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SPECIAL ISSUE

Current Practice of Neurofeedback: Where We Are and How We Got There

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This article tracks the evolution of the practice of neurofeedback over the past quarter century from the perspective of services offered at a private clinic. It describes why and how the authors changed their practices from interventions including medication, psychotherapy, and tutoring to biofeedback interventions. Their evolving practices required complex assessments including single- and two-channel quantitative electroencephalograph (QEEG) and later 19-channel QEEG combined with evoked potentials, heart rate variability, continuous performance testing, and neuropsychological assessment. The article stresses that interventions require a multimodal approach. The neuroanatomical rationale for combining neurofeedback and heart rate variability (HRV) training is provided as well as a discussion of how a systems theory of neural synergy helps explain how neurofeedback influences brain networks. Assessment procedures are described in some detail because that information is used to develop effective interventions that typically combine neurofeedback (single-channel or LORETA Z-score neurofeedback, as indicated) with HRV training. The authors stress using evidence-based approaches, basing intervention on assessment, and keeping current with new developments in applied neuroscience.

Introduction and Overview

A retrospective look at the past quarter century allows us to review current practice in neurofeedback (NFB) from the perspective of how our clinical center has evolved since the early 1990s. Many approaches exist in the field of NFB and biofeedback, and no two clinics will be alike; thus, this is a personal view based on evidence-based approaches that have led to good outcomes for clients in our practice. The interventions are ones we have learned from others and refined over the years: We pay homage to our teachers (especially Joel and Judy Lubar plus Barry Sterman for NFB, and Dick Gevirtz plus Paul Lehrer for biofeedback and heart rate variability [HRV] training) by passing on their knowledge in our own teaching, which now spans presentations in more than 20 countries on five continents.

What represents state-of-the art NFB practice circa 2016? Much remains the same as when the field started more than four decades ago, namely, the provision of a carefully tailored, individualized program of electroencephalography (EEG) training for each client that is based on a comprehensive assessment. Although there have been some widely promoted instruments designed for one-size-fits-all approaches and other interventions that are symptom based, the research evidence strongly favors customized, individualized training based on assessment (see Tan, Shaffer, Lyle, & Teo, 2016). The gold standard has always used EEG assessment findings that are then matched to history, current symptoms, and client goals in order to design training. Obviously, the clinician's knowledge of disorders, brain function, and neuroanatomy also comes into play when developing the treatment approach.

A lot has changed, too, in the 21st century. The equipment for providing NFB has become more refined, with faster sampling rates possible with faster computers, so we can now look accurately at activity in the Gamma range. The biggest advance has been applying the mathematics of Roberto Pasqual Marqui's LORETA and linking that source localization with existing databases so that specific sites and networks within the cortex can be identified and trained. As well as advances in NFB, the range of adjunctive techniques has broadened, with biofeedback approaches being more widely applied alongside NFB. HRV training, for example, is developing a solid research base. Neuromodulatory techniques that involve stimulation are becoming increasingly more popular, too, although most are not yet well researched. Thus, the learning curve for the practitioner is different, with more material to cover and a wider range of equipment and approaches available. Although there are more learning opportunities available at a lower cost because of technological advances, such as webinars and the use of computerized supervision opportunities via Skype and GoToMeeting, there is also more to learn because the field of neuroscience continues to expand. *The Neurofeedback Book*, which provides an introduction to basic concepts and knowledge all in one volume, has grown from 457 pages in the first edition (Thompson & Thompson, 2003) to 857 pages in the second edition (Thompson & Thompson, 2015b). The Biofeedback Certification International Alliance (BCIA) continues to be the gold standard for certification in our field, and there is an additional small separate training and credentialing body for quantitative EEG (QEEG). BCIA offers top-quality webinars to make certification more accessible and to help those already certified stay up to date.

Public awareness of NFB has also increased. This is partly due to books that make the field accessible for the broader public. In the 1990s, we had Jim Robbin's *Symphony in the Brain*. More recently, Norman Doidge's *The Brain That Changes Itself* and *The Brain's Way of Healing* have contributed to the concept of neuroplasticity becoming common knowledge. NFB is mentioned in passing in the second book, and Doidge intends to write a further volume that contains detailed NFB stories. Awareness of brain health is also on the rise as baby boomers age and worry about cognitive decline and athletes become more circumspect about head injuries due to media headlines and films such as *Concussion*. It is thus an exciting time, both because our field has more to offer in the way of interventions and because the public is more aware of our services. Licensed professionals may actually be able to make a living providing NFB services.

One continuing weak link is the availability of graduate programs that teach about our field and the paucity of research money available for graduate students interested in the area of NFB. Strong programs at the University of Tennessee and the University of North Texas folded when their founders retired. Saybrook University in Oakland, California, now provides PhD specializations as well as nondegree certificates in biofeedback and NFB, with coursework on QEEG assessment as well as HRV training. Alliant University (formerly the California School of Professional Psychology) continues to offer a strong program in psychophysiology that includes biofeedback under the guidance of Dick Gevirtz. Graduate students there have also produced research concerning neurofeedback.

Outside the United States, NFB training at universities appears to be on the rise. Many campuses of the national university in Mexico, for example, offer courses. In Korea, physicians are leading the field, and with financial support from government, EEG data have been recorded on more than 900 people and a Korean normative database is being developed (SeungWan Kang, personal communication, February 16, 2016).

Research has also been expanding exponentially, although grassroots demand, not research, is what seems to increase demand for NFB training. It is interesting to note that much of the research comes from countries outside the United States. In North America, there has been a bias toward research designs that were developed for drug studies. NFB, however, does not act like a drug that has an effect only while in the body: NFB is like exercise for the brain, and like exercise, it can produce lasting changes. Research designs used in studies concerning the benefits of exercise would be more appropriate than double-blind, placebo-controlled research designs used in drug studies. World Health Organization standards for research are that comparisons should be made to already established interventions, not to a placebo, if an efficacious treatment exists and there are studies showing that, for attention-deficit/hyperactivity disorder (ADHD), NFB training produces outcomes that are equivalent to those obtained with the standard treatment of stimulant medication (Fuchs, Birbaumer, Lutzenberger, Gruzelier, & Kaiser, 2003).

The applications of NFB used in studies that try to replicate research methods used in drug studies—double-blind, randomized, placebo-controlled trials—are not what constitutes the gold standard for the clinical practice of NFB. The persons providing the service should not be blind to the intervention; indeed, they should be actively working with the patient while also monitoring the EEG and making sure good-quality feedback is being provided. Otherwise, you may be primarily reducing muscle artifact or suppressing eye blinks rather than training EEG patterns. Also, NFB is not a stand-alone treatment when one is doing good clinical practice. NFB is simply a tool that, in good clinical practice, is applied along with coaching and counseling and in combination with other modalities, such as biofeedback and metacognitive strategies, or even in combination with medications. There are carefully done case studies and case series papers (Lubar, 1995; Lubar & Shouse, 1976; Lubar, Swartwood, Swartwood, & O'Donnell, 1995; Shouse & Lubar, 1979; Thompson & Thompson, 1998; Thompson, Thompson, & Reid, 2010) that describe acceptable clinical practice and good outcomes, but these papers are never included in the meta-analyses that set particular criteria for research design that eliminate most of the clinical studies and case series. An egregious example was a recent meta-analysis purporting to evaluate the efficacy of NFB for ADHD. It was sponsored mainly by drug companies, and the authors examined 16 studies, excluding more than 200 research publications that did not meet their narrow criteria for review (Cortese et al., 2016). They concluded that the more blinded the raters, the weaker the support for NFB efficacy. An alternative conclusion is that the more blind the raters, the poorer the quality of the NFB provided to subjects. For a meta-analysis involving a similar number of studies (15) but with a more favorable conclusion drawn from the controlled studies concerning ADHD, one that accords NFB the highest level of efficacy, see the article by Martijn Arns and an international group of researchers (Arns, De Ridder, Strehl, Breteler, & Coenen, 2009).

Decisions Regarding Training

Joel Lubar taught us 25 years ago that the real criterion for successful NFB that gets lasting results is whether there are EEG changes. Yet pre-post EEG measures are not often included among the outcome criteria in studies, so we urge practitioners to record the learning curves regarding EEG parameters. Good outcomes also depend to a large extent on the therapeutic alliance between the patients and their trainer. If this encourages nonspecific factors that affect improvement and thus add to efficacy, while not taking away from the planned training effect related to changing brainwave patterns, then this should be applauded. As Herbert Benson said in an address at the Association for Applied Psychophysiology and Biofeedback (AAPB), "Recruit the placebo: it is remembered wellness" (Benson, 1997). Many years later, Dirk De Ridder, a noted neurosurgeon from Belgium who is now professor of neurosurgery in New Zealand, cited evidence for a placebo network in a talk given at the annual meeting of the International Society for Neurofeedback and Research. He reviewed research (Benedetti, Mayberg, Wager, Stohler, & Zubieta, 2005) that showed that, indeed, there is a placebo network that involves the hippocampus, thus validating the idea that placebo effects involve memory-based improvements, which aligns nicely with Benson's idea of getting back to a remembered state of wellness.

At the ADD Centre and Biofeedback Institute of Toronto, we have always combined biofeedback with NFB. We currently use HRV training with all our patients, although the objectives for training with this modality will vary from person to person. (With young children, we may not have sensors on but will teach belly breathing, having the child place one hand on their tummy and the other on their chest so they can learn the difference between thoracic and diaphragmatic breathing.) Other biofeedback measurements beyond HRV training will be used depending on the patient and the results of a stress assessment. The stress assessment can delineate which variables should be monitored and trained. These might include skin temperature, electrodermal response/skin conductance, electromyogram, respiration, and heart rate. Perhaps more importantly, this assessment allows the patients to observe how even a minor stress can change a number of physiological parameters and that by relaxing and breathing diaphragmatically, they can move these variables in a favorable manner.

Decisions as to what approach we should employ when we are using NFB with a patient have grown steadily more complex and thus more difficult over the past 25 years. A practitioner must decide, for example, on single- and/or two-channel training versus 19-channel LORETA Z-score NFB (LNFB). Or perhaps using both is appropriate. We have numerous current clients whose training combines single-channel NFB alternating with LNFB twice a week. LORETA mathematics takes the data that are measured on the surface at the standard 19 locations of the International 10-20 System of electrode placements and finds the source of that activity deeper in the cortex. The LORETA program displays the source in horizontal, sagittal, and coronal sections that look much like a magnetic resonance image (MRI) display. When linked with databases, the standard deviations for the activity can also be determined. A person with depression, for example, might have excess Beta activity at 26 through 30 Hz at Fz, F3, F4, as seen on brain maps, and source localization might indicate Brodmann area 25 (subgenual cingulate) as the source and indicate that the amplitude of this activity is 3.5 standard deviations above the database norms. The practitioner, based on this information plus myriad other findings from interview and assessment measures, may then decide to do single-channel training at Fz to reduce 26 to 30 Hz (and also set parameters to inhibit and/or enhance other frequency ranges, as appropriate) or may decide to do LNFB and directly target Brodmann area (BA) 25 along with other appropriate parameters. If depression is the main symptom, there will also be counseling regarding diet (take a fish oil supplement rich in omega-3 essential fatty acids), exercise (increase physical activity and watch the YouTube video "23 and ½ Hours" to review the benefits of being active), and sleep hygiene.

One example of doing both regular NFB and LNFB is a young man, age 25, who does one session of single-channel NFB each week that emphasizes increasing sensorimotor rhythm (SMR; 12–15 Hz) at C3 and C4 to improve management of epileptic seizures that are poorly controlled by medications alone. He does a second session of LNFB to target other areas that were found with 19-channel assessment to be well outside database norms and that match with other symptoms related to mood and learning problems.

For every client, we have to make decisions as to sites for training, frequencies to be enhanced or inhibited, connectivity measures, and other targets for training involving combinations of amplitude, coherence, and phase. With LNFB, one can alternatively choose networks for training. Making these choices can be daunting for beginners in this field, especially if they do not have a working knowledge of functional neuroanatomy, and delineating training parameters continues to be difficult even for experienced people because it requires hours of painstaking analysis, including looking at every second of the raw EEG. (Using automatic artifacting without examining the whole raw EEG might lead to missing high-amplitude activity that was clinically important, such as a series of spike-followed-by-a-slow wave that suggests seizure activity.) After EEG analysis is done, there is thinking about matching findings to symptoms, targeting problem areas while being careful not to change anything that is outside database norms that relates to positive functioning for the client. (Examples we have seen include differences in the auditory cortex in someone who is a musician and has perfect pitch and differences in Wernicke's area in a best-selling author who has extraordinarily well-developed linguistic skills.) To help clinicians increase their comfort with neuroanatomy, we wrote a book specifically designed to assist NFB practitioners called *Functional Neuroanatomy Organized With Reference to Networks, Lobes of the Brain, 10-20 Sites, and Brodmann Area* (Thompson & Thompson, 2015a). It was published by the AAPB in 2015 and is available on their Website.

Neuromodulation

Some people seem to be opting out of the requirement to do careful EEG analysis in the face of this complexity, and instead they are trying stimulation approaches that are not yet evidence based. This is not true NFB and is not a learning approach based on operant conditioning principles. Thus, terms such as *neuroregulation* and *neuromodulation* are used to cover the broader field. With the exception of transcranial direct current stimulation (tDCS) and some cranial-electrical-stimulation methods that have research behind them (see the chapter on adjunctive techniques in *The Neurofeedback Book*; Thompson, & Thompson, 2015b), we do not currently use methods that involve stimulation. Before using any of the various stimulation techniques at our center, we are awaiting research studies that clearly inform us as to what sites and connections are being changed and the effects (and side effects) of the approach, as well as information on what kind of assessment to do to determine who the appropriate candidates are for the various stimulation techniques that are available, such as LENS, Neurofield, and high-performance NFB. Note that those three approaches, although all use stimulation, are very, very different so you have to evaluate them separately and cannot lump them together. It is, of course, prudent to do additional training specific to an instrument before using that system with clients.

Our recommendation to people entering the field is to begin by taking the time and effort required to acquaint yourself with single-channel EEG assessment and training and to slowly enter the field of NFB by working initially with relatively simple cases such as attention difficulties, reading problems, or anxiety. We also suggest augmenting the NFB with some easy-to-do biofeedback, such as HRV training.

Historical Perspective

At the ADD Centre and Biofeedback Institute of Toronto, we are using approaches today that combine traditional approaches to patient care learned in the 1960s and 1970s with methods developed in psychophysiological research laboratories over the past 50 years. Reviewing how we got to where we are today helps explain the methods we use, when we use them, and how and why we combine techniques. We came into this field of NFB with backgrounds in anthropology, teaching, applied psychology (Lynda), biochemistry, physiology, medicine, psychiatry, and a little neurology plus a lot of neuroanatomy (Michael). There was also some real-world experience in business as Lynda owned and ran learning centers. It became clear that NFB interventions were achieving gains in academic functioning levels that equalled those achieved with the best tutoring practices. In addition, the clients were improving their attentional skills and showing better performance on intellectual measures (Thompson & Thompson, 1998). The learning centers were sold as the ADD Centre grew.

From a business perspective, the downside to a NFB intervention was that you did not get repeat business: Once the child with ADHD did 40 or so sessions of training and shifted their brainwave patterns to a more mature pattern (less Theta relative to Beta, for example), they could pay attention in school and did not require additional NFB. When you run a tutoring business without any NFB, children with ADHD are repeat customers. You get them up to speed and then, the next year, they fall behind again because they are not paying attention in class, and they come back for more individualized teaching to close the new gaps in their skills.

We were enthusiastic about a nondrug approach to improving attention because, over the years, we had observed that stimulant drugs for ADHD had only short-term efficacy and that innumerable side effects were associated with psychotropic medications. Lynda's doctoral dissertation—a longitudinal study concerning self-concept and locus of control in hyperactive children treated with methylphenidate—had made her familiar with the utility and the downside of stimulant medications. Michael had been prescribing medications for 30 years and was similarly aware of the pros and cons of drug therapy, in particular for ADHD. Concerning medications, our guiding principle has been, "Medications when necessary, but not necessarily medications," as espoused in *The A.D.D. Book* (Sears & Thompson, 1998).

A half century ago, when Michael graduated in medicine and began training in psychiatry, the main tools were talking to our patients (psychotherapy) and giving them medications (psychopharmacology). He also encouraged meditation, which was popular in the 1960s. The terms used for these three approaches have changed over the years, not unlike fashions in other areas, but the basic methods have been used for millennia. That long period of use is obvious when it comes to listening to someone and giving advice, whether it be a priest, pastor, psychiatrist, or someone doing cognitive behavior therapy. Similarly, meditation in various forms is a mainstay of ancient Eastern traditions and martial arts. Medications, too, are thousands of years old when you consider medicinal plants; indeed, among the medications used today, about a third are plant based. Recall that acetylsalicylic acid, marketed as aspirin, originally came from the willow tree; reserpine, an antihypertensive, came from snakeroot; atropine from deadly nightshade; physostigmine from calabar bean; and digitalis from foxglove. For foxglove, there is a written reference with its use recorded in Wales in 1250. Such remedies were used for centuries before the forerunners of multibillion dollar drug companies copied them and marketed them as drugs.

Medications or Learning Through Operant Conditioning?

Psychotherapy, meditation, and educational approaches can all have good effects, although outcomes are seldom carefully measured. This is an area in which NFB practitioners have an edge—we do measure a lot of variables before, during, and after training. Medications for psychiatric illnesses can be life-saving, but medications have long lists of side effects that remind us that these drugs are typically delivered throughout the body, rather than targeting a specific brain area. The medicines can help relieve the patient's symptoms; however, for disorders such as ADHD or depression, when medications are removed, the symptoms usually return. From a biochemical viewpoint, this makes perfect sense because down-regulation of receptivity at synaptic junctions was first described in the late 1950s. The receptor sites on the dendrite have a surfeit of neurotransmitter available, so over time, there is a decrease in receptivity (Vles et al., 2003; Yanofski, 2010, 2011).

Now it perhaps occurs to the reader that this down-regulation is exactly the opposite effect to that which occurs with learning. With repeated stimulation, as occurs during NFB, the receptor sites change and become more sensitive due to a process called long-term potentiation (LTP). More receptor sites, including the NMDA sites on the receptor surface of the dendrite that were blocked by magnesium, are opened and, in addition, new receptor sites are formed. This has two completely different results as compared with the use of medications. First, changes are made only by receptors that are involved in the learning of a new skill or state; thus, changes target specific brain networks. Second, these changes have the potential to be long-term if the pathways continue to be exercised. This process of LTP is postulated as being one of the factors involved in obtaining lasting effects after NFB training.

In the early 1970s, Michael was aware of biofeedback because it was introduced at the University Hospital in London, Ontario, by Gil Heseltine, an innovative head of the Department of Psychiatry when Michael was director of training in psychiatry at the University of Western Ontario. Biofeedback was an appealing approach because it was noninvasive treatment based on learning to self-regulate physiological variables not usually under conscious control. The patient was rewarded for changing finger temperature and muscle tension. Cold peripheral skin temperature in some patients correlated with tension and anxiety. When they relaxed their neck and shoulders and breathed at a yoga rate of about six breaths per minute through abdominal/diaphragmatic breathing and then did imagery of their hands getting warm, their finger temperature indeed rose. Patients could also learn to decrease blood pressure while being monitored. This seemed like a miracle, but the problem was that effects did not last unless patients practiced on a regular basis. Because of the lack of generalization to everyday life, the biofeedback unit at the University Hospital eventually folded.

What is different and exciting about the HRV training done today is that you are training an oscillatory system. With HRV training you can change baroreceptor gain, so results may be lasting. This parallels training the EEG, which is also an oscillatory system. You get lasting effects as you train thalamo-cortical loops associated with the production of EEG rhythms when doing NFB. You are resetting the pacemaker.

Alpha Awareness and SMR Training: The Tools of NFB

In the mid-1950s, Joe Kamiya showed that a person could be aware of mental states associated with the production of Alpha frequencies. Applications for relaxation using Alpha training and for studying consciousness via introspection and awareness of mental states grew out of his work (Kamiya, 1968). On the operant conditioning front, Barry Sterman's careful animal research established that brainwaves could be trained. He focused particularly on 12- to 15-Hz activity measured across the sensorimotor strip that he named *sensorimotor rhythm* (Sterman & Bowersox, 1981; Wyrwicka & Sterman, 1968). Both Sterman and Joel Lubar did careful work in human subjects who had epilepsy as they fine-tuned methods of operant conditioning of EEG patterns in the 1970s and 1980s. Lubar branched out into treatment for a hyperactive child (Shouse & Lubar, 1979), and soon ADHD became the most common condition treated with NFB.

Awareness of NFB in the medical community has never been high, and we did not hear about Kamiya, Sterman, Lubar, or NFB until 1991. Once we were aware of it, the logic of using learning to target the exact neural systems that required correction, and thus being able to change only that which required some adjustment, as well as the potential, through learning, to effect a long-term change, was simply irresistible. NFB as an intervention additionally had the tremendous advantage of giving us measurements, something that is generally lacking in psychotherapy. As Lubar has always stressed, NFB involves learning, and you should track learning curves for variables of interest (amplitude of Theta activity in a particular frequency band, for example) both within and across sessions.

19-Channel Data

Deciding what data to track for measuring changes with 19-channel data is more complex than tracking frequency bands of interest in a single-channel assessment done at the vertex. Certainly, changes in both EEG amplitudes and coherence patterns show up clearly using database comparisons. All databases involve financial investment and considerable time spent learning to apply them. We have used Sterman-Kaiser Imaging Labs (SKIL), WinEEG (from Juri Kropotov's group in St. Petersburg), and Neuroguide (from Robert Thatcher) over the years. Currently, we do our own in-house analysis using Neuroguide on data collected with Mitsar equipment and also collect data using the eVox from Evoke Neuroscience. This New York–based company has developed equipment that uses the most modern EEG amplifiers, and they provide data analysis to physicians. Based on 20 minutes of data collection, they provide analysis of 19-channel EEG (brain maps for eyes-open and eyes-closed conditions, plus dominant frequency information), a report on evoked potentials that indicate brain-processing speed, scores from a continuous performance test (CPT), and HRV assessment, all in one report. As they further develop feedback software, it is likely that more doctors in the United States will start providing both brain function assessments and NFB training.

As an aside, it is interesting that, whereas psychologists have dominated the field of NFB in North America, in other countries, notably Korea, physicians have taken the lead. As mentioned above, data for a Korean database have been collected on more than 900 people, and the project is supported by government funding. Funding for NFB research in the United States, on the other hand, has been hard to come by. Currently, the National Institute of Mental Health has approved more money for research using functional MRI (fMRI) NFB than it has for regular NFB.

Thatcher's group has done an innovative job of linking the LORETA mathematics developed by Roberto Pasqual-Marquis with the Neuroguide database to make LNFB relatively easy to apply, and more recently, this has also been done by Evoke Neuroscience. The tough part is in the decision making regarding which of the myriad possible variables to train, which requires considerable thought concerning matching EEG findings to symptoms.

Beginning with Single- and Two-Channel NFB

Once we heard about NFB, we were intrigued, especially because it offered a nondrug alternative to treating attention problems. So Michael attended a workshop given by Joel Lubar in Florida in February 1991. He came home enthusiastic about the scientific basis for EEG biofeedback and embarked on learning more, with time spent productively with Tom Allen, who had been asking the best questions at Lubar's workshop. Allen at that time was both seeing patients and helping design equipment for Thought

Technology. We spent a week with Joel and Judy Lubar in Knoxville learning about their effective approaches for treating children with attention problems. After measuring EEG in our own children and their friends, doing at least 100 single-channel assessments following Joel Lubar's methods, we decided that there was enough face validity, as well as published studies, to embark on offering NFB training to paying clients. We opened the ADD Centre using the Autogen A620 equipment with the software Joel Lubar had designed and the F-1000 equipment from Focused Technology that Tom Allen was using. ADD Centres Ltd. was incorporated in 1993, a year after the first NFB center in Canada, the Cognitive Re-Regulation Program run by George Fitzsimmons, was opened in the Education Department at the University of Alberta in Edmonton. Although we did not know him at the time, we subsequently learned how to do 19-channel assessments using Lexicor equipment from George Fitzsimmons when he offered a week-long workshop in Hamilton, Ontario, in the mid-1990s.

Admittedly, it all began with a very basic and simple degree of knowledge about NFB and its mechanisms. The idea of neuroplasticity was still not well researched, and publications about NFB producing increases in gray matter and white matter volume were still more than 20 years off (Ghaziri et al., 2013). Although we had a good theoretical basis for training SMR in seizure disorders and ADHD, we did not have quite as good a rational for using NFB for the comorbidities commonly found in people with ADHD, such as Asperger's syndrome, autism spectrum disorders, depression, anxiety, learning disabilities, and so on. So our mantra became "Promise less and deliver more." Lynda, who ran the clinical side of things, would tell prospective clients that NFB had been shown to improve self-regulation of attention but that NFB was still considered experimental for conditions other than ADHD and epilepsy, because not enough randomized controlled research had been done. This is still true today. Nevertheless, improving attention is something that is important in many disorders. Improving attention also benefits people who have no "disorder" but who want to optimize performance. There is thus, potentially, a very broad market for NFB.

Tracking Results

Because we were initially still somewhat skeptical, from the start the ADD Centre procedures used not only EEG measures but also both subjective measures (questionnaires) and objective testing (intellectual and academic measures, plus scores on a CPT) to measure results. Tracking results, we were astonished to find an average 12-point gain in scores on the Wechsler Intelligence Scales. This was in line with gains in intellectual functioning measured by Joel Lubar (Lubar et al., 1995) and Michael Linden (Linden, Habib, & Radojevic, 1996). We documented these results when we published our first case series, based on pre- and posttesting of 111 patients with ADHD who had done 40 sessions of training. Other results included not just IQ gains but also statistically significant grade point gains in reading, spelling, and mathematics, plus significant gains in scores on the T.O.V.A. CPT. (Later we added the Integrated Visual and Auditory [IVA] CPT to our test battery as well.) We also documented reductions in the Theta/Beta power ratio that Lubar had taught us about (Thompson & Thompson, 1998). Indeed, in those 111 cases reviewed for the 1998 publication, there was a drop in the Theta/Beta power ratio in 110 cases. The single case that did not show a drop remained at the exact same level.

Note that, over time, we have had some cases that actually showed a Theta/Beta increase. In those cases, some other parameter of interest, usually the "busy-brain"/SMR ratio (23–35 Hz/12–15 Hz) showed a decrease and the individual had the excess Beta pattern seen in people with ADHD plus anxiety, so high Theta/Beta was not their problem in the first place.

The normative database for single-channel assessment of Theta to Beta power ratios was subsequently published in 1999 (Monastra et al., 1999) with an update in 2001. We continue to find those norms highly useful. Recent reviews of the ability of a Theta/Beta ratio to discriminate between people with and without ADHD suggest that it is not, however, as sensitive as it used to be. This appears to be due to increased Theta amplitudes in the general population, not due to any changes in patterns seen in people with ADHD (Arns, Connors, & Kraemer, 2013). Although the reason for this increase in Theta has not been established, reduced hours of sleep is a likely candidate. That, in turn, may be linked to increased use of electronic devices and electronic entertainment by children, adolescents, and young adults (Swingle, 2016).

Combining NFB with Biofeedback

From the beginning, we looked at combining NFB with biofeedback because, after obtaining the F-1000 equipment from Tom Allen, we did training with Frank and Mary Diets in Arizona and learned more about the use of their F-1000 equipment. It measured temperature and electrodermal response as well as respiration and the EEG. It was amazing equipment that had both analog and digital filters for the EEG. Frank remains the only person we have ever met who could, at will, produce an increase in any frequency. You could hook him up to his equipment and tell him to produce 7-Hz activity and, amazingly, you could see an increase in 7-Hz amplitude on the spectral array. Because Mary had been a biofeedback practitioner teaching relaxation techniques at Canyon Ranch before she convinced Frank to use his electrical engineering skills to build her some EEG equipment, we learned biofeedback from her and started combining NFB and biofeedback very early in our practice. Lubar's assessment and training programs for the Autogen A620 equipment were also superb, and we used the A620 for our initial assessment and practice training session with every client for more than a decade.

There were also workshops with Siegfried and Susan Othmer. Although we subsequently used their software for the A620 for feedback, we were never comfortable with a symptom-based approach (underarousal vs. overarousal, for example) or with training using bipolar (sequential) placements across the hemispheres or ultra-slow-frequency training. Both the latter approaches lack a theoretical and research basis grounded in neuroanatomy and neurophysiology. Instead, we based our training on the single- and two-channel assessments Lubar had taught. Lubar has noted that when sequential training is done, it should usually be within one hemisphere or along the midline sites, such as FCz and CPz for training clients with ADHD.

Note that training slow cortical potentials (SCP), as researched at the University of Tuebingen, does have research backing and theoretical underpinnings. The efficacy of SCP NFB has been shown to be equivalent to regular Theta-Beta training for ADHD, and the effects were shown to last with 2-year follow-up (Gani, Birbaumer, & Strehl, 2008). The ADD Centre approach remained firmly grounded in using quantitative data from single-channel assessments as the basis for NFB interventions for uncomplicated ADHD while doing 19-channel assessments in complex cases, such as head injuries or ADHD with comorbidities. We respect the SCP work involving training the DC shifts that reflect polarity changes in broad sheets of glial cells. This is not the same as the EEG activity produced by pyramidal cells. SCP work was pioneered by Niels Birbaumer and Ute Strehl and is well established for treating ADHD (Strehl et al., 2006). Regular NFB, however, seems to us to be easier to do.

Developing a Rational for NFB Interventions Based on Functional Neuroanatomy

We faced a quite perplexing question. Why were ADD Centre staff getting good, indeed, excellent results with a single electrode sitting at the vertex (Cz) with such complex disorders as Asperger's syndrome and even in some cases of autism? This was in the realm of too-good-to-be-true, and we really were reluctant to share some of our results because we had neither theoretical nor research-based explanations.

Particular frequencies measured at Cz appeared to correlate fairly well with specific mental states. We knew areas of the brain could have different functions and that BAs could be even more specific with respect to functions, but we could put our electrode over only some of these BA sites, and they did not really appear to be the most important ones for some of our patient's symptoms. Yet the symptoms were getting better when we just left the electrode at Cz or FCz (FCz in adults because some functions move slightly forward as the frontal lobes mature through to the mid-20s, so that what you see at Cz in a child may be better measured at FCz in an adult). Why these widely based, very positive results from Cz training? In particular, Michael was astonished at improvements in children with autism because in the early 1980s, he had been medical director of a large center for the most seriously disturbed preschoolers in the Toronto area. Children with autism in the 1980s receiving daily state-of-the-art psychiatric and educational methods showed slow gains over years of therapy. Why was NFB training twice a week getting far better results in children on the spectrum, including changes in emotional understanding of themselves and themselves in relation to others? We were using single-channel NFB at Cz or FCz. Why was it that the emotional understanding of gesture and speech intonation and the understanding of nuance and innuendo did not require moving that electrode to T6 (new nomenclature, T8) over the temporal-parietal junction? And why did we not have to train at F10 to influence the inferior frontal area (BA 11) to reduce the high-amplitude slow waves or to decrease Beta spindling?

Systems Theory of Neural Synergy (Networks)

With Michael's background in neuroanatomy, he began to think about what might be influenced at Cz and FCz. When we reduced spindling Beta at that location and observed that our patient's anxiety was reduced, what might have occurred? Well, the cingulate gyrus was beneath those electrode sites. The cingulum runs through that gyrus. We knew the cingulum was a key to understanding the limbic system and its connections. These white matter tracks connect the frontal lobes, including the medial and ventral aspects, to the central, parietal, and temporal lobes, even connecting as far around as the temporal pole. We could theorize that it might even connect to areas that were themselves connected to the uncinate fasciculus and thus, perhaps, to the amygdala, the hippocampal region, and to the inferior and medial aspects of the frontal lobes. Suddenly we were considering the connections of the anterior cingulate to the anterior insula and thus to functions related to sustaining attention and salience. It was not a large jump to theorize that the posterior cingulate's strong connections to the right parietal regions might influence the sensory aprosodia symptoms of our clients with Asperger's or autism. We developed and published on our systems theory of neural synergy (Thompson & Thompson, 2009). It took us a bit longer to realize we were actually reinventing the wheel because some of the basics that underlie neural networks had already been described by Alexander, DeLong, and Strick back in 1986.

It was not much of a jump to hypothesize that we must be affecting complex networks that involve many different cortical and subcortical areas to achieve such wide-ranging changes in cognitive and affect functioning with relatively simple single-channel feedback procedures. Indeed, it may be possible that single-channel NFB training, in some patients, could have a theoretical advantage over training that involves multiple sites. By having an effect on a network from a single central site, and by having a direct influence on only one site, single-channel NFB may allow the brain to balance the degree to which other areas within a network are changed. We therefore were cautious when Z-score training became a new approach to doing NFB. We were particularly cautious about using Z-scores to normalize amplitudes at surface 10-20 sites that did not appear to directly correlate with our knowledge of the functions of BAs and neural networks.

Targeting Connectivity Between BAs

We had been using 19-channel assessments with quantitative analysis for some time to guide our single-channel work in complex cases; indeed, we had acquired Sterman's SKIL database, Juri Kropotov's Win-EEG program, and Thatcher's Neuroguide databases along with a number of 19-channel recording instruments, starting with the Lexicor in 1995. But it was a leap forward when LNFB was introduced because at least then we could see which BAs we were targeting, both with our amplitude and, perhaps more importantly, our connectivity training. However, this did not mean that we abandoned the use of single-channel NFB. NFB at one site theoretically could avoid making incorrect decisions about the degree to which multiple sites should be normalized when we use Z-score–directed LORETA NFB. As noted above, it could be argued that single-channel NFB might be a more "balanced" approach to changing the brain, and it does not have the theoretical danger of adversely affecting a site that is outside database norms because of genius or compensatory mechanisms. This theoretical dilemma concerning single-channel versus 19-channel LNFB will be resolved only through years of careful data collection and research. In the meantime, we continue to use both approaches: single channel for straightforward cases of ADHD or when 19-channel assessment is not feasible (for example, in children with Asperger's syndrome who have tactile sensitivity and could not initially tolerate "full cap" data collection) and LORETA NFB for complex cases such as helping people with postconcussion syndrome.

We were getting very good results at Cz and knew that approximately 50% of the EEG amplitude at any single site, such as Cz, arises from neurons directly beneath the electrode and 95% arises from an area within a 6-cm distance around the site (Thatcher, 2012, pp. 35, 305, citing Nunez et al., 1981, 1995, 2006). Training at central midline sites such as Cz, Fz, and Pz could therefore be hypothesized to influence key networks including, but not limited to, the executive, affect, salience, and default networks. All of these networks are involved in difficulties seen in patients with Asperger's and autism spectrum disorders, and most of them are involved to a greater or lesser extent in affect disorders and concussion. A network serves to synchronize the functions of groups of neurons in many different but related areas of the cortex, and the question became how we could target areas and connections more directly. However, the chain (team, network) is only as strong as its weakest link. Thus, with cortical dysfunction, our NFB training must either strengthen the performance of that link or help the network readjust in order to compensate for its dysfunction. The brain has a plasticity that should allow this to take place, as has been seen with other interventions, too. (For excellent examples of a range of neuroplastic changes, see Norman Doidge's 2007 book, *The Brain That Changes Itself* and his 2015 book, *The Brain's Way of Healing*.)

Therefore, we cautiously, and with some misgivings, took the next quite expensive step of beginning to do LNFB. Once again, we were following in the footsteps of Joel Lubar, who published the first research in this field (Congedo, Lubar, & Joffe, 2004). With some complex cases, we wanted to be more precise and try to have an effect on a number of different areas, with some of them being distant from surface electrode sites. We also wanted to simultaneously train a number of different parameters, such as amplitude, phase, and coherence. We could theoretically accomplish these objectives using LNFB.

To have such broad effects, the cortical area to which we are directing our NFB must have a way of connecting to many functionally related, even though spatially distant, cortical areas. At the same time, other functionally nonrelevant areas of the cortex must be inhibited. The loops that go from cortex to basal ganglia to thalamus and then to functionally related areas of the cortex gave a theoretical explanation as to how some appropriate cortical areas could be activated whereas other areas that were not needed for the task at hand could be inhibited. In this manner, many functionally related cortical areas could be synchronized and recruited to operate as a specific network to accomplish the task at hand (Kropotov, 2009, pp. 292–309; Thompson, 2015a, pp. 15–22).

NFB and HRV: Similar Cortical Connections

But we have forgotten where we got started. It was with something as simple, yet so incredibly effective, as a tiny skin temperature sensor on the little finger. Sometimes things become incredibly complicated when you just are not paying attention to the simple things. Remember the Principle of Parsimony: Do the least complicated, the least invasive, the least expensive intervention first. Finger temperature, muscle relaxation, noting electrodermal changes with stress, and diaphragmatic breathing all had an important part to play in our early work. Then we moved on to respiratory sinus arrhythmia training and eventually began to use measurements of HRV. This procedure brought up another big "why" question. Why were we getting similar results with HRV training as we did with NFB in some of our patients who were anxious and some who were feeling chronically stressed? Symptoms of anxiety can be incredibly important in clients who have diagnoses as far ranging as depression with anxiety, Asperger's, autism, concussion, and so forth.

HRV training made changes that, through vagal (cranial nerve X) and glossopharyngeal (cranial nerve IX) afferents from baroreceptors in the arch of the aorta and the carotid sinus to the nucleus tractus solitarius in the medulla section of the brain stem, seemed to be having some influence on the very same neural networks that we were attempting to address using NFB. Indeed, that nucleus of the solitary tract has connections not only to other brain stem nuclei but also to the thalamus and to important cortical areas such as the cingulate and even BA 25 (subgenual cingulate), which recently has proven to be very important in depression (see Figures 1 and 2). Indeed, these connections led to the amygdala and the hypothalamus and, importantly, to the paraventricular nucleus of the hypothalamus, which has afferent and efferent connections to both the sympathetic and parasympathetic sides of the autonomic nervous system as well as to the hypothalamic-pituitary-adrenal axis that is key to our understanding of the stress response.

Comprehensive Assessment to Comprehensive Intervention: From Single-Channel Training to 19-Channel LNFB

Thus, we had moved from what now, in retrospect, appears to have been a relatively simple intervention with single-channel and two-channel NFB combined with some forms of peripheral biofeedback to what appears to be an inordinately complex array of procedures to assess patients (Figure 3) and then to treat them. *Inordinate* is perhaps a little too strong a word, but it does convey some of the emotional response that a newcomer to this field must have. We now augment data from a single-channel assessment at Cz (Figure 4) with 19-channel assessments that tell us which BAs are outside database norms with respect to amplitude and connectivity. The use of QEEG combined with LORETA analysis gives an incredible amount of data. Now, 19-channel assessments done with the eVox system can include evoked potentials (also called event-related potentials [ERPs]), which measure the speed of the brain's processing of incoming information. Brain speed data are derived from information collected while the patient is carrying out a CPT. This CPT provides information on variability of reaction time, which is the most sensitive variable for assessing drifting attention, as well as on response time, omission errors (inattention), and commission errors (impulsivity). (This CPT, done while EEG is being recorded, supplements the results of the T.O.V.A. and IVA CPTs that we have routinely used for more than 20 years.) HRV data are collected while the patient sits during the 5-minute eyes-closed section of the recording.

We may also do a stress test where we measure biofeedback variables. For this, we use Thought Technology eight-channel Infiniti equipment that is also the hardware we use for single-channel NFB. (See Thompson & Thompson, 2007 or 2015b for details.) Finally, clients do an online, quite difficult, battery of neuropsychological tests and answer multiple questionnaires, a service provided through CNS Vital Signs (2016). This organization provides a very quick turnaround time with scoring and full reports that can be shared with clients.

The assessment measures in Figure 3 include QEEG with brain maps and LORETA source correlations and Z-score coherence and phase between BAs, ERPs, neuropsycholog-

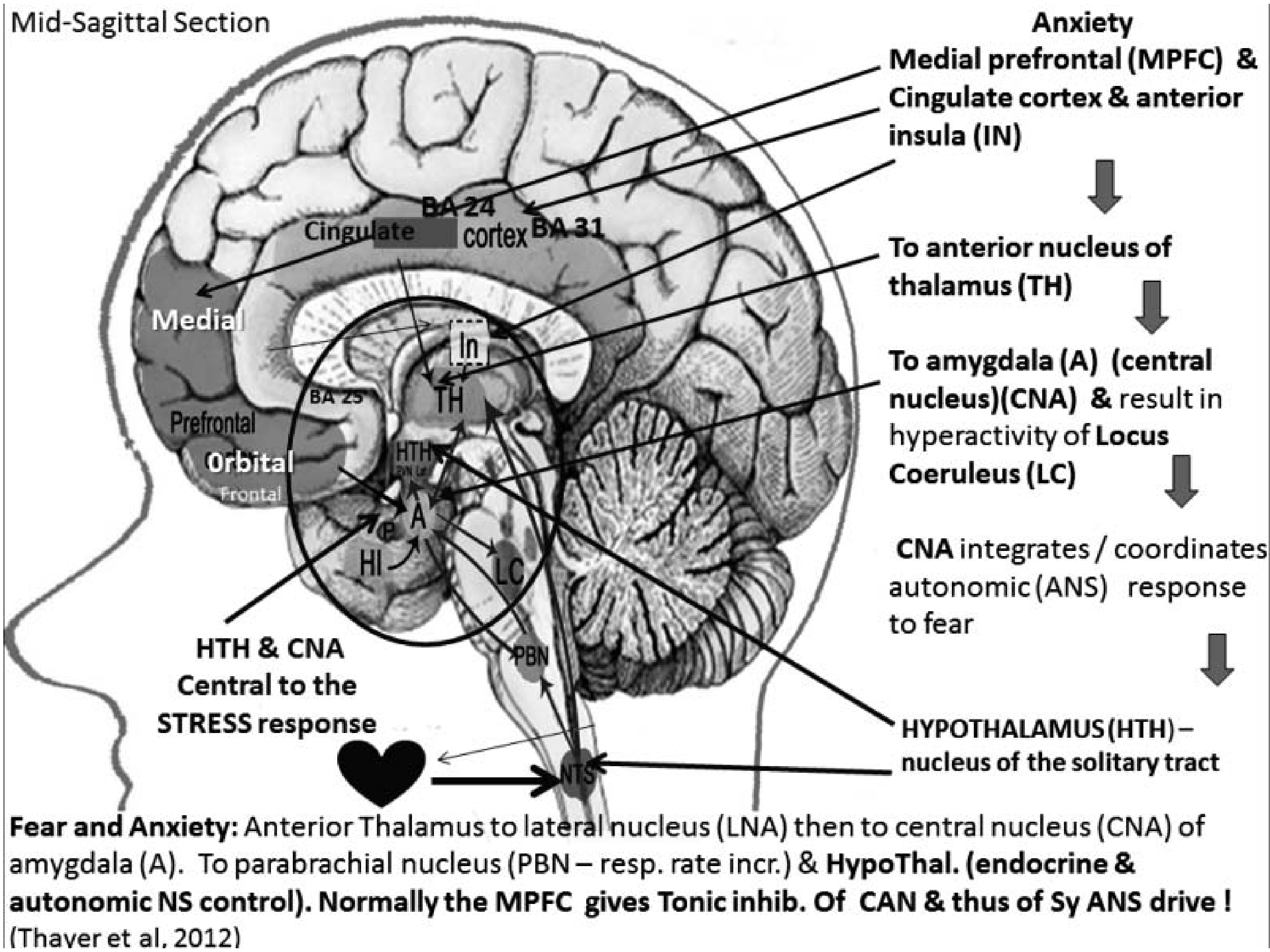

Figure 1. Illustration in graphic form of how neurofeedback and heart rate variability affect the same central structures. (Figure from *The Neurofeedback Book*, second edition, used with permission.)

ical testing, CPTs, HRV with international measurements, and, as required, biochemical testing. Recently, especially for those with concussions, we have added measures of balance (Balance Error Scoring System in this diagram). In some university centers, the assessment additionally uses virtual reality environments to assess visual input to kinesthetic output response time measurements. (Virtual reality is not used at our center.)

We never merely apply a so-called "protocol" intervention because this implies a one-size-fits-all approach rather than the careful application of the findings from a comprehensive assessment. Multimodal assessment is required to determine a unique combination of interventions for an individual patient.

The graph in Figure 4 is from a boy diagnosed with both ADHD and autism spectrum disorder, more accurately known clinically as Asperger's syndrome. He was a gifted daydreamer with severe problems in social communication. This graph shows data from a single-channel recording, eyes-open, resting state, with placement at Cz. This graph, generated with Excel, has a y-axis showing magnitude in microvolts and an x-axis showing frequencies from 2 to 38 Hz. There is a high Theta/Beta ratio and also high-amplitude, low-frequency Alpha (8 and 9 Hz), a pattern often observed in those with Asperger's syndrome but not in those with classic autism.

In planning an NFB intervention for the patient whose data are shown in Figure 6, treatment of her anxiety involved reducing the 29-Hz spindling Beta. Thus, we obtained sufficient information from the single-channel assessment to proceed. You see the same pattern of spindling 29-Hz Beta at Cz in a single-channel Excel graph that is shown in the 19-channel QEEG with the raw EEG, the Z-score comparison graph, brain maps, and LORETA

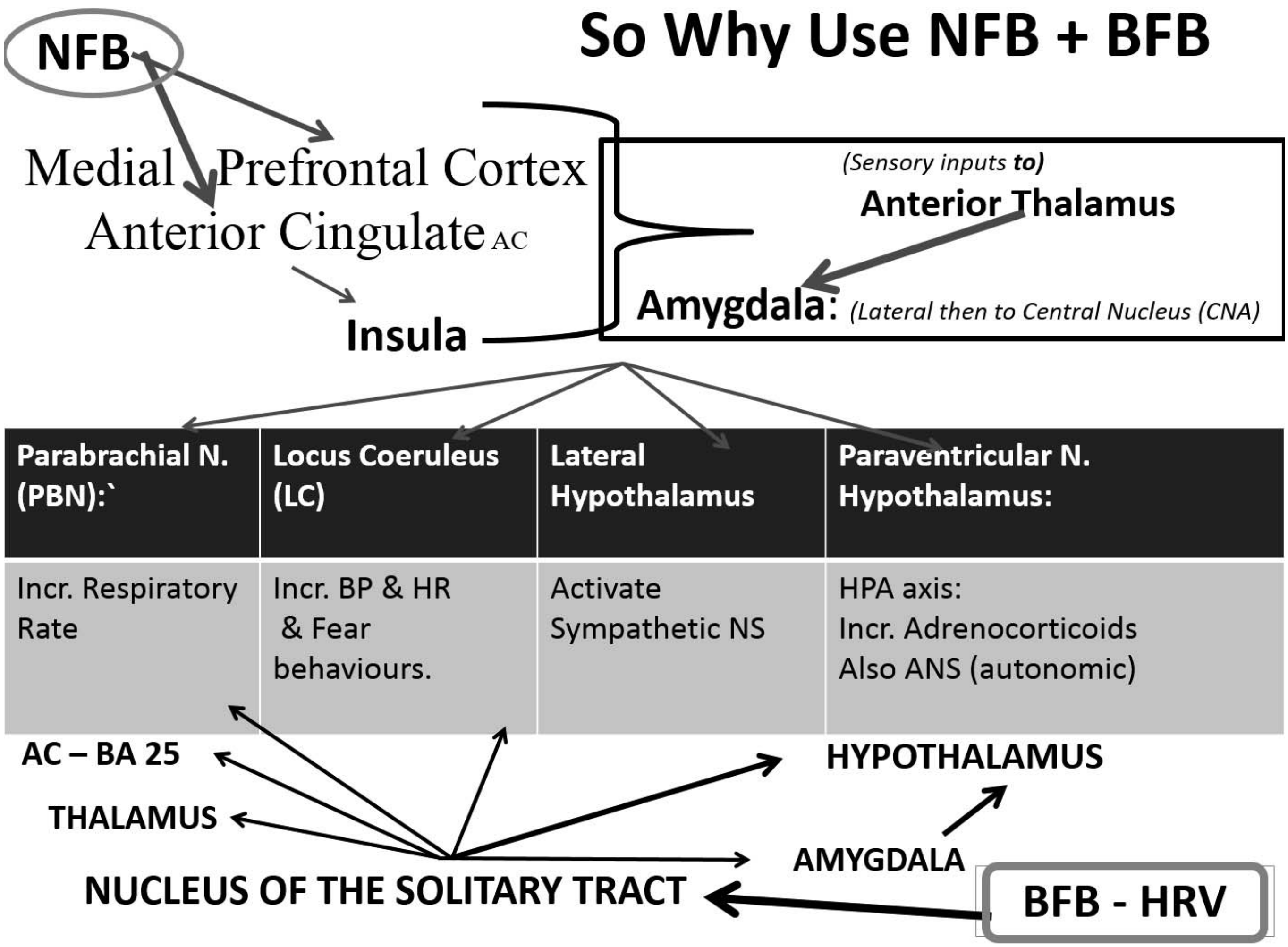

Figure 2. Illustration in tabular form of how neurofeedback and heart rate variability affect the same central structures. (Figure from *The Neurofeedback Book*, second edition, used with permission.)

source derivation. QEEG analysis was done with Neuroguide. The single-channel recording was done with Thought Technology's Infiniti equipment.

The Neuroguide illustrations in Figure 7 show data from a client with a very different presentation than the woman whose data appear in Figure 6. Data displayed are from the linked ears montage, eyes-open, resting state recording. The subject was male, age 19, recorded 4 years after he had a snowboarding accident that left him unconscious for 15 minutes. Note the high-amplitude Theta and the low-amplitude Alpha and Beta. This pattern is typical after traumatic brain injury in people with persistent symptoms (Haneef, Levin, Frost, & Mizrahi, 2013, after Tebano et al., 1988).

The multimodal assessment helps us decide on our initial intervention. All cases receive counseling on diet, sleep, and exercise, and all patients learn metacognitive strategies. The strategies that are learned and practiced while doing NFB are hypothesized to influence which neural network is being used and reinforced during the NFB session. Other treatment modalities that include tDCS, passive infrared hemoencephalography, audiovisual stimulation, and

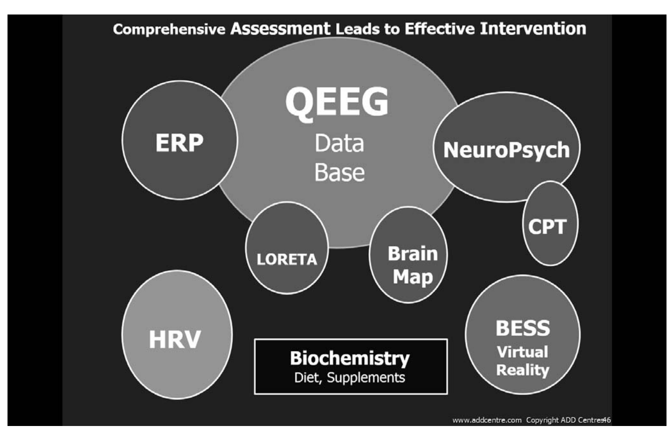

Figure 3. Summary of multifaceted assessment parameters.

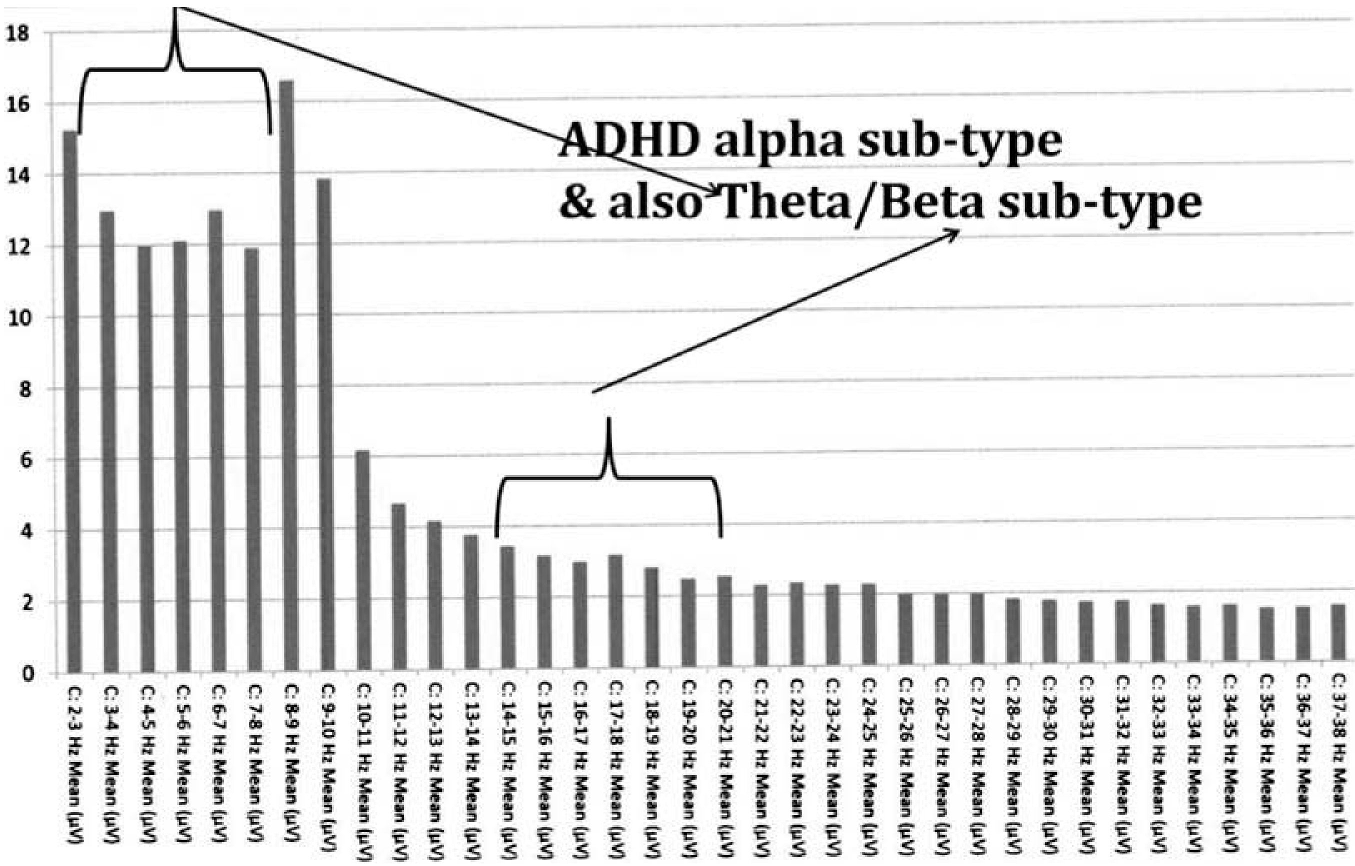

Figure 4. Spectral array based on data from a 6-year-old boy.

Cogmed (computer exercises for home use to improve attention and memory) may additionally be used in selected patients. With respect to the core EEG training, we may choose between several EEG interventions or chose a combination of interventions. The choices at our center are the following:

- Single-channel NFB + HRV (or other biofeedback modalities)
- 19-channel LNFB + HRV (or a combination of other peripheral biofeedback modalities)
- One LNFB and one single-channel NFB session, both with HRV training, each week

The Principle of Parsimony comes into play here. When we address a relatively simple case of ADHD without other significant complicating factors, we will just do single-channel NFB + HRV. If it is a person with postconcussion symptoms, they probably have suffered diffuse axonal injury, and multiple areas, with many deep in the ventral aspects of the cortex, plus many central areas, may be affected to varying degrees. This kind of complexity has responded well in the past to a very large number of sessions (80 to >100) of single-channel NFB, usually done at FCz or Cz. Today, patients appear to be recovering more quickly when we use LNFB plus HRV, with some having good results (amelioration of all cognitive, memory, and emotional symptoms) with just 40 sessions of LNFB.

We should note again at this juncture that stimulation methodologies are not NFB. They are not learning methods that use operant conditioning. The one stimulation methodology that is used at the ADD Centre is tDCS, which has many years of investigation and published research behind it. And it is not used alone. This stimulation has short-term effects; thus, it is always followed by NFB, which is hypothesized to reinforce long-term changes. We might, for example, do 8 minutes of tDCS to induce negativity at a particular site (more activation, that is, neurons depolarized and more likely to fire) and follow that with single-channel NFB that rewards 15 to 18 Hz activation at that site. This has been particularly helpful in recovery of motor functions when done over the appropriate part of the motor cortex; for example, anodal stimulation at C4 for 8 minutes using tDCS followed by

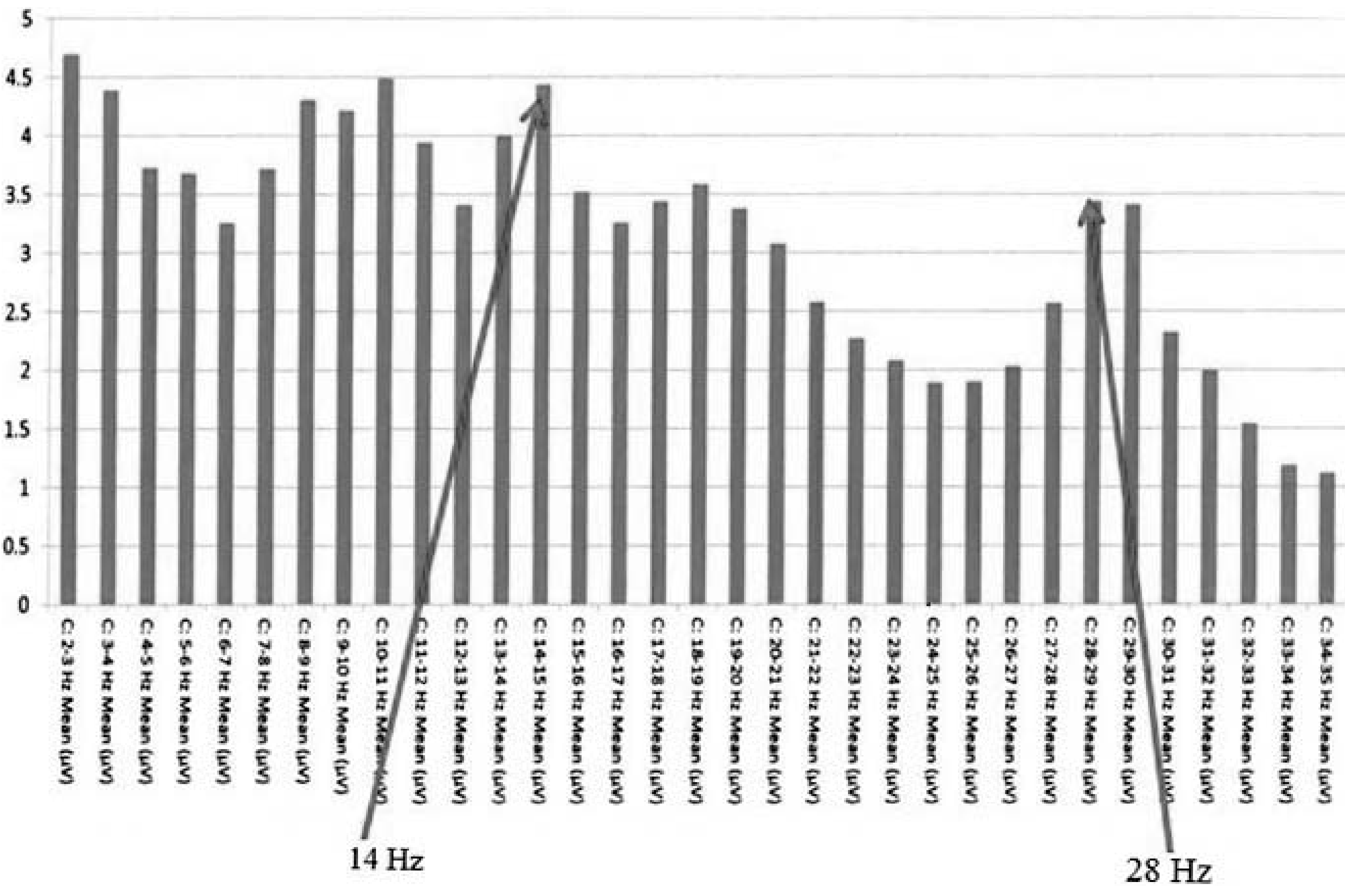

Figure 5. Single-channel profile of 2- to 35-Hz activity: anxious, depressed, ruminating patient. Single-channel recording, eo, at Cz. The source of the spindling Beta was the anterior cingulate gyrus, Brodmann area 24.

rewarding 15- to 18-Hz activation at that site with regular NFB to improve use of the left hand and digits.

The brain is constantly working to achieve homeostasis, to reduce uncertainty, and to make the environment both consistent and predictable. It is finding meaning in information, making patterns and associations. It is continuously analyzing and reanalyzing information in order to understand it in a personally relevant manner. Thus, when we do an assessment, whether it be eyes closed, eyes open, or on a specific task, the brain is always working. There is no true "resting" state, although that is what we call an eyes-open recording without a task. Before we decide on what combination of procedures to use in intervention, our first step has to be a careful and thorough assessment.

Initial Assessment at the ADD Centre

The first part of the initial assessment takes a half day (about 3.5 hours) and includes completion of questionnaires, clinical interview, two CPTs (the T.O.V.A./Test of Variables of Attention, and the IVA CPT), and a single-channel EEG recording at Cz with the results graphed. (See Figures 4 and 5 for examples of the graphs showing the spectral information.) A sample NFB + HRV training session is then carried out. Statistics for relevant parameters are graphed across five eyes-open conditions: 3-minute (eyes open) baseline with a raw EEG screen (no feedback), 3-minute HRV training screen (visual feedback showing lines for respiration and heart rate changes, which the client tries to get "in sync"), then three 2-minute segments using training screens for NFB. The NFB provides visual feedback in the form of animations plus audio feedback (music), and both are activated when brain wave amplitudes for selected frequency bands change in the correct direction; for example, three parameters for training might be (a) decrease 4 to 8 Hz to reduce tuning out; (b) increase 13 to 15 Hz, Sterman's sensorimotor rhythm and Steriade's expectancy rhythm (Steriade & McCarley, 2005) for a calm and alert mental state; and (c) keep 52 to 58 Hz very low to minimize muscle artifact. The five segments of the practice training session are graphed to show a learning curve. Artifacts are removed from the patient's EEG sample from the baseline condition, and the EEG is then graphed as a

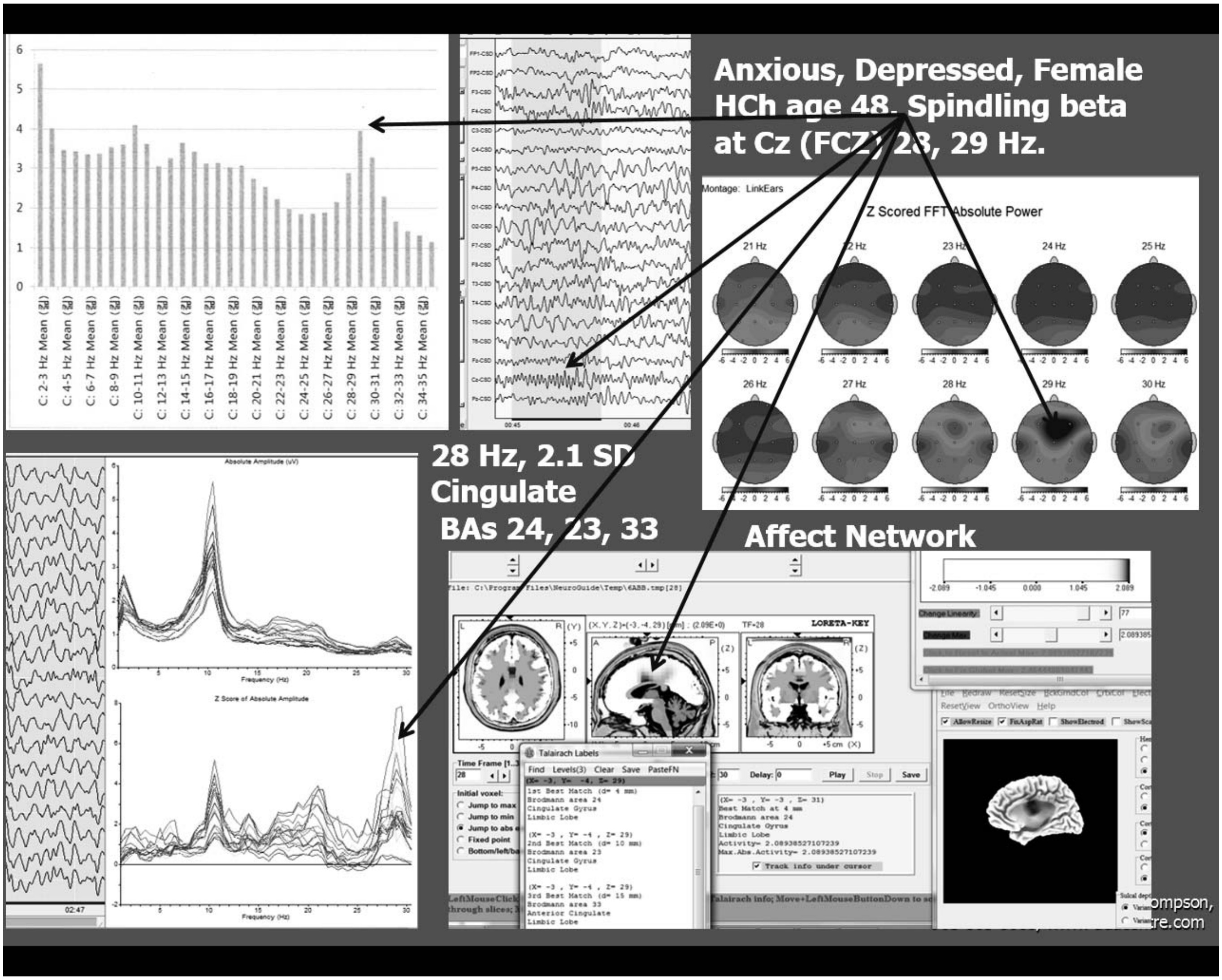

Figure 6. Illustration to show the similar results from 19-channel and single-channel assessment.

spectral array showing the magnitude (mean amplitude) for each frequency from 2 to 60 Hz. We are also observing here the 38- to 42-Hz range, which reflects Steriade's focused attention and Sheer's learning rhythm (Sheer, 1977). The learning curve and this graph, plus important ratios that were tracked, such as the Theta/Beta power ratio for investigating ADHD (Monastra et al., 1999), are discussed with the client and their parents or spouse, as applicable. If the person is an appropriate candidate for an NFB intervention, goals for training are also discussed. The client receives a folder that contains our written policies and procedures consent form, which they then sign and bring back if they proceed with training. They also receive information about ADHD (if that is their presenting complaint) and a fee schedule. Every client also receives a free copy of *The A.D.D. Book* by Sears and Thompson (1998) because it not only explains ADHD and a multimodal approach to handling symptoms but also is the first book written for parents that contains a chapter that discusses NFB. There is also an informative chapter on diet, and that information is important whether or not ADHD is the presenting problem.

Decisions Regarding Further Testing and Intervention(s)

At the end of the initial assessment, three decisions are made. The first is whether the assessor deems the person to be an appropriate candidate for training. Exclusions might be because of severe family dysfunction, in which case family therapy or marital therapy might be recommended as a first step, with a biofeedback intervention held in reserve for future consideration. A second decision concerns

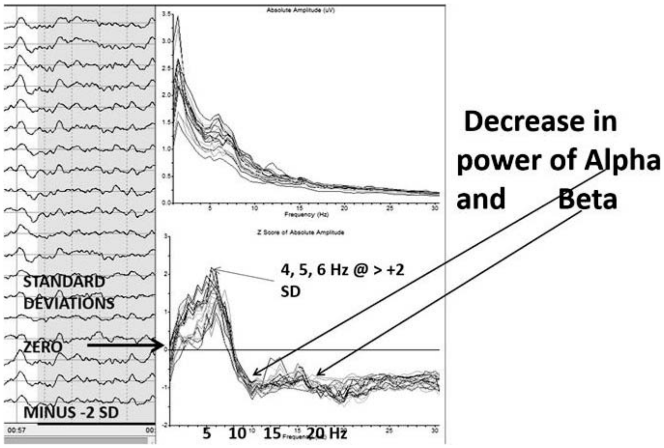

Figure 7. Example of two graphs from a 19-channel quantitative electroencephalograph. Data are shown from the eyes-open assessment using the Neuroguide program. Top graph displays absolute amplitudes on y-axis, and the x-axis shows frequencies from 2 to 30 Hz. Bottom graph has Z-score comparison on the y-axis and frequencies on the x-axis. You can observe a high 4–8/8–12 Hz ratio, which should decrease with recovery.

whether psychoeducational testing should be booked to assess learning strengths and weaknesses where this information would help guide the metacognitive strategies component of training. Increasingly, to save the client time and money, we are having children, adolescents, and adults complete an online neuropsychological test battery available through CNS Vital Signs (2016). With students who might have a learning disability, however, we will do full intellectual and academic testing. The third decision concerns whether a 19-channel QEEG assessment, including LORETA analysis, should be carried out. As was noted previously, the 19-channel ("full-cap") assessment at our center includes not only EEG data collection (eyes open and eyes closed) but also data collection for evoked potentials (ERPs) done during a CPT and HRV data collection (Figures 3 and 11). We like to follow the Principle of Parsimony: "First, do the least disruptive, the least invasive, the least expensive intervention that has a probability of helping." Thus, if training HRV and counseling on diet/sleep/exercise will suffice, then that is what we recommend. In some cases, such as clients with ADHD or anxiety, single-channel NFB training plus HRV are the components that have the greatest likelihood of helping. We only use 19-channel assessment when there are complex comorbidities or conditions that involve many areas of the cortex with some of them ventral and midline. We never use so-called "protocols" based on symptoms without an EEG assessment because this implies a same-size-fits-all approach, which is not the accepted standard for professional practice. Instead, we respect individual differences and follow the findings of a careful, comprehensive assessment.

Descriptions of 19-channel procedures that we use can be found in *The Neurofeedback Book*, second edition (Thompson & Thompson, 2015b). They also are delineated in a chapter in the textbook on Z-score NFB, edited by Thatcher and Lubar (Thompson, Thompson, & Reid-Chung, 2014).

Why Use 19 Channels in Complex Cases?

Some practitioners do an assessment using multiple (two, four, six, or eight) surface sites. Often, this methodology requires taking more than one sample of data in order to include the different sites. We feel, as does Thatcher (personal communication, March 2016), that the data are discontinuous and thus fail to provide a complete view of connectivity. Also, because data may be recorded from different pairs or groups of channels at different times, even the amplitude or power measures may be misleading if there was a state change, such as drowsiness or arousal, when one group of channels was being measured that was not a factor when other groups were measured.

We decided in the late 1990s that if we needed more information than could be provided from single or two-channel assessments, we would do a 19-channel assessment. We also found it took us less time to make good connections (defined as impedance measures at every channel less than 5 Kohms and within 1 Kohm of each other) using an electrocap than it did to measure a number of pairs of sites and achieve impedance readings that met research criteria. With the 19-channel cap, we automatically had a common ground and linked ear reference for each site. When we do two-channel assessments, we use a special common ground electrode and linked ear reference electrodes while being very careful to have the two active electrodes with virtually the same impedance at the two sites we are comparing. Two examples of two-channel assessments we might conduct are (a) comparing F3 to F4 in depression where low activation (higher-amplitude Theta and/or Alpha) at F3 may indicate depression and (b) comparing P7 (T5) with P8 (T6) in someone with Asperger's traits. We often observe higher-amplitude Theta or Alpha at P8 as compared with P7. This is associated with sensory aprosodia symptoms (difficulty discerning nonverbal cues, such as gestures, facial expression, and voice intonation).

Connectivity Measurements

There are now newer ways to view simultaneous activation in different areas of the brain. A carefully constructed commercial program that illuminates connectivity between BAs has been created by Bob Thatcher's group and is called Brain Surfer. Tom Collura developed a similar system

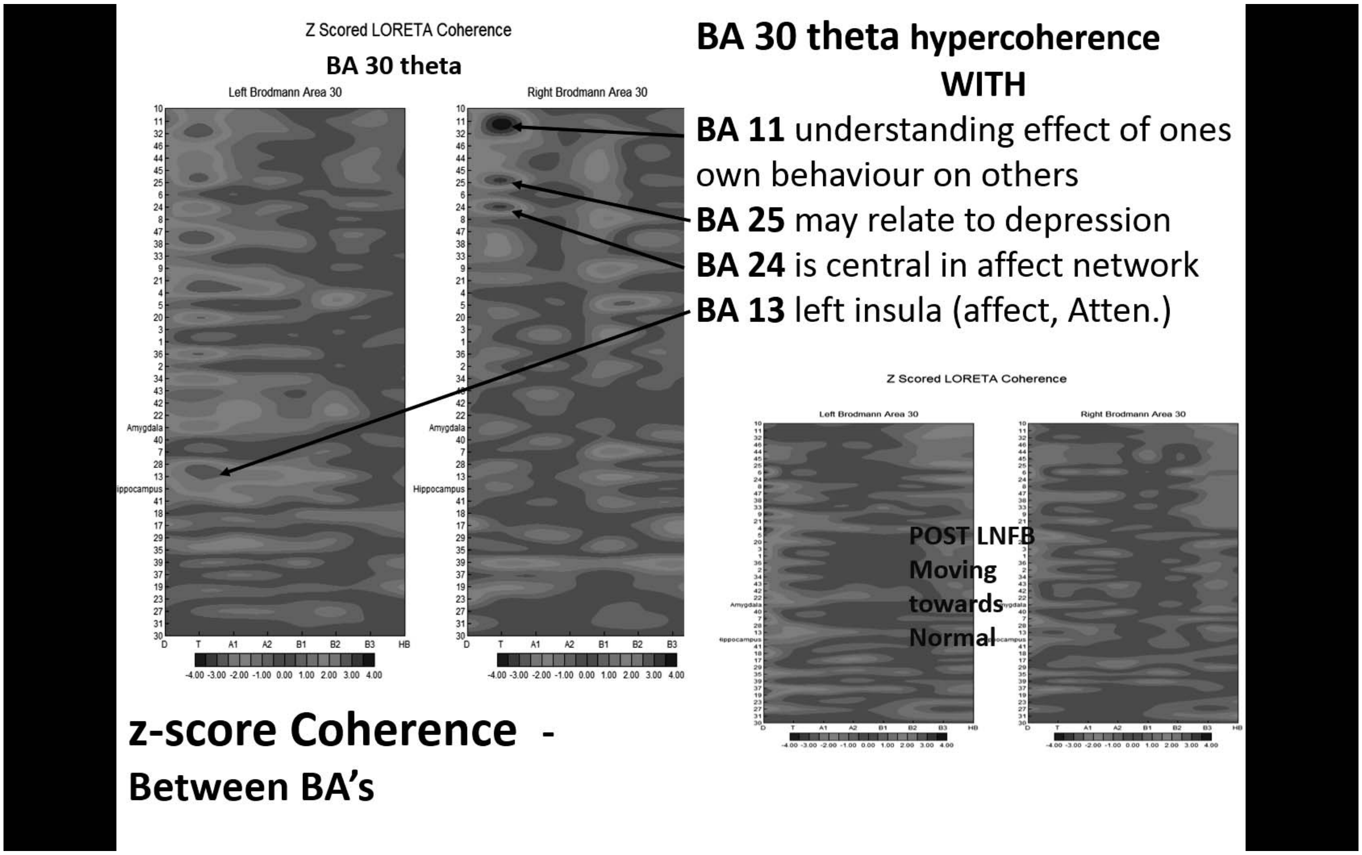

Figure 8. Illustration to show coherence measures between Brodmann area 30 and other Brodmann areas pre- and post–LORETA Z-score neurofeedback.

called Brain Avatar for use with equipment from Brainmaster. With NeuroGuide and BrainSurfer, one can view a client's brain activation in real time and examine a specific functional network. Programs like this allow the practitioner to explain the concept of neural networks, such as the executive, affect, salience, or default networks, and even more specific networks such as the addiction network, to a patient while they watch the activations occurring in their own brain. Feedback can also be carried out with the Brain Surfer system to stabilize a network by rewarding activation patterns that are within defined Z-score norms of a database. During this feedback, the connections between nodes (BAs) change from a red color, indicating that the signal is more than 3 SD from the database norms, through yellow to green when there is effective deactivation, which might be defined as movement toward maintaining activation within 1.5 standard deviations, for example. Maintaining the connections within a chosen network in green is the objective. This program can compute "effective connectivity," which is a measure of the magnitude and direction of information flow between BAs.

Connectivity in our experience is becoming the most sensitive measurement to follow during an NFB treatment program. See Figure 8 for an illustration of one area's changes in connectivity subsequent to LNFB training. BA 30 is a transitional area between the posterior cingulate and the temporal lobe. It plays a role in mood regulation and in insight and is an area that often reflects dysfunction in those with symptoms of Asperger's syndrome.

The Neuroguide program gives 43 coherence (or phase) Z-scores. In the example shown in Figure 8, BA 30 connectivity (hypercoherence in red and hypocoherence in blue, set in this example at 4 SD) is compared with 42 other BAs plus the amygdala and the hippocampus. It demonstrates that sites that were relevant to this patient's symptoms were 4 SD from the database means in Theta frequencies and, to a lesser degree, in Beta frequencies. The smaller insert showing BA 30 coherence data after training shows that these deviant coherence differences had changed significantly after 40 sessions of LNFB training. This change in coherence more accurately corresponded to symptom amelioration in this patient than did changes in amplitude for particular frequencies.

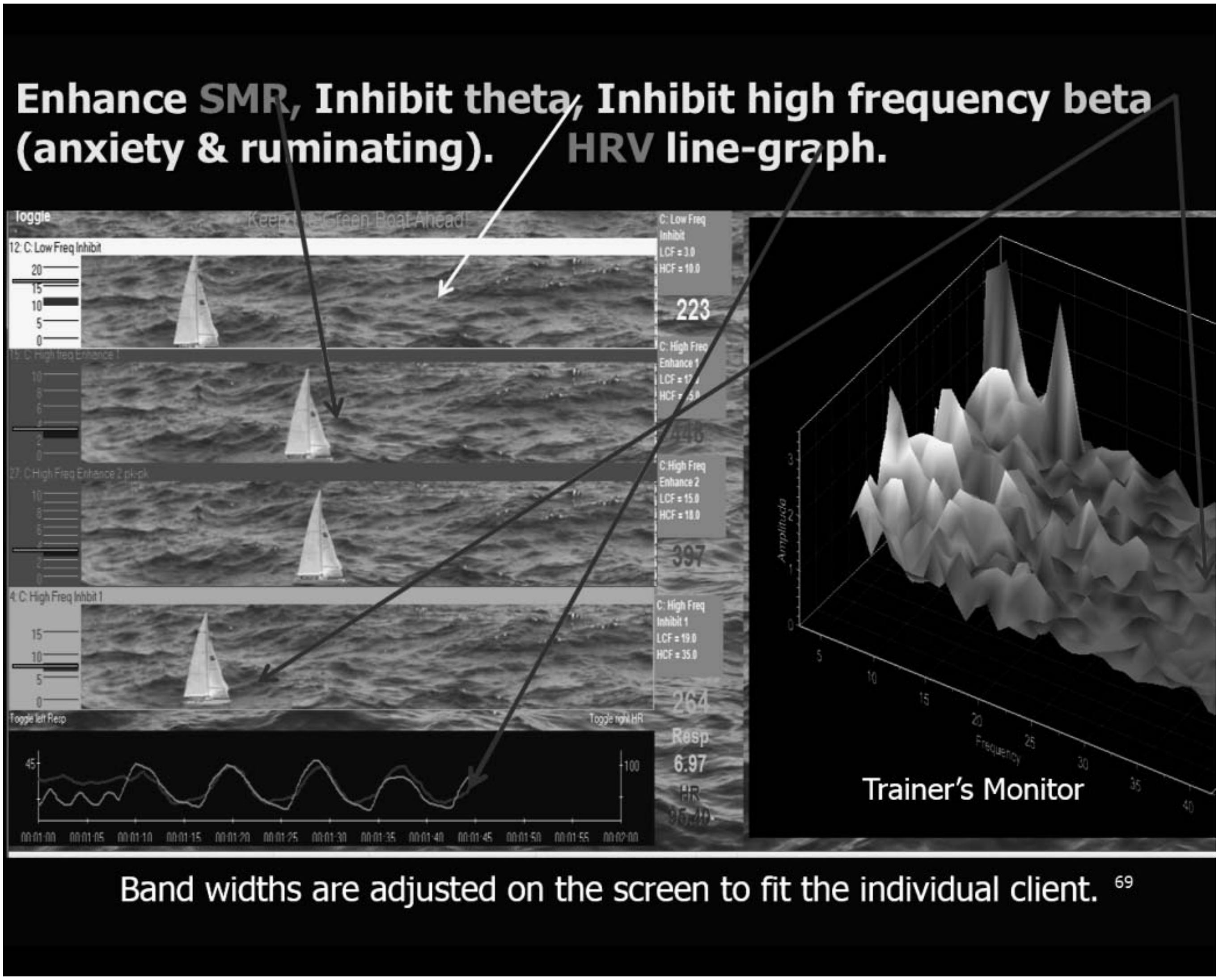

Figure 9. Training screen combining neurofeedback with heart rate variability training.

Some Notes on Interventions

Interventions involve the patient learning self-regulation skills. The objectives usually include gaining a calm, relaxed state where the patient eliminates anxiety and circular thinking then learns to focus, problem solve, encode, and recall information. Each of these mental states requires that attention is paid to factors that support healthy physiology (diet, sleep, exercise, and a supportive environment), and this is combined with specific training using NFB, biofeedback, and strategies.

As mentioned above, at our ADD Centre, we use NFB training on only one or two surface sites if we are dealing with a relatively easy problem such as ADHD. If we feel it necessary to move to more sites and want to know precisely which BAs (and networks) we are targeting and for what specific functions, then we need the kind of information obtained through LORETA analysis. In addition, compared with putting electrodes on more than two sites, it takes less time to put on a 19-channel cap for data collection. And for more precise NFB training involving a number of different areas, with some of them deep in the cortex, we use LNFB either with Neuroguide or with Evoke Neuroscience programs.

Example of Simple One-Channel NFB + HRV

Single-channel NFB + HRV (and other biofeedback modalities as necessary) plus coaching in metacognitive strategies is our usual intervention for clients who present with ADHD or a learning difficulty without complex comorbidity. It is quite simple to carry out, and its effectiveness has been well recorded in large case series where decreased symptoms and impressive 10- to 12-point

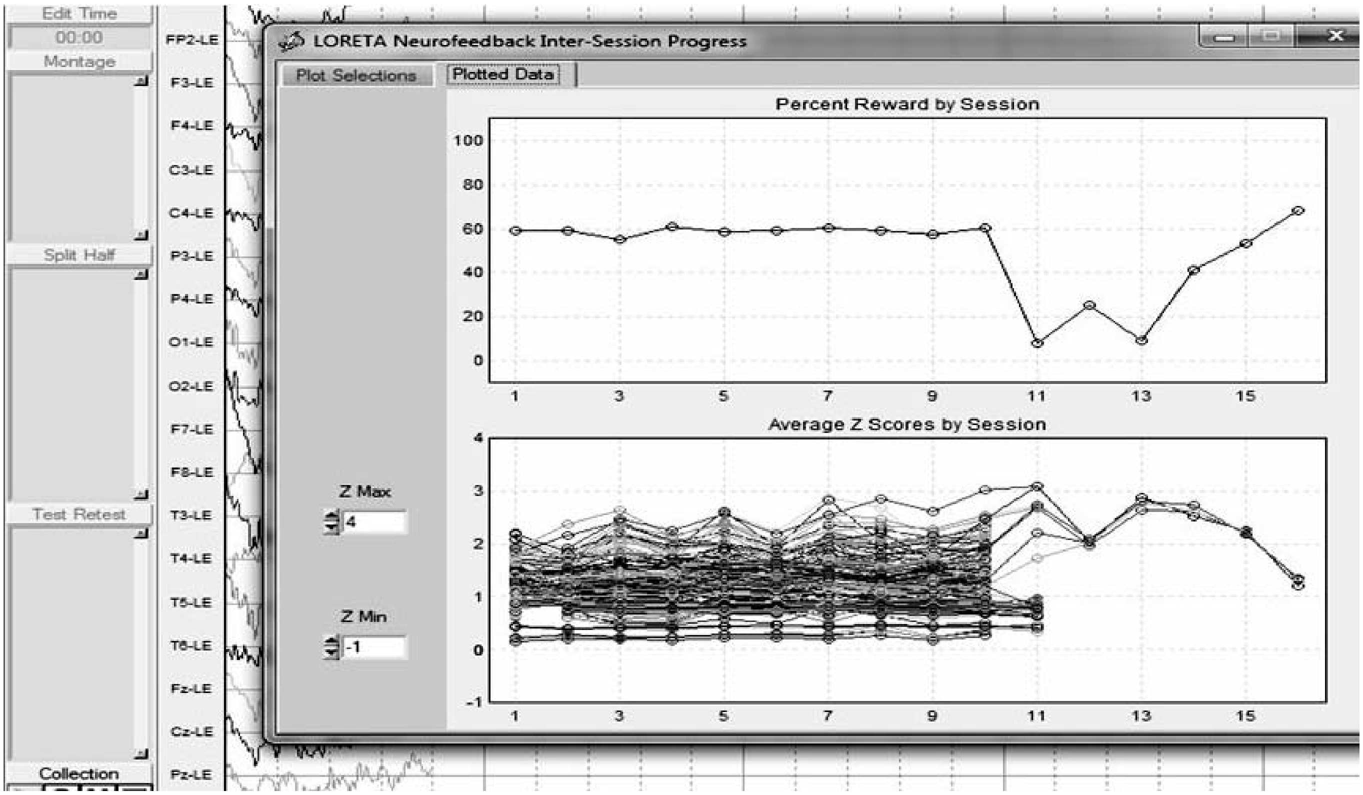

Figure 10. Illustration to show progress over 16 LORETA Z-score neurofeedback (+ heart rate variability) sessions.

IQ gains have been reported (Linden, Habib, & Radojevic, 1996; Lubar et al., 1995, Thompson & Thompson, 1998). An example feedback screen is illustrated in Figure 9. The details for doing this type of feedback can easily be replicated from the Methods section of our case series study (Thompson & Thompson, 1998) or from *The Neurofeedback Book* (second edition).

The illustration in Figure 9 shows both the patient's and the trainer's monitors. The program rewards sustaining attention. The sailboat race captures the interest of all age groups. The trainer subtly changing thresholds can make it a real race but always allow the patient to win by a narrow margin. Note that this patient's HRV was poor at the start. Then the trainer and patient started to breathe at a rate close to six breaths per minute, and synchrony was seen between heart rate changes and respiration. (Initially, the trainer models the six breaths per minute breathing with the patient.)

Two Distinct Kinds of Feedback for Single-Channel Training

In operant conditioning terms, it can make sense to reward bursts of activity with a brief (2-second) mental rest between rewards. Barry Sterman has emphasized this method of training, and he has developed a suite for training, available from the Biofeedback Federation of Europe for use with Thought Technology's Infiniti equipment, that emphasizes applying strict operant conditioning principles. This program gives visual feedback and a discreet tone as the reward for a burst of SMR, rather than having continuous music when amplitudes are maintained above a set threshold. For enhancement of SMR in seizure disorders, we would certainly choose this type of training, alternating sessions between C3 and C4 to stabilize the cortex. (Of course, we would have done a full cap assessment to make sure training the SMR frequency range made sense. Not every client with epilepsy will have low SMR. Another caution is that you sometimes find spindling Beta associated with anxiety at a frequency of 14 or 15 Hz, particularly at Cz, and you would not want to increase that. As we have said before, always match EEG findings with symptoms.) For training SMR, which occurs in bursts, it makes a great deal of sense to reward distinct bursts of focused attention.

Training to increase SMR will reduce hyperactivity in most people. However, it likely rewards the ventral selective attention network. On the other hand, when we

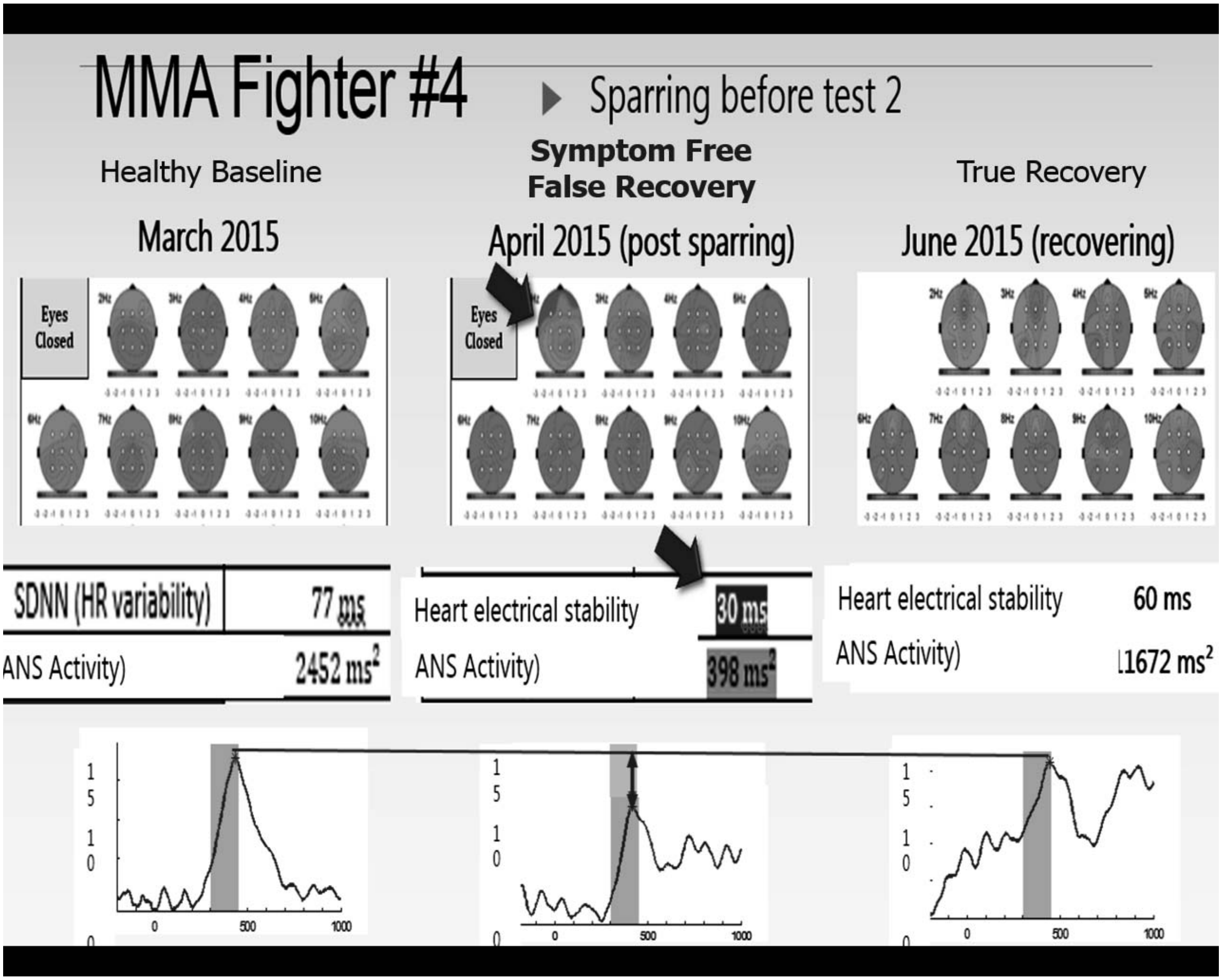

Figure 11. Illustration from Evoke Neuroscience with permission.

are training children with ADHD, we may be more interested in activation of the right hemisphere, dorsal, sustaining attention network during a state of motoric stillness and sustained mental alertness. This is because sustaining their attention is a primary difficulty that they experience in the classroom. Certainly we do not wish to reinforce moving in and out of attention as they are often already doing that to the detriment of their classroom learning. Thus, we do reward maintaining a mental state with continuous music and visual feedback when the mental state is maintained.

Complex Cases Treated with 19-Channel LORETA NFB

Complex cases might be ADHD with one or more comorbidities such as Asperger's, autism, anxiety, depression, and so on. Postconcussion syndrome also presents with multiple symptoms and multiple targets for training. Such clients are now nearly always treated with LNFB. The process when using the Neuroguide program involves choosing the BAs of interest for a particular patient and matching that individual's symptoms (rated for severity) to BAs that are known from the literature to relate to those functions. We always carefully check that the areas that will be targeted are the BA areas that we identified in our assessments as being most important with respect to our patient's symptoms. We do not target areas that are outside database norms that might be related to superior functioning in an area or due to compensatory functioning. This can be done precisely with LNFB, whereas we do not feel that we can do this as accurately or as quickly when we just use single electrodes on surface 10-20 sites. In some clients, LNFB may shorten the number of sessions required for resolution of symptoms. The immediate reward when playing a DVD for the patient is the display being seen full screen and sharp. However, one may just use a simple green circle for feedback. Simpler can be better! In addition to the visual and auditory feedback, line graphs of time versus Z-scores at each site are shown on the therapist's monitor. This is a similar graph to Figure 10 but depicts only segments of training within a single session. In our experience, the BA amplitudes normalize rapidly, but the coherence and phase deviations take longer and seem to correlate better with symptom resolution.

With LNFB, it is possible to train 168 measurements at one time. Importantly, the clinician has the option of changing the feedback criteria from the default of 85% of scores within a defined limit to 100%. That would mean that all targeted variables at all targeted BAs, including relatively rare outliers, would have to be met in order to get positive feedback. This option is used when one or two of the most important areas for a particular patient are well outside the database norms and could continue to be outside the chosen Z-score range and thus not be influenced if the 85% default setting is used. Choosing fewer variables but asking for 100% of them to be within a particular Z-score range forces the client to move all the training parameters into the chosen Z-score window to receive feedback (see Figure 10).

The bottom figure graphs BAs as different colored lines with Z-scores on the y-axis and session number on the x-axis. In this example, the trainer changed the program at session 11 from the default of 85% of scores within a defined limit to targeting just six variables but requiring all scores (100%) to be within the desired Z-score range. This resulted in more rapid progress.

LNFB allows us to target specific networks. Networks connect many BAs in the cortex to regulate thinking, feeling, and behavior. The principle broad networks include the executive (including attention and memory), affect, salience, and default mode systems. More than one network, and thus many BAs, often from quite diverse areas of the cortex, are involved in any given syndrome or so-called "disorder." The connections between different areas of the brain are the crux of the matter for helping the patient make significant changes in brain functioning. LNFB and HRV are merely tools the patient uses to assist in making these changes. But the changes made in the office are helpful long-term only if patients can integrate new thinking, feeling, and behavior into their activities of daily living. Teaching metacognitive strategies during a portion of the feedback session can assist in this generalization, as can having the patients practice their muscle relaxation, hand warming, and emptying their mind of circular thinking (negative ruminations) while practicing diaphragmatic breathing at their resonant frequency at times when they are carrying out routines in daily living. Although practicing for 20 minutes twice a day, perhaps using an app such as MyCalmBeat or DrStress, might be ideal, we are realistic in our expectations and suggest that clients can also just attach brief periods of diaphragmatic breathing to other routine activities, such as driving, settling down to enjoy a meal, sitting down at their computer, or falling asleep at night. Lynda's personal favorite practice time is whenever she encounters a red light while driving: Instead of tensing up and feeling annoyed, she exhales slowly, relaxes her shoulders and thinks, "Ah, three breaths!" When the light changes back to green 30 seconds later, she is relaxed and focused and feels good about having practiced her diaphragmatic breathing instead of feeling annoyed about the delay.

The reader will note that we have moved, when doing Loreta NFB, from an emphasis on amplitude training to following the suggestions of both Bob Thatcher and Joel Lubar and emphasizing connectivity as being central to treatment. Of importance in this shift in emphasis is the research that has demonstrated that NFB training can produce increases in the volume of both gray and white matter. Using healthy university students as the subjects, researchers trained connectivity in the right arcuate fasciculus within the superior longitudinal fasciculus between superior frontal and parietal areas in the right hemisphere. The parietal area is known to help enable the prefrontal cortex to supervise the allocation of attentional resources for sustained attention. The NFB training parameters in this research enhanced 15- to 18-Hz activity at F4 and P4 and thus stimulated neuronal communication between frontal and parietal regions. They demonstrated (a) increased volume in white matter pathways, measured using fractional anisotropy, and (b) increased gray matter volume, detected with MRI, in cerebral structures involved in sustained attention (Ghaziri et al., 2013). These findings are interesting in light of Thatcher emphasizing that coherence and phase are amplitude independent and reflect the degree of coupling or synchrony between nodes in a network. Thatcher emphasizes that changes in these metrics are more representative of changes in a network than is power.

What Are We Targeting?

Targets for change are findings that (a) are outside database norms and (b) match with symptoms. There may be some deviations from database norms that one should not target for change. For example, as previously noted, if there are findings that are 2 SD outside the norms near Wernicke's area in someone who is a gifted speaker and author of an international "bestseller," you do not want to normalize that brain activity any more than you would want to decrease that person's IQ to being average rather than being above 130.

Another point to keep in mind is that LNFB is limited by the original databases only going to 30 Hz because the computers in use when the standard databases were developed were slower and the sampling rate for EEG was only 128 samples per second. Although the range from 0.5 to 30 Hz does cover almost all the spontaneously generated EEG that is used in NFB, it still leaves us using single-channel surface NFB for patients who require training at higher frequencies. For example, some patients show Beta spindling associated with negative ruminations in the 31- to 36-Hz range. In addition, some patients benefit from careful enhancement of Gamma activity, 39 to 41 Hz. Those Gamma frequencies can be measured accurately with newer equipment.

Whether we do single-channel NFB or LNFB, we are influencing neural networks (Thompson, Thompson, Thompson, & Hagedorn, 2011). These are interconnected, functionally related groups of neurons that involve various BAs. Brodmann published his work on the human cortex in 1909 (Broadmann, 2006/1909) showing all the different sections of the cortex, numbering them from 1 to 52, based on cytoarchitecture (cell shape/morphology). Starting near the center of the cortex below the central sulcus, he named the area "1." He then gave a new number to each adjoining area that was made up of new cell types. The adage, "structure dictates function," for the most part, is reasonably true with respect to this method of identifying different areas of the cortex. Each BA does appear to have a primary function; however, it is also true that each BA can have a number of other functions and can be involved in many different functional networks (D. Lloyd, Trinity College, Hartford, CT, personal communication, 2007). The function of the moment depends on which network is activated, and that depends on what task engages the brain at that moment.

Hypothetically, affecting the activity of the cingulate gyrus may be assumed to have indirect effects on many deeper structures even though the NFB operant conditioning of brain wave activity is done at a site on the surface of the scalp. Strong support for this hypothesis comes from research done in Montreal, Canada, concerning children with ADHD who received NFB training with electrode placement at Cz. Using fMRI as the pre-post measure, the experimental group, as compared with the control group, showed increased activation in a number of cortical and subcortical areas. Specifically, during a counting Stroop task, there were changes in activation in the left substantia nigra and left caudate, right anterior cingulate gyrus, and left superior parietal area. During a GO/NO GO task, there was again increased activation in left substantia nigra, left caudate, and right anterior cingulate gyrus, plus changes in left thalamus and also the right and left lateral frontal areas (Beauregard & Levesque, 2006).

Using EEG and HRV Measures in Other Contexts

In situations that differ from a clinic providing treatment, people may use EEG assessment equipment and brain mapping to measure brain function without providing training. Monitoring athletes who have experienced a blow to the head in order to make return-to-play decisions is one example. Reported symptoms may have normalized even though one or more of the objective brain measures that reflect functioning has not returned to a normal range. Ideally, one would have a baseline for the athlete, so one could monitor a return to the athlete's personal healthy baseline. Knowing whether recovery is real or apparent can be critical to a person's well-being. It is especially important if one has to recommend suitability for return-to-play of an athlete after a concussion. Figure 11 shows monitoring of brain health in a mixed martial arts (MMA) fighter who was not receiving treatment but who was just being monitored. The information from the second assessment was crucial in making the decision to wait before returning to fight. The data from the third set of measurements show he had recovered further during his rest period, although recovery was not yet complete, that is, not yet back to baseline on all measures.

The Illustration in Figure 11 shows brain maps from 19-channel EEG, HRV statistics (SDNN and power in ms^2 that is labeled ANS [autonomic nervous system] activity) and ERP data (the P3b response). It shows data for an MMA fighter before sparring amd then after sparring in the cage and incurring a head injury. When retested after postconcussion symptoms had "normalized" according to self-report in April, objective measures still showed brain dysfunction because his QEEG, ERP, and HRV values were not yet back to his preinjury level. When retested a second time in June, these objective measures had moved closer to their presparring, pre–head injury levels. Note that the P3b is the second P300 response. It is the response measured at Pz that reflects monitoring, working memory, and information processing.

Summary and Closing Thoughts

Assessment and interventions using NFB combined with biofeedback have changed rather rapidly in the past 25 years, although the basic principles of applying operant conditioning techniques to achieve lasting learned changes in a person's psychophysiological measures, and hence their behavior, has not. At our center, we have gradually been moving from single- and, occasionally, two-channel assessment and training in the 20th century to 19-channel assessments and training using LORETA source analysis and database Z-score comparisons in the 21st century. The combining of biofeedback with NFB has shifted a little from using mainly peripheral skin temperature, electrodermal response, and electromyography to an emphasis on HRV training. All our interventions have support from clinical research. We encourage clinicians to measure outcomes and report case series. We also encourage using appropriate multimodal assessment and intervention methods. We also encourage people to consider research designs that go beyond randomized, placebo-controlled trials assessing a single intervention. Research, however, is not the main driver of demand for NFB training. Lack of demand stems more from lack of awareness of NFB. Once people become aware that there is a way to exercise the brain and improve functioning, they usually want this nondrug alternative treatment.

To recapitulate our observations and recommendations regarding NFB in 2016, current practice suggests that practitioners always start with a careful, comprehensive assessment. (See Figure 3 for a summary of assessment measures.) At our center, we then train using single-channel (or sometimes two-channel) NFB in straightforward cases. We may choose to train amplitudes for particular frequency bands, or we may train coherence between two sites. With complex cases, we can apply 19-channel assessment and use LNFB, which is done with the 19-channel cap on and equipment that simultaneously records EEG and applies the mathematics of LORETA to target changes (amplitude, phase, coherence) in numerous areas in the cortex, including areas such as BA 25 (important in depression) that lie deep in the cortex. LNFB alternatively allows entire neural networks to be directly addressed in terms of connectivity between BAs that are involved in a particular network. We advocate tracking of learning curves within and across sessions and doing progress testing after 40 sessions of training using the same measures as were used in the initial assessment. With clients who require more training, there are updates after every 20 sessions thereafter until goals have been met.

As well, NFB practitioners may use adjunctive techniques that include biofeedback, particularly HRV training, relaxation techniques, and neuromodulation approaches, such as transcranial direct current stimulation, other forms of cranial electrical stimulation, blood flow biofeedback, referred to as hemoelectroencephalography, and audiovisual entrainment. Interventions are always based on a thorough initial assessment so that the most appropriate combined therapies can be applied. For those with appropriate training, this can include psychotherapy. Intervention should also involve discussion and advice regarding diet, sleep, and exercise, which constitute the pillars of a healthy lifestyle that helps someone get the most out of NFB training. As clinicians, we are not trying to tease out the relative contribution of each intervention but, rather, we are looking for the combination of interventions that allows for optimization of each individual's potential.

When helping people improve their functioning, whether they are someone with a disorder or an athlete or executive seeking optimal performance, remember that NFB is just one tool in your toolbox. Do not get so tied up in the technology that you forget your clinical skills. Guiding principles include these three:

1. They have to know that you care before they care what you know.
2. Promise less and deliver more.
3. Apply the Principle of Parsimony.

A final thought comes from Roman times. *Qui docet, discit*. (He who teaches, learns.) Much is learned collaboratively in working with each individual client. You are teaching them about their physiology and how to regulate it, and you are learning by observing their responses to interventions. There is always more to discover when doing applied neuroscience.

References

Alexander, G. E., DeLong, M. R., & Strick, P. L. (1986). Parallel organization of functionally segregated circuits linking basal ganglia and cortex. *Annual Review of Neuroscience*, *9*, 357–381.

Arns, M., Conners, C. K., & Kraemer, H. C. (2013). A decade of EEG Theta/Beta ratio research in ADHD: A meta-analysis. *Journal of Attention Disorder*, *17*, 374–383.

Arns, M., De Ridder, S., Strehl, U., Breteler, M., & Coenen, A. (2009). Efficacy of neurofeedback treatment in ADHD: The effects on inattention, impulsivity and hyperactivity: A meta-analysis. *Clinical EEG and Neuroscience*, *40*, 180–189.

Beauregard, M., & Levesque, J. (2006). Functional magnetic resonance imaging Investigation of the effects of neurofeedback training on the neural bases of selective attention and response inhibition in children with attention-deficit/hyperactivity disorder. *Applied Psychophysiology and Biofeedback, 31*, 3–20.

Benedetti, F., Mayberg, H. S., Wager, T. D., Stohler, C. S., & Zubieta, J. K. (2005). Neurobiological mechanisms of the placebo effect. *Journal of Neuroscience, 25*, 10390–10402.

Benson, H. (1997). *Healing: The power and biology of belief*. New York: Scribner.

Brodmann, K. (2006). *Brodmann's localisation in the cerebral cortex* (L. J. Garey, Ed. & Trans.). New York: Springer. (Original work published 1909.)

CNS Vital Signs (2016). CNS Vital Signs, LLC, Morrisvile, NC. http://www.cnsvs.com/

Congedo, M., Lubar, J. F., & Joffe, D. (2004). Low-resolution electromagnetic tomography neurofeedback. *IEEE Transactions on Neural Systems & Rehabilitation Engineering, 12*, 387–397.

Cortese, S., Ferrin, M., Brandeis, D., Holtmann, M., Aggensteiner, P., Daley, D., Santosh, P., et al. (2016). Neurofeedback for attention-deficit/hyperactivity disorder: Meta-analysis of clinical and neuropsychological outcomes from randomized controlled trials. *Journal of the American Academy of Child and Adolescent Psychiatry, 55*, 444–455. doi:http://dx.doi.org/10.1016/j.jaac.2016.03.007

Doidge, N. (2007). *The brain that changes itself*. New York: Viking Press.

Doidge, N. (2015). *The brain's way of healing*. New York: Viking Press.

Fuchs, T., Birbaumer, N., Lutzenberger, W., Gruzelier, J., & Kaiser, J., (2003). Neurofeedback treatment for attention-deficit/hyperactivity disorder in children: A comparison with methylphenidate. *Journal of Applied Psychophysiology and Biofeedback, 28*, 1–12.

Gani, C., Birbaumer, N., & Strehl, U. (2008). Long term effects after feedback of slow cortical potentials and of Theta-Beta amplitudes in children with attention-deficit/hyperactivity disorder (ADHD). *International Journal of Bioelectromagnetism, 10*, 209–232.

Ghaziri, J., Tucholka, A., Larue, V., Blanchette-Sylvestre, M., Reyburn, G., Gilbert, G., Lévesque, J., et al. (2013). Neurofeedback training induces changes in white and gray matter. *Clinical EEG and Neuroscience, 44*, 265–272.

Haneef, Z., Levin, H. S., Frost, J. D., & Mizrahi, E. M. (2013). Electroencephalography and quantitative electroencephalography in mild traumatic brain injury. *Journal of Neurotrauma, 30*, 653–656.

Kamiya, J. (1968). Conscious control of brain waves. *Psychology Today, 1*, 56–60.

Kropotov, J. D. (2009). *Quantitative EEG, event-related potentials, and neurotherapy*. San Diego, CA: Academic Press.

Linden, M., Habib, T., & Radojevic, V. (1996). A controlled study of the effects of EEG biofeedback on cognition and behavior of children with attention deficit disorder and learning disabilities. *Biofeedback and Self Regulation, 21*, 106–111.

Lubar, J. F. (1995). *Neurofeedback for the management of attention-deficit/hyperactivity disorders*. In M. S. Schwartz & Associates, *Biofeedback: A practitioner's guide* (2nd ed., pp. 493–522). New York: Guilford Press.

Lubar, J. F., & Shouse, M. N. (1976). EEG and behavioral changes in a hyperkinetic child concurrent with training of the sensorimotor rhythm (SMR): A preliminary report. *Biofeedback and Self-Regulation, 3*, 293–306.

Lubar, J. F., Swartwood, M. O., Swartwood, J. N., & O'Donnell, P. H. (1995). Evaluation of the effectiveness of EEG neurofeedback training for ADHD in a clinical setting as measured by changes in TOVA scores, behavioural ratings, and WISC-R performance. *Biofeedback and Self Regulation, 21*, 83–99.

Monastra, V. J., Lubar, J. F., Linden, M., VanDeusen, P., Green, G., Wing, W., Phillips, A., et al. (1999). Assessing attention deficit hyperactivity disorder via quantitative electroencephalography: An initial validation study, *Neuropsychology, 13*, 424–433.

Sears, W., & Thompson, L. (1998). *The A.D.D. book: New understandings, new approaches to parenting your child*. New York: Little Brown.

Sheer, D. E. (1977). Biofeedback training of 40 Hz EEG and behavior. In N. Burch & H. I. Altshuler (Eds.), *Behavior and brain electrical activity* (pp. 325–362). New York: Plenum.

Shouse, M. N., & Lubar, J. F. (1979). Sensorimotor rhythm (SMR) operant conditioning and methylphenidate in the treatment of hyperkinesis. *Biofeedback & Self-Regulation, 4*, 299–311.

Steriade, M., & McCarley, R. W. (2005). *Brain control of wakefulness and sleep*. New York: Springer.

Sterman, M. B., & Bowersox, S. S. (1981). Sensorimotor EEG rhythmic activity: A functional gate mechanism. *Sleep, 4*, 408–422.

Strehl, U., Leins, U., Goth, G., Klinger, C., Hinterberger, T., & Birbaumer, N. (2006). Self-regulation of slow cortical potentials: A new treatment for children with attention-deficit/hyperactivity disorder. *Pediatrics, 118*, 1530–1540.

Swingle, M. (2016). *I-Minds: How cell phones, computers, gaming, and social media are changing our brains, our behavior, and the evolution of our species*. Gabriola Island, British Columbia, Canada: New Society Publishers.

Tan, G., Shaffer, F., Lyle, R., & Teo, I. (2016). *Evidence-based practice in biofeedback and neurofeedback* (3rd ed.). Wheat Ridge, CO: Association for Applied Psychophysiology.

Tebano, M. T., Cameroni, M., Gallozzi, G., Loizzo, A., Palazzino, G., Pezzini, G., & Ricci, G. F. (1988). EEG spectral analysis after minor head injury in man. *Electroencephalography and Clinical Neurophysiology, 70*, 185–189.

Thatcher, R. W. (2012). *Handbook of quantitative electroencephalography and EEG biofeedback: Scientific foundations and practical applications*. St. Petersburg, FL: AniPublishing. Retrieved from www.appliedneuroscience.com

Thayer, J. F., Åhs, F., Fredrikson, M., Sollers, J. J., III, & Wager, T. D. (2012). A meta-analysis of heart rate variability and neuroimaging studies: Implications for heart rate variability as a marker of stress and health. *Neuroscience & Biobehavioral Reviews, 36*, 747–756.

Thompson, L., & Thompson, M. (1998). Neurofeedback combined with training in metacognitive strategies: Effectiveness in students with ADD. *Applied Psychophysiology and Biofeedback, 23(4)*, 243–263.

Thompson M., & Thompson, L. (2003). *The neurofeedback book: an introduction to basic concepts in applied psychophysilogy*. Wheat Ridge, CO: Association for Applied Psychophysiology. Polish Translation 2012.

Thompson, M., & Thompson, L. (2007). Neurofeedback for stress management. In P. M. Lehrer, R. L. Woolfolk, & W. E. Sime (Eds.), *Principles and practice of stress management* (3rd ed.). New York: Guilford.

Thompson, M., & Thompson, L. (2009). Systems theory of neural synergy: Neuroanatomical underpinnings of effective intervention using neurofeedback plus biofeedback. *Journal of Neurotherapy, 13*, 72–74.

Thompson, M., & Thompson L. (2015a). *Functional neuroanatomy organized with reference to networks, lobes of the brain, 10-20 sites, and Brodmann areas*. Wheat Ridge, CO: Association for Applied Psychophysiology.

Thompson, M., & Thompson, L. (2015b). *The neurofeedback book: An introduction to basic concepts in applied psychophysiology* (2nd ed.). Wheat Ridge, CO: Association for Applied Psychophysiology.

Thompson, M., Thompson, L., Thompson, J., & Hagedorn, D. (2011, summer). Networks: A compelling rationale for combining neurofeedback, biofeedback, and strategies. *NeuroConnections*, 8–17.

Thompson, M., Thompson, L., & Reid, A. (2010). Neurofeedback outcomes in clients with Asperger's syndrome. *Journal of Applied Psychophysiology and Biofeedback, 35(1)*, 63–81.

Thompson, M., Thompson, L., & Reid-Chung, A. (2014). LORETA Z-score neurofeedback combined with heart rate variability training. In R. Thatcher & J. Lubar (Eds.), *EEG Z-score neurofeedback: Clinical applications* (pp. 159–188). New York: Academic Press.

Vles, J. H. S., Feron, F. J. M., Hendriksen, J. G. M., Jolles, J., Kroonenburgh, M. J. P. G., & Weber, W. E. J. (2003). Methylphenidate down-regulates the dopamine receptor and transporter system in children with attention deficit hyperactivity disorder (ADHD). *Journal of Neuropediatrics*, *34*, 77–80.

Wyrwicka, W., & Sterman, M. B. (1968). Instrumental conditioning of sensorimotor cortex EEG spindles in the waking cat. *Physiology and Behavior*, *3*, 703–707.

Yanofski, J. (2010).The dopamine dilemma: Using stimulants and antipsychotics concurrently. *Psychiatry (Edgmont)*, *7*(6), 18–23.

Yanofski, J. (2011). The dopamine dilemma—Part II: Could stimulants cause tolerance, dependence, and paradoxical decompensation? *Innovations in Clinical Neuroscience*, *8*, 47–53.

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