficacy following Neurofeedback and Biofeedback.

2005

- First to Implement LORETA Source Correlations (Thatcher, Biver, & North, 2007a, 2007b).

2008

- First to create and implement a 19 channel Z Score DL that was licensed to numerous EEG companies.
- First to Implement Surface EEG Phase Shift & Phase Lock measures for Research and for Neurofeedback (Thatcher, North, & Biver, 2008a, 2008b).

- First to Implement Cross-Frequency Phase Lock & Phase Shift Duration of the surface EEG for assessment.

2009

- First to seamlessly integrate Z score QEEG Assessment and Neurofeedback in the same software platform and linking symptoms to Brodmann areas.
- First to Implement Surface Laplacian EEG Neurofeedback.
- First to Implement Average Reference EEG Neurofeedback.
- First to Implement a Symptom Check List to produce Neurofeedback protocols of the Surface EEG.

2011

- First to Implement LORETA Z Score Neurofeedback of the 88 Key Institute Brodmann area center voxels.
- First to Implement a Symptom Check List and PET, fMRI and neurological history to LORETA Z score Neurofeedback of Brodmann areas and functional connections between Brodmann areas.

2012

- First to Implement LORETA Coherence and Phase Difference in Neurofeedback.
- First to Produce the "Handbook of QEEG and EEG Biofeedback" a Textbook for Students and Professionals.

2013

- First to Implement LORETA Z Scores of Phase Lock & Phase Shift to Neurofeedback.
- First to Implement Real-Time Nodes (Brodmann Areas) and Connections (Coherence/Phase) between Nodes for Assessment and Neurofeedback (BrainSurfer).
- First to Implement Real-Time Phase Shift and Phase Lock Duration Between Nodes (Brodmann Areas) for Assessment and Neurofeedback (BrainSurfer).

2014

- First to Implement LORETA Phase Shift and Phase Lock Duration Z Scores for Assessment with Color Coded Contour Maps
- First to Implement an Automatic Clinical Report Writer that is Generated Locally to Empower Individual Clinicians Removing the need for External QEEG Report Services
- First to integrate a 19 channel Dry electrode headset with EEG Neurofeedback

2015

- First to Implement NeuroLink to allow patients/clients to assess symptom severity and seamlessly select a protocol to reinforce stability in dysregulated brain networks linked to the symptoms
- First to implement a Neural Network Injury Index of patients/clients following a concussion and TBI
- First to implement Effective Connectivity or measures of information flow between all combinations of 19 surface EEG channels using the Phase Slope Index (PSI) for assessment
- First to implement Effective Connectivity or measures of information flow between all combinations of 88 Brodmann Areas using LORETA with the Phase Slope Index (PSI) for assessment

2016

- First to Implement the Brain Function Index to allow patients/clients to assess symptom severity and seamlessly select a protocol to reinforce stability in dysregulated brain networks linked to the symptoms

- First to implement a Neural Network Injury Index of patients/clients following a concussion and TBI

2017

- First to Implement the Brain Function Index to allow patients/clients to assess symptom severity and seamlessly select a protocol to reinforce stability in dysregulated brain networks linked to the symptoms
- First to implement a Neural Network Injury Index of patients/clients following a concussion and TBI
- First to implement Effective Connectivity or measures of information flow between all combinations of 19 EEG channels using the Phase Slope Index (PSI) for assessment
- First to implement Effective Connectivity or measures of information flow between all combinations of 88 Brodmann Areas using LORETA with the Phase Slope Index (PSI) for assessment.
- First to implement Cross-Frequency Coupling and Cross-Frequency Coherence and Cross-Frequency Phase-Amplitude for assessment

2018

- First to implement EEG Biofeedback (Neurofeedback) using Cross-Frequency Coupling, Cross-Frequency Coherence and Cross-Frequency Phase-Amplitude Coupling.
- First to use swLORETA (Soler et al., 2007) with 12,700 MRI voxels for EEG Neurofeedback protocol design using the new NeuroNavigator in NeuroGuide.
- First to design and prepare for a future Cerebellum EEG Neurofeedback protocol. To be distributed in 2019 pending testing results.

2019

- First to Include Diffusion Tensor Imaging (DTI) Fiber Connectivity with Both Raw Scores and Z Scores to Help Neurofeedback Protocol Development and to Evaluate Pre versus Post treatment Brain Changes. Also the first to introduce Cerebellar EEG Biofeedback for patients with Parkinsonism and balance problems.

References

Bell, A. N., Moss, D., & Kallmeyer, R. J. (2019). Healing the neurophysiological roots of trauma: A controlled study examining LORETA z-score neurofeedback and HRV biofeedback for chronic PTSD. *NeuroRegulation, 6*(2), 54–70. https://doi.org/10.15540/nr.6.2.54.

Collura, T. (2008a). *Whole head normalization using live Z-scores for connectivity training* (pp. 12–18). Neuroconnections. April 2008.

Collura, T. F. (2008b). Whole-Head Normalization Using Live Z-Scores for Connectivity Training. In *Part 2 of 2* (pp. 9–12). NeuroConnections.

Collura, T. (2008c). Time EEG Z-score training: Realities and prospects. In J. Evans, L. Arbanel, & T. Budsynsky (Eds.), *Quantitative EEG and Neurofeedback*. San Diego, CA: Academic Press.

Collura, T. F. (2009). Practicing with Multichannel EEG, DC, and Slow Cortical Potentials. *NeuroConnections, January*, 35–39.

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

Collura, T., Thatcher, R., Smith, M. L., Lambos, W., & Stark, C. (2009). *EEG biofeedback training using live z-scores and a normative database*. Philadelphia: Elsevier.

Decker, S. L., Roberts, A. M., & Green, J. J. (2014). LORETA Neurofeedback in College Students with ADHD. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Duff, J. (2004). The usefulness of quantitative EEG (QEEG) and neurotherapy in the assessment and treatment of post-concussion syndrome. *Clin EEG Neurosci, 35*, 198–209.

Engelbregt, H. J., Keeser, D., Van Eijk, L., Suiker, E. M., Eichhorn, D., Karch, S., & Pogarell, O. (2016). Short and long-term effects of sham-controlled prefrontal EEG-neurofeedback training in healthy subjects. *Clinical Neurophysiology, 127*(4), 1931–1937.

Foster, D. S., & Thatcher, R. W. (2014). Surface and LORETA Neurofeedback in the Treatment of Post-Traumatic Stress Disorder and Mild Traumatic Brain Injury. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Frey, L. C., & Koberda, J. L. (2015). LORETA Z-score neurofeedback in patients with medically-refractory epilepsy. *J Neurol Neurobiol, 1*, 102.

Gluck, G., & Wand, P. (2014). LORETA and Spec Scans: A Correlational Case Series. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Gomez, J., & Thatcher, R. W. (2001). Frequency domain equivalence between potentials and currents using LORETA. *Int. J. of Neuroscience, 107*, 161–171.

Guan, J. (2016). The efficacy of Z-score neurofeedback training. In T. F. Collura, & J. A. Frederick (Eds.), *Handbook of clinical QEEG and neuropathy* (pp. 312–325). New York, NY: Routledge.

Hammer, B. U., Colbert, A. P., Brown, K. A., & Ilioi, E. C. (2011). Neurofeedback for insomnia: A pilot study of Z-Score SMR and individualized protocols. *Applied Psychophysiology and Biofeedback, 36*(4), 251–264. https://doi.org/10.1007/s10484-011-9165-y.

Keeser, D., Kirsch, V,Rauchmann, B, et al. The impact of source-localized EEG phase neurofeedback on brain activity-A double blind placebo controlled study using simultaneously EEG-fMRI- (submitted for publication).

Kerson, C., Gunkelman, J., & Collura, T. (2008). Neurofeedback using the phenotype and Z-score modalities. *Neuro-Connections* April, 24–28.

Koberda J, L., & Stodolska-Koberda, U. (2014). Z-score LORETA Neurofeedback as a Potential Rehabilitation Modality in Patients with CVA. *J Neurol Stroke, 1*(5), 00029.

Koberda, J. L. (2011). Clinical advantages of quantitative electroencephalogram (QEEG) application in general neurology practice. *Neuroscience Letters, 500*(Suppl), e32.

Koberda, J. L., et al. (2012a). Cognitive enhancement using 19-electrode Z-score NeurofeedbackJ. *Neurotherapy, 3*.

Koberda, J. L. (2012b). *Autistic Spectrum Disorder (ASD) as a Potential Target of Z-score LORETA Neurofeedback. The Neuroconnection- winter 2012* (p. 24). edition: ISNR).

Koberda, J. L. (2012c). Comparison of the effectiveness of Z-score Surface/LORETA 19-electrode Neurofeedback to standard 1-electrode. *Neurofeedback- J. Neurotherapy*.

Koberda, J. L. (2014a). Z-score LORETA Neurofeedback as a Potential Therapy in Depression/Anxiety and Cognitive Dysfunction. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Koberda, J. L. (2014b). LORETA Z-SCORE NEUROFEEDBACK IN CHRONIC PAIN AND HEADACHES. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Koberda, J. L. (2014c). Z-Score LORETA Neurofeedback as a Potential Therapy in Cognitive Dysfunction and Dementia. *J Psychol Clin Psychiatry, 1*(6), 00037. https://doi.org/10.15406/jpcpy.2014.01.00037.

Koberda, J. L. (2014d). Neuromodulation-An Emerging Therapeutic Modality in Neurology. *J Neurol Stroke, 1*(4), 00027.

Koberda, J. L. (2014e). Therapy of Seizures and Epilepsy with Z-score LORETA Neurofeedback. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Koberda, J. L. (2014f). Z-score LORETA Neurofeedback as a Potential Therapy in Depression/Anxiety and Cognitive Dysfunction. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Koberda, J. L. (2014g). LORETA Z-SCORE NEUROFEEDBACK IN CHRONIC PAIN AND HEADACHES. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Koberda, J. L. (2014h). Z-Score LORETA Neurofeedback as a Potential Therapy in Cognitive Dysfunction and Dementia. *J Psychol Clin Psychiatry, 1*(6), 00037. https://doi.org/10.15406/jpcpy.2014.01.00037.

Koberda, J. L. (2015a). LORETA Z-score Neurofeedback-Effectiveness in Rehabilitation of Patients Suffering from Traumatic Brain Injury. *J Neurol Neurobiol, 1*(4). https://doi.org/10.16966/2379- 7150.113.

Koberda, J. L. (2015b). Application of Z-score LORETA Neuro-feedback in Therapy of Epilepsy. *Neurol Neurobiol Volume1, 1*. https://doi.org/10.16966/noa.e001.

Koberda, J. L. (2015c). Traumatic Brain Injury: Is Neurofeedback the Best Available Therapy? *J neurol Neurobiol, 1*(3). https://doi.org/10.16966/2379- 7150.110.

Koberda, J. L., & Frey, L. C. (2015a). Application of Z-score LORETA Neurofeedback in Therapy of Epilepsy. *J Neurol Neurobiol, 1*, e101.

Koberda, J. L., & Frey, L. C. (2015b). Z-score LORETA Neurofeedback as a Potential Therapy for Patients with Seizures and Refractory Epilepsy. *Neurol Neurobiol, 1*. https://doi.org/10.16966/noa.101.

Koberda, J. L., Hiller, D. S., Jones, B., Moses, A., & Koberda, L. (2012). Application of Neurofeedback in general neurology practice. *J. of Neurotherapy, 16*(3), 231–234.

Koberda, J. L., Koberda, P., Bienkiewicz, A., Moses, A., & Koberda, L. (2013a). Pain Management Using 19-Electrode Z-Score LORETA Neurofeedback. *Journal of Neurotherapy, 17*(3), 179–190.

Koberda, J. L., Koberda, P., Bienkiewicz, A., Moses, A., & Koberda, L. (2013b). Pain Management Using 19-Electrode Z-Score LORETA Neurofeedback. *Journal of Neurotherapy, 17*(3), 179–190.

Koberda, J. L., Koberda, L., Koberda, P., Moses, A., & Bienkiewicz, A. (2013c). Alzheimer's dementia as a potential target of Z-score LORETA 19-electrode Neurofeedback. *Neuroconnection* (Winter edition, pp. 30–32).

Koberda, J. L., Moses, A., Koberda, P., & Koberda, L. (2012). Comparison of the Effectiveness of Z-Score Surface/LORETA 19-Electrodes Neurofeedback to Standard 1-Electrode Neurofeedback. *J Neurotherapy, 4*, 302.

Koberda, J. L., Moses, A., Koberda, L., & Koberda, P. (2012). Cognitive enhancement using 19-Electrode Z-score neurofeedback. *J. of Neurotherapy, 16*(3), 224–230.

Koberda, J. L., Moses, A., & KoberdaP, Winslow J. (2014). *Cognitive Enhancement with LORETA Z-score Neurofeedback.* AAPB meeting.

Koberda, JL. "QEEG/LORETA Electrical Imaging in Neuropsychiatry-Diagnosis and treatment Implications"- Advances in Neuroimaging Research"-Editor-Victoria Asher-Hansley-chapter2- published in September 2014. P-121-146. Nova Biomedical Publishing.

Koberda, JL. "QEEG/LORETA Electrical Imaging in Neuropsychiatry-Diagnosis and treatment Implications"- Advances in Neuroimaging Research"-Editor-Victoria Asher-Hansley-chapter2- published in September 2014. P-121-146. Nova Biomedical Publishing.

Krigbaum, G., & Wigton, N. L. (2014). A Methodology of Analysis for Monitoring Treatment Progression with 19-Channel Z-Score Neurofeedback (19ZNF) in a Single-Subject Design. *Appl Psychophysiol Biofeedback*, 2015 Mar 17 Mar 17. [Epub ahead of print].

Lambos, W. A., & Williams, R. A. (2014). Treating Executive Functioning Disorders Using LORETA Z-scored EEG Biofeedback. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Little, R. M., Bendixsen, B. H., & Abbey, R. D. (2014). 19 Channel Z-Score Training for Learning Disorders and Executive Functioning. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Lubar, J. L. (2014). Optimal procedures in Z score neurofeedback: Strategies for maximizing learning for surface and LORETA Neurofeedback. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.

Pérez-Elvira, R., Carrobles, J. A., López Bote, D. J., & Oltra-Cucarella, J. (2019). Efficacy of Live Z-Score neurofeedback training for chronic insomnia: A single-case study. *NeuroRegulation, 6*(2), 93–101. https://doi.org/10.15540/nr.6.2.93.

Pérez-Elvira, R., López Bote, D. J., Guarino, S., Agudo Juan, M., De León, R. J., Feiner, T., & Perez, B. (2018). Neurometric results of a case series using live Z-scores neurofeedback. *International Journal of Psychophysiology, 131*, S139–S140. https://doi.org/10.1016/j.ijpsycho.2018.07.375.

Simkin, D. R., Thatcher, R. W., & Lubar, J. (2014). Quantitative EEG and Neurofeedback in Children and Adolescents: Anxiety Disorders, Depressive Disorders, Comorbid Addiction and Attention-deficit/Hyperactivity Disorder, and Brain Injury. *Child Adolesc Psychiatr Clin N Am, 23*(3), 427–464. https://doi.org/10.1016/j.chc.2014.03.001.

Smith, M. L. (2008). *Case study.* April: Jack. Neurosconnections.

Soler, E. P.,.Dolan, V., Hadamschek, et al. (2007). swLORETA: a novel approach to robust source localization and synchronization tomography. *Physics in medicine and biology, 52*, 1783–1794.

Stark, C. R. (2008). *Consistent dynamic Z-score patterns observed during Z-score training sessions – Robust among several clients and through time for each client.* April: Neuroconnections.

Thatcher, R. W. (1998). EEG normative databases and EEG biofeedback. *Journal of Neurotherapy, 2*(4), 8–39.

Thatcher, R. W. (2000a). *3-Dimensional EEG Biofeedback using LORETA.* Minneapolis, MN: Society for Neuronal Regulation. September 23, 2000.

Thatcher, R. W. (2000b). EEG Operant Conditioning (Biofeedback) and Traumatic Brain Injury. *Clinical EEG, 31*(1), 38–44.

Thatcher, R. W. (2000c). An EEG Least Action Model of Biofeedback. In *8th Annual ISNR conference, St. Paul, MN, September.*

Thatcher, R. W. (2010a). *LORETA Z Score Biofeedback* (pp. 14–17). December: Neuroconnections. pg.
Thatcher, R. W. (2010b). Higher-Order Network Reworking – New Findings. In M. Ferrari, & L. Vuletic (Eds.), *The Developmental Relations between Mind, Brain and Education*. Springer.
Thatcher, R. W. (2010c). Reliability and validity of quantitative electroencephalography (qEEG). *J. of Neurotherapy, 14*, 122–152.
Thatcher, R. W. (2012). *Handbook of Quantitative Electroencephalography and EEG Biofeedback*. St. Petersburg, Fl: Anipublishing, Inc.
Thatcher, R. W. (2013). Latest Developments in Live Z-Score Training: Symptom Check List, Phase Reset, and Loreta Z-Score Biofeedback. *Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience, 17*(1), 69–87.
Thatcher, R. W., Biver, C. J., & North, D. (2007a). Intelligence and EEG current density using Low Resolution Electromagnetic Tomography. *Human Brain Mapping, 28*(2), 118–133.
Thatcher, R. W., Biver, C. J., & North, D. (2007b). Spatial-Temporal Current Source Correlations and Cortical Connectivity. *Clin. EEG and Neuroscience, 38*(1), 35–48.
Thatcher, R. W., North, D., & Biver, C. (2008a). Development of cortical connectivity as measured by EEG coherence and phase. *Human Brain Mapp, 12*, 1400–1415.
Thatcher, R. W., North, D., & Biver, C. (2008b). Intelligence and EEG phase reset: A two-compartmental model of phase shift and lock. *NeuroImage, 42*(4), 1639–1653.
Thatcher, R. W., North, D. M., & Biver, C. J. (2014a). Technical foundations of Z score neurofeedback. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.
Thatcher, R. W., North, D. M., & Biver, C. J. (2014b). Network Connectivity and LORETA Z score NFB. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.
Thatcher, R. W., North, D. M., & Biver, C. J. (2014c). BrainSurfer 3-Dimensional Z Score Brain-Computer-Interface. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.
Thatcher, R.W. EEG database guided neurotherapy (1999). In: J.R. Evans and A. Abarbanel Editors, Introduction to Quantitative EEG and Neurofeedback, Academic Press, San Diego.
Thompson, M., Thompson, L., & Reid, A. (2010). Functional Neuroanatomy and the Rationale for Using EEG Biofeedback for Clients with Asperger's Syndrome. *Journal of Applied Psychophysiology and Biofeedback, 35*(1), 39–61.
Thompson, M., Thompson, L., & Reid-Chung, A. (2014). Combining LORETA Z-Score Neurofeedback with Heart Rate Variability Training. *RW Thatcher and JF Lubar "Z Score Neurofeedback: Clinical Applications"*. San Diego, CA: Academic Press.
Thompson, M., Thompson, L., & Reid-Chung, A. (2015). Treating postconcussion syndrome with LORETA Z-score neurofeedback and heart rate variability biofeedback: Neuroanatomical/neurophysiological rationale, methods, and case examples. *Biofeedback, 43*(1), 15–26.
Wigton, N. L. (2013). Clinical Perspectives of 19-Channel Z-Score Neurofeedback: Benefits and Limitations. *Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience, 17*(4), 259–264.
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. *J Atten Disord*, 2015 Mar 30. pii: 1087054715577135. [Epub ahead of print].

NEUROFEEDBACK

THE FIRST FIFTY YEARS

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