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SPECIAL ISSUE

Treating Postconcussion Syndrome Using Neurofeedback: A Case Study

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The present article provides a case study showing the application of neurofeedback and biofeedback training with heart rate variability (HRV) training to a 27-year-old man, Mike, who suffered a severe traumatic brain injury (TBI) in a motor vehicle accident. The study demonstrates the use of single-site neurofeedback training, metacognitive strategies, and low-resolution brain electromagnetic tomography (LORETA) z-score training along with HRV. A review of the initial assessment and subsequent progress updates included an examination of continuous performance tests such as test of variables of attention, integrated visual and auditory continuous performance test, and single-channel electroencephalography results, HRV statistics, and 19-channel quantitative electroencephalogram results. The client demonstrated significant improvements on all measures posttraining with marked improvement in five areas: memory, sleep and energy level, academics, mood and irritability, and mental sharpness. Working with clients such as Mike supports the view that one- and two-channel neurofeedback and LORETA z-score neurofeedback, combined with HRV training, are promising interventions for clients with TBIs.

Introduction

In this issue of *Biofeedback*, Thompson, Thompson, Reid-Chung, and Thompson (2013) provide an overview of the use of quantitative electroencephalography (QEEG), neurofeedback, and heart rate variability (HRV) biofeedback in the assessment and treatment of traumatic brain injury (TBI). The present article provides a case study showing the application of this neurofeedback and biofeedback approach to a 27-year-old man, Mike, who suffered a severe TBI in a motor vehicle accident.

In the summer of 2006, a client we shall refer to as Mike (name changed to protect confidentiality) was assessed at the ADD Centre on referral from his physician. Another of this physician's patients had benefitted from neurofeedback training after a head injury sustained during martial arts sparring, so he felt neurofeedback might also assist Mike regarding his cognitive functioning. Mike had sustained serious head injuries, in addition to injuries to his back and one arm, a year earlier when his car was struck by a truck that ran a red light. He was in coma for 2 days and suffered retrograde amnesia. At the time we saw him, he had typical postconcussion symptoms of headaches, severe memory problems, irritability, and "a short fuse." Training did not begin until March 27, 2007 (20 months postaccident), after his insurance company approved the neurofeedback intervention. In the intervening 8 months, there had been no further cognitive recovery, and his injuries were deemed "catastrophic" through an insurance company review based on further outside psychometric testing. His neurofeedback training included both amplitude and coherence training with sites based on 19-channel assessments, updated as needed, usually after each block of 40 sessions of training. At the present time, he is receiving low-resolution brain electromagnetic tomography (LORETA) z-score neurofeedback training while continuing his HRV training. Mike has become our longest-term client.

Working with this client has demonstrated how neurofeedback and biofeedback training can help ameliorate the cognitive and affective symptoms of TBI so that a person can move on with his or her life. This article provides an overview of this client's assessment and training and discusses the impact of single-channel neurofeedback training combined with biofeedback as well as LORETA neurofeedback training.

Case Study

Presenting Problems

Mike was 27 years old when he presented for an assessment in July 2006, a year after he suffered from a brain injury, along with physical injuries to his neck and back, in a motor vehicle accident. When his car was T-boned by a truck running a red light, the force was such that his seatbelt snapped, which caused him to be flung forward and hit the left side of his forehead on the windshield. There was amnesia for the accident when he came out of coma 2 days later. When he regained partial consciousness, he behaved in an aggressive and violent manner and had to be restrained. He did not remember any of his violent behavior and threatening words when he fully regained consciousness. A traditional EEG reading done 9 months later indicated normal EEG waves with no focal or epileptiform activity. In a computed tomography scan done just before Mike started training, two pinhole fractures in the frontal area of the skull were discovered, and calcium deposits had developed there.

In the year following the accident, some spontaneous recovery had taken place and many of his physical injuries had healed, although he still had a sore back, could not lift anything heavy, suffered severe headaches a couple of times a month, and had limited mobility in his left arm and shoulder. Previously very athletic, he had gained 20 lb due to restrictions in his activities. Medications were an antacid and prescription pain medication used on an as-needed basis.

Residual cognitive and affective problems were in memory function, concentration, distractibility, irritability with some anger management difficulties ("a short fuse"), excessive tiredness, and poor sleep. The extent of his fatigue was such that he had to nap during the day. His extreme fatigue and lack of adequate attention span meant that he had not finished revisions to his thesis, the last degree requirement of his automotive engineering studies. Fortunately, the company where he was working at the time of the accident continued to employ him as a process engineer once he was deemed fit for work after his initial recovery, but instead of the overtime and 60-hour week he had relished previously, he worked a 35-hour week and had a nap as soon as he got home in the afternoon. Friendships were affected by the accident, too, both because of loss of his sense of humor and because he was unable to indulge in the active sports he loved, such as golf, and was unable to make the previously frequent 5-hour drive to see friends in the city where he had studied engineering. Because he was living at home, his parents were around to help him, but he was now unable to help them with household or garden chores. He had a girlfriend he had started to date prior to his accident, and she was emotionally supportive.

Prior to the accident, Mike enjoyed good health with only minor problems, such as seasonal allergies that sometimes caused asthmatic symptoms. He was allergic to nuts, peanuts, dust, pollen, and pets. He had been high energy and very active in sports and a person who liked to get in and fix things. His reduced mobility and inability to take part in his favorite sports or take lengthy car rides to visit friends were thus a great frustration to him.

Assessment Procedures and Results

The initial assessment involved a clinical interview, review of his medical records, computerized tests of attention (namely, the Integrated Visual and Auditory [IVA; Sandford & Turner, 1995] continuous performance test and the Test of Variables of Attention [T.O.V.A.; Greenberg, 2011]), questionnaire data, a single-channel (CZ) QEEG profile, and a 19-channel QEEG assessment with the Neuroguide database applied for interpretation.[1] It should be noted that Mike had a tendency to underreport symptoms and was not at all a "complainer" but rather was someone who wanted to get back to normal and downplayed his difficulties. He put great effort into all the assessment tasks.

The IVA indicated good accuracy but a slow and variable reaction time. His visual attention and visual response control scores were within the normal range (50th and 39th percentile ranks, respectively); however, auditory attention at the 18th percentile rank and auditory response control at the 13th percentile were in the low-average range. Response time and variability of response time were both in the bottom 1% for 27-year-old men on the T.O.V.A. test. He was vigilant regarding the visual stimuli and not impulsive, although he reported that he found the T.O.V.A. difficult as the target seemed to be moving (which is not the case). Self-ratings on three questionnaires, the ADD Centre Questionnaire, the *DSM-IV* rating scale (American Psychiatric Association, 1994), and the Wender Utah Rating Scale, which assess for the symptoms of attention-deficit

[1]The International 10–20 system defines scalp location in a grid organized around two axes. CZ is the vertex or absolute center of the scalp, defined by the intersection of the two axes. PZ is a midpoint in the parietal region.

disorder, indicated elevated scores but not quite in the clinically significant range. Deficits in attention are some of the most common symptoms after suffering a brain injury (Auerbach, 1986; Dockree et al., 2004; Levin & Goldstein, 1989; Van Zomeren & Brouwer, 1987). Talking excessively, blurting things out, and having difficulty waiting his turn were DSM-IV items that he rated as "quite a bit true" of himself. This tendency to blurt things out is typical of individuals with frontal lobe damage (Shallice & Burgess, 1991).

The single-channel EEG recording done at CZ showed excessive slow-wave activity and also excessive hi-beta (>20 Hz) activity. There was a relatively low amplitude of sensorimotor rhythm. Based on these findings, a neurofeedback training program was designed to reduce both 2 to 5 Hz and 23 to 35 Hz, while enhancing 13 to 15 Hz at the central location.

The 19-channel QEEG assessment indicated excessive delta and theta activity at many sites, which is a typical finding in head injuries. There was excessive central alpha at CZ and PZ. We also found dysfunction in the posterior cingulate cortex that may correlate with his memory problems. In addition, there was spindling beta in the frontal and central areas of the brain. These were interpreted as correlating with the irritable behavior he experienced.

The conclusion was that neurofeedback plus biofeedback training could play a role in improving Mike's memory and overall functioning because areas that were outside normative database means, using the Neuroguide database, matched with his symptoms. A secondary goal was to improve sleep and have him experience less fatigue and return to a more energetic lifestyle. We also hoped for improvement in his mood and less irritability. Both the breathing technique and muscle relaxation taught during HRV training and strategies were expected to further assist him with the development of self-regulation skills. It was explained that the training would be complementary to other interventions already in place: physiotherapy, occupational therapy, and a healthy diet with supplements that included fish oil. Finishing his thesis to complete his graduation requirements as an engineer was a goal that required him to be able to sustain his concentration at a nonpreferred task.

Training Methods and Procedures

Single-channel neurofeedback uses a brain-computer interface that involves learning, through feedback, to regulate brainwave (EEG) activity. This provides a person with the mental edge—the ability to choose to be in the mental state appropriate for the activity at hand. The training program can improve executive functioning (including attention, focus, organization, learning, listening, and memory) through individualized neurofeedback. There is established efficacy for neurofeedback in the treatment of both attention-deficit/hyperactivity disorder (ADHD) and epilepsy. It is still considered an experimental approach to treating head injuries as sufficient randomized controlled studies to establish efficacy are lacking, although good clinical outcomes have been reported. Case studies support the effectiveness of neurofeedback for individuals with TBI to improve learning and memory (Reddy, Jamuna, Indira Devi, & Thennarasu, 2009). Researchers have also seen improvements in functioning in small groups of people who had suffered brain injuries (Ibric, Dragomirescu, & Hudspeth, 2009). See the International Society for Neurofeedback and Research Web site at www.isnr.org for a bibliography of articles related to neurofeedback and TBI.

Single site EEG training. Mike's training parameters were set according to the 19-channel and single-channel assessments that were carried out. Initially, multiple scalp sites that were outside the database norms were selected as parameters for training. These sites were trained one at a time using single-channel training to either increase or decrease amplitudes for particular brainwave frequency bands. There were several sites to train, and it is beyond the scope of this article to describe the whole series. Training started at the central location to influence the widest range of cognitive and affective networks. TBI causes diffuse axonal injury, which is associated with disturbances in connectivity between different areas of the brain (Meythaler, Peduzzi, Eleftheriou, & Novack, 2001). Hence, after the initial amplitude training was completed, Mike started coherence training (for alpha, beta, and theta) for multiple pairs of sites. His training also included biofeedback, primarily HRV training. This biofeedback technique requires the client to achieve synchrony between breathing and changes in heart rate so that a high variability in the interbeat intervals of the heart is achieved. HRV depends on physiological states that reflect alertness, tension, and anxiety, and healthy HRV is known to reduce anxiety and stress (Mikosch et al., 2010; Reiner, 2008). It can also improve cognitive functioning in stressful conditions (Prinsloo et al., 2011). In addition, we included electrodermal response training for level of arousal and alertness due to his problems with fatigue, and electromyogram training to improve his muscle relaxation and reduce muscle tension. His training regimen has been lengthy due to the extensive number of abnormalities with many sites to be addressed using single-channel training. However, steady improvement was measureable, and thus his insurance company has continued to fund further blocks of 40 sessions of training at a time over the years. His initial twice-a-week training has tapered to once a week.

Metacogitive strategies. Metacognitive strategies were also included in the treatment plan. Metacognition, in simplest terms, is “thinking about thinking.” It refers to executive thinking skills that monitor your cognition. It involves being conscious about how you plan, execute, and evaluate your approach to a task and involves awareness of how to learn and remember things. Combining these approaches (neurofeedback, biofeedback, and metacognition) leads to an efficient, calm, reflective, and organized approach to work. In work and everyday life, individuals can work consistently at a higher level as they learn to be flexible in applying problem-solving strategies.

LORETA z-score training. With the introduction of LORETA z-score neurofeedback training at the ADD Centre, we were able to target amplitude, coherence, and phase concurrently for up to 24 Brodmann areas that (a) were outside the database norms and (b) correlated with his difficulties. We hypothesized that the training was likely to affect networks for memory in addition to affect. LORETA is the acronym for *low-resolution brain electromagnetic tomography*, and the mathematics were developed and tested by Roberto D. Pasqual-Marqui of The KEY Institute for Brain-Mind Research at the University Hospital of Psychiatry in Zurich, Switzerland. LORETA mathematics provides the inverse solution that allows us to take EEG information from sites on the scalp and convert this into information about the source deeper in the cortex for each frequency. One advantage of QEEG plus LORETA is that it has the best temporal resolution as compared with other methods of neuroimaging (positron emission tomography, single-photon emission computed tomography, and functional magnetic resonance imaging, for example). Based on these computations, in LORETA neurofeedback, the EEG data are continuously compared with database norms from Robert Thatcher’s Neuroguide, and feedback is provided to the client, who must shift his EEG patterns to bring as many as 24 parameters (amplitude, coherence, phase involving various Brodmann area sites) to within the z-score limits set by the practitioner. The z-score variations are calculated using a comparison of the client’s EEG data with a normative database. The Brodmann areas (BA) of interest for a particular client are chosen by matching that individual’s symptoms (rated for severity) to BAs that are known from the literature to relate to those functions. The continuous neurofeedback display usually comprises bar graphs, animations, or movies on the client’s screen, plus line graphs of time versus z-scores at each site on the clinician’s screen. Thus, the display reflects changes in z-score deviations from the database in the chosen BA locations. In this manner, the client is rewarded for maintaining brainwave activity within a designated z-score range (say, –2.5 to +2.5 SD) at all the designated BA sites, also called regions of interest, that are important for that client. Once the client can consistently meet those criteria, the z-score range is set lower, with a goal of eventually getting all designated parameters normalized to within 1 or 1.5 standard deviations (SD).

The advantage of using LORETA neurofeedback over traditional neurofeedback is increased specificity of the training and the possibility to train activity at locations not otherwise easily influenced by conventional surface EEG. Examples of these areas might include the parahippocampal gyrus (involved in memory and affect) and BA 25 (involved in depression). It also allows the client to train up to 24 targeted areas/parameters at the same time. However, this procedure takes more time to set up at each session because the 19-channel EEG cap must be in place with low and even impedances at all sites before you begin. In addition, we feel it is best done by experienced clinicians who have a good working knowledge of neuroanatomy and BA functions who can make reasonable judgments as to which z-score deviations represent pathology and which represent positive attributes or, perhaps, compensatory functions. Areas that are outside database norms for good reasons, perhaps reflecting an individual’s strengths, must not be trained.

Starting in fall 2012, we began LORETA neurofeedback training with Mike after he had completed 249 sessions of regular neurofeedback. At the ADD Centre, the usual number of sessions for clients is 40, with some more complex clients having about 60 sessions. However, this was a most unusual case due to the extreme severity of the head injury, and with repeated reassessments, he was found to be steadily improving with neurofeedback, and therefore it was continued. The first training program targeted symptoms such as short-term memory, slowness of thinking (easily confused), slow reading, sequential planning, low motivation, attention deficits, and multitasking problems. We also targeted the mood, pain, and attention networks. In July 2013, after 25 sessions of LORETA neurofeedback, we updated his LORETA symptom checklist, and the new goals were to improve concentration, multitasking, and attention deficits.

Results

Since spring 2007, there have been tremendous improvements in Mike’s overall functioning. His scores on the

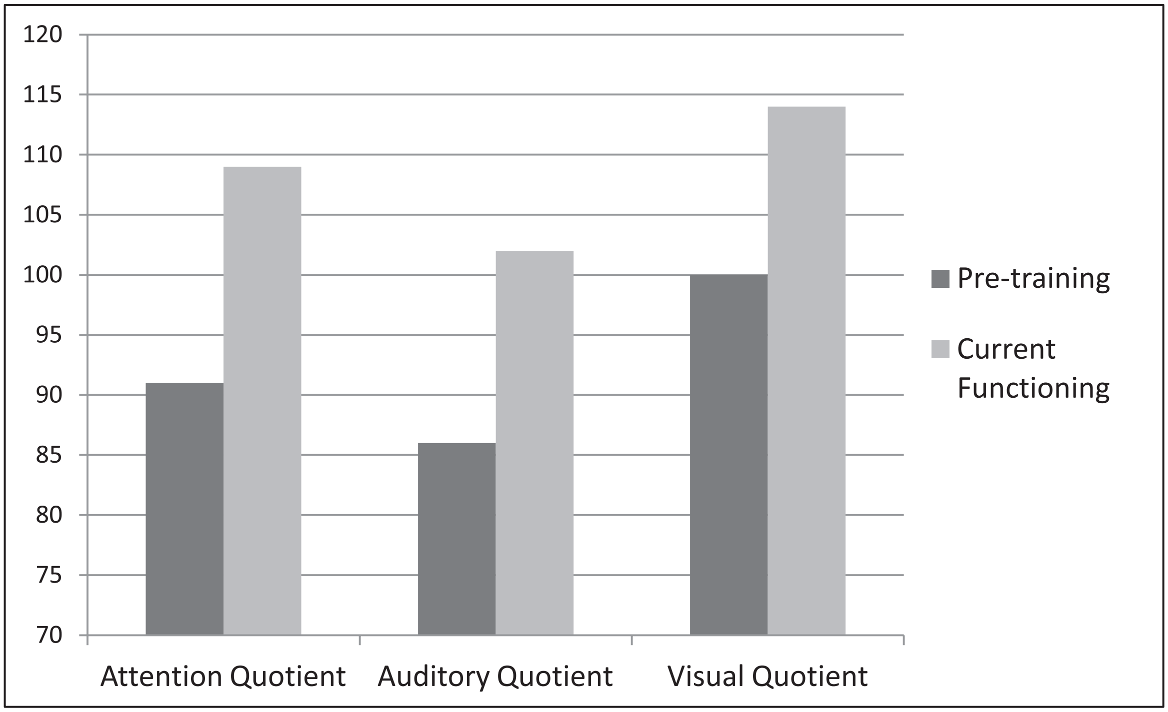

Figure 1. Integrated visual and auditory continuous performance test results comparing March 2007 to July 2013 (standard scores with mean of 100 ± 15 [SD]).

continuous performance tests normalized; for example, response time and variability on the T.O.V.A. improved from being in the bottom 1% for age norms to being at the 37th and 23rd percentile ranks, respectively, in mid-2008. On the IVA, by 2008 his visual attention quotient had improved from the 50th percentile rank to the 66th percentile, and his visual response control quotient had changed from the 39th to the 45th percentile. By 2009, Mike had completed his master's thesis and thus finally graduated with his engineering degree. In 2010, the highlight was that he married his long-term girlfriend and had lots of energy to dance at his wedding. By this time, Mike was doing coherence training, working through the various pairs of sites that showed significant deviations, and this training continued with some breaks for holidays and travel until October 2012, when he began LORETA neurofeedback training. Figure 1 summarizes the changes in his functioning on the IVA from the initial assessment up to his last testing early in 2013.

There was no significant change in questionnaire data over the years as the questionnaire ratings were never in the significant range for symptoms from the very beginning. It should be noted that, even though functioning has been improving, there have been challenging life events and major adjustments to make in the years since the accident. Although he initially had kept his job, albeit with reduced hours, he was let go when his company downsized with the recession at the end of 2008. He has had two jobs since then, both obtained without seeking any accommodations in the workplace. One involved an extremely long commute that was unsustainable, and the second, although close to home, did not use his full range of talents as an engineer and he felt underemployed, so he was not overly upset when he was let go earlier this year in a management reshuffle. His newly unemployed status comes on top of ongoing extreme stress due to life-threatening health problems in other members of the immediate family since the beginning of 2013. All of this would influence his most recent questionnaire ratings, shown in the graph below. He attended this progress test off all medication (including pain medication that he still takes as needed for his back pain). Note that the ratings, though high, are not in the significant range for ADHD symptoms at either pre- or posttest. His resiliency and generally optimistic attitude during the stressors of the past 6 months has been impressive, and he has certainly used his diaphragmatic breathing on a regular basis to maintain his equanimity.

A comparison of the 19-channel QEEG data across 2007, 2009, 2010, and October 2012 (done before LORETA training initiated) revealed quantifiable changes in his EEG. Although not currently used in adults, and not normed for adults, the Learning Disability Probability Index from

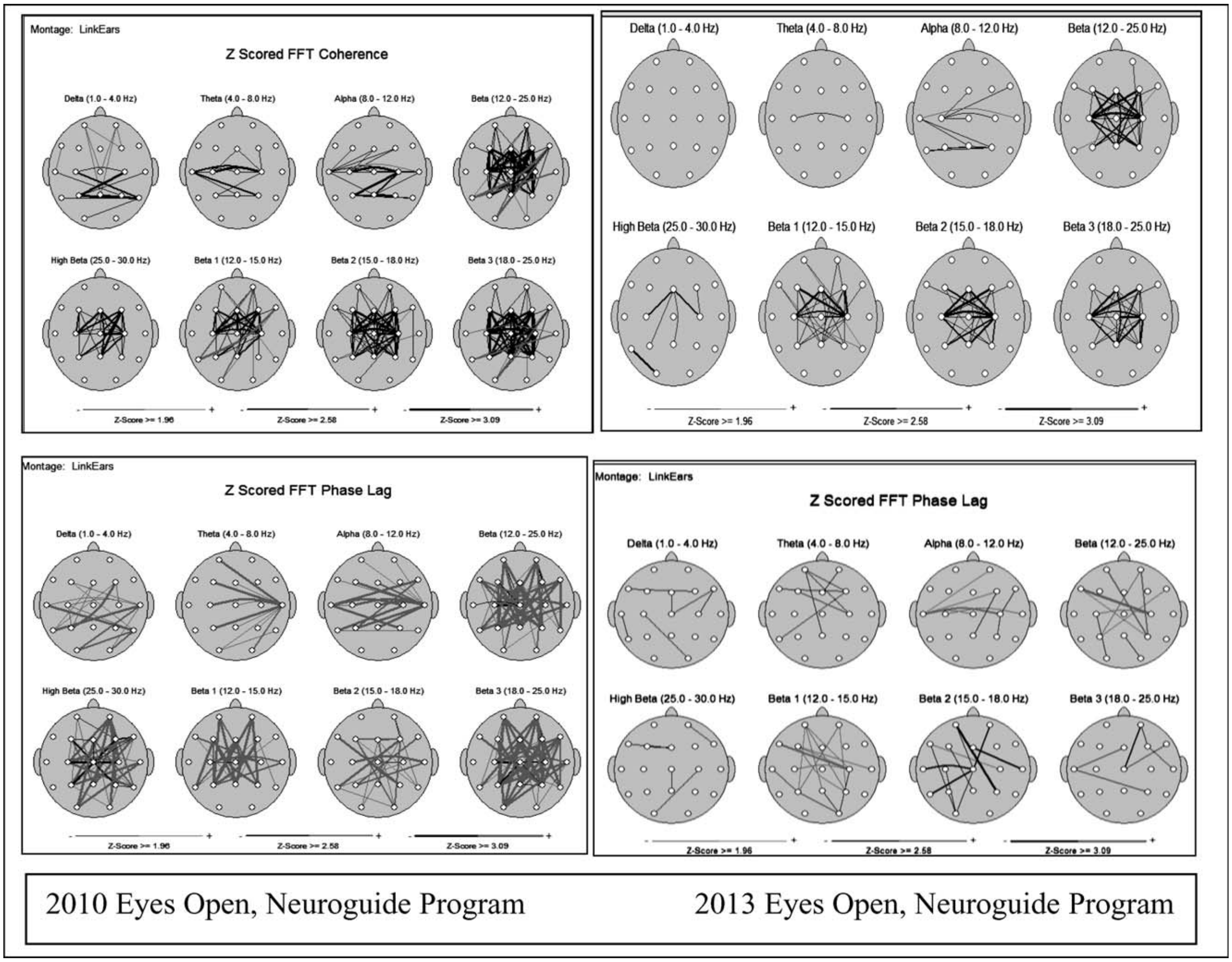

Figure 2. Neuroguide pre- and postcomparison.

Neuroguide showed a shift from a 55% probability of LD in 2007 to 0% by 2010. His TBI Probability Index showed a remarkable reduction from 97.5% in 2007 to 0% by 2009. His peak alpha frequency (PAF) increased from 9.89 in 2007 to 10.1 in 2010 and was at 10.19 in October 2012. PAF correlates with cognitive performance, and the mean alpha frequency in adults is 10 Hz with a range between 10 and 11 Hz in healthy adults (Angelakis, Lubar, Stathopoulou, & Kounios, 2004; Grandy et al., 2013; Hanslmayr, Sauseng, Doppelmayr, Schabus, & Klimesch, 2005). One study showed that training to increase high alpha power correlated with improved performance on a mental rotation task (Hanslmayr et al., 2005). Individuals with TBI demonstrate a lower PAF when compared with healthy individuals (Angeliakis et al., 2004). A reduced PAF is also an indicator of physical fatigue (Ng & Raveendran, 2007).

By 2013, there was a considerable decrease in coherence abormalities. Changes in coherence correlated with reduction in cognitive, emotional, and physical dysfunctions has been previously reported (Ibric, 2006; Ibric & Hudspeth, 2004), and this has certainly been true in Mike's case. A comparison of his 19-channel updates between 2010 and 2013 reveal significant quantitative improvements. Analysis of a Laplacian view of the left hemisphere in the 2010 EEG showed spindling beta at C3 and P3. With LORETA training, his z-scores changed from being 2.49 SD outside the norm at C3 to 1.91 SD. At P3, the improvement has been from 2.26 to 0.85 SD at P3. The improvement at C3 correlates with a feeling of being calm, and Mike exhibited more typical-amplitude beta brain waves. Improvement at P3 appeared to correlate with enhanced cognitive reasoning, attention, spelling, and short-term memory. In 2010, there were five areas of the brain within the left hemisphere that

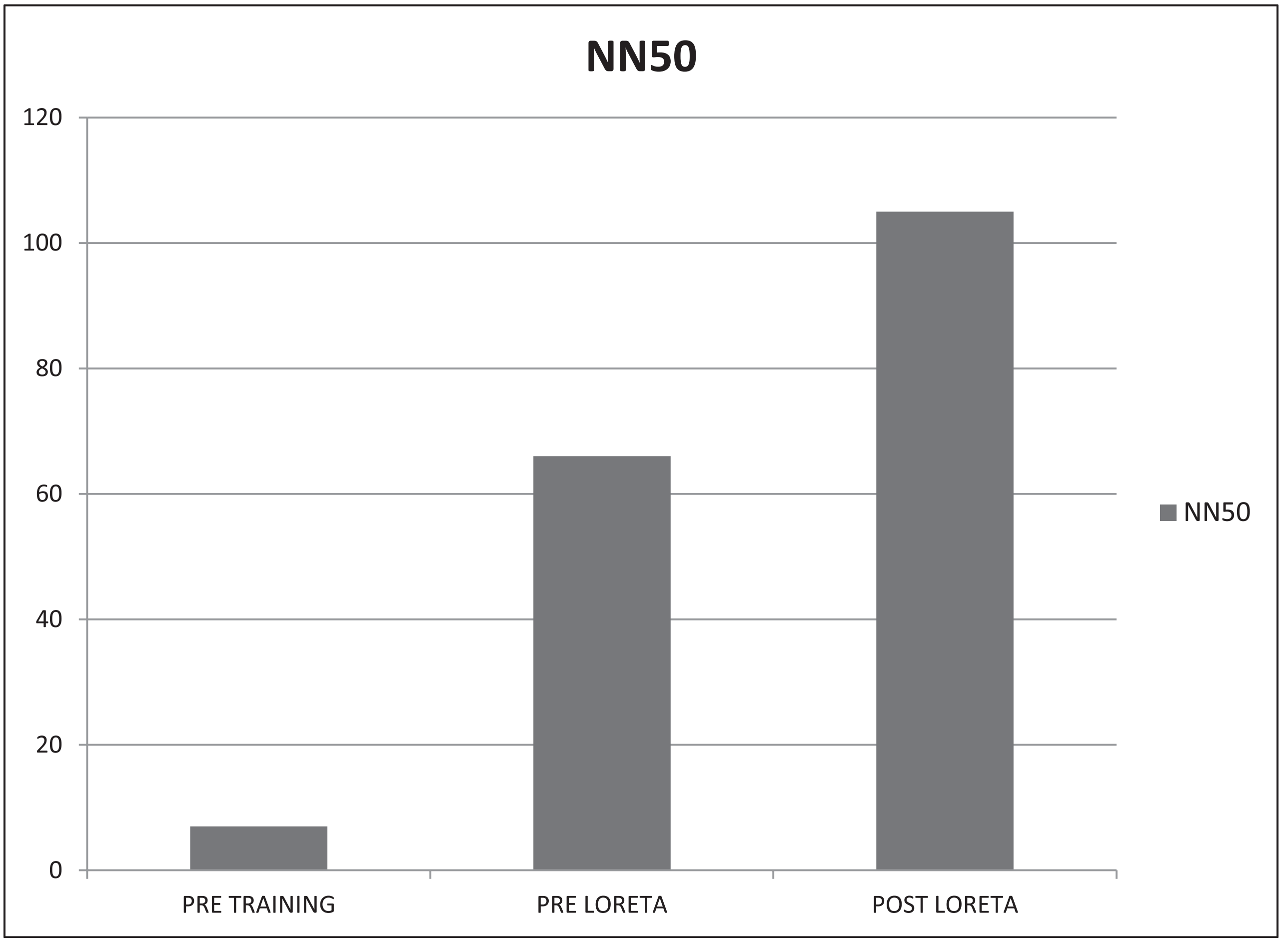

Figure 3. Heart rate variability, successive normal intervals differing by more than 50 milliseconds.

were outside the database norms (greater than 2 SD). This was reduced to one area by 2013.

A Laplacian view of the right hemisphere showed increased alpha at C4. This alpha was reduced by 2013 to within the normal range. This appeared to be correlated with improved focus and attention. Mike also exhibited elevated beta at P4 and C4 in 2010. This communication between C4 and P4 may correlate with improvements in understanding emotional undertones and reading nonverbal cues, innuendo, and nuance. There was a definite deficit in Mike's ability to interpret emotional undertones when he began training as he was often unable to understand jokes his boss at work made, and this constrained his relationships at both work and home. We saw improvements in beta activity at C4 and P4 as well as spindling beta that had existed at F4, C4, and P4 in 2013. Mike showed normalization in four of the eight areas that were outside the norms in the right hemisphere in 2010.

Looking at midline sites, there was high-amplitude, high-frequency beta activity outside the normal range at FZ. This can correlate with feelings of worrying, getting stuck on certain tasks or thoughts, and lack of inhibition (for example, the previously mentioned blurting things out). By 2013, all four parameters have normalized and are functioning within normative boundaries. At the ADD Centre, high-amplitude, high-frequency beta has been found to correlate with a "busy brain" (Thompson & Thompson, 2006). This busy brain pattern existed at CZ, and it also showed improvement. We also saw improvement at PZ, which initially showed high z-scores of alpha, beta, and hi-beta. This site is responsible for integrating sensory information and working memory.

Hypocoherence in 15- to 18-Hz beta and 18- to 25-Hz beta between parietal and central, parietal and frontal, and central and frontal sites improved from 2010 to 2013, as shown in Figure 2. This seems to correlate with clinical improvements in the synthesis and integration of new incoming information and in his memory. The left hemisphere showed the largest improvement in delta waves at T3. This appeared to correlate with improved

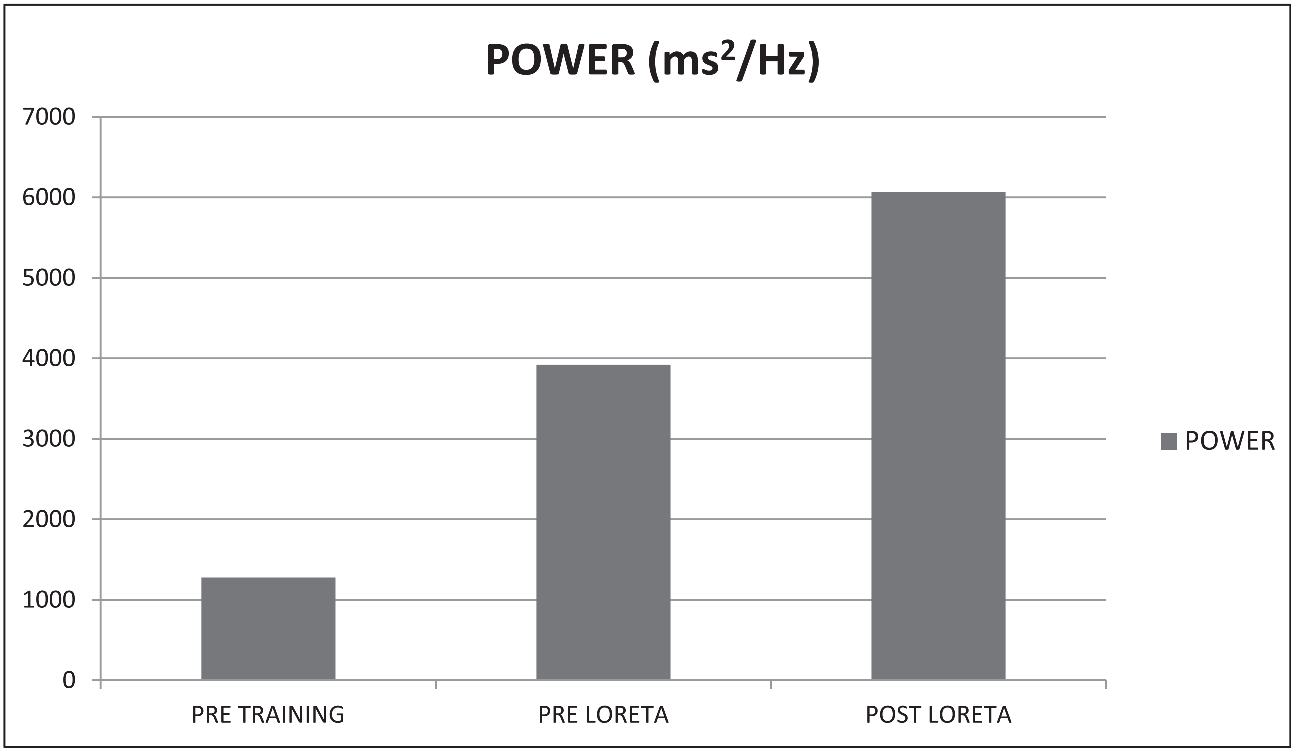

Figure 4. Heart rate variability data, power.

auditory listening skills and reading comprehension. There used to be excess beta at C3. Both T3 and C3 normalized by 2013. In the right hemisphere, excess beta at C4 has normalized, hi-beta at C4 has improved, and beta at P4 has normalized. At midline sites, beta activity at PZ showed normalization going from 2.23 to 1.66 SD. This improvement at PZ was parallel to Mike making progress in synthesizing and integrating new information.

We also measured Mike's progress in terms of HRV changes. Mike showed significant improvement in three measures: SD of normalized interbeat intervals (that is, after artifacting), called SDNN (milliseconds); successive normal intervals differing more than 50 milliseconds (NN50); and power (milliseconds^2). The results are shown in Figures 3 and 4.

Conclusion

Working with clients like Mike supports the view that single-channel neurofeedback training and LORETA neurofeedback training are promising interventions for clients with TBIs. Our approach is multimodal with neurofeedback, biofeedback, and metacognitive strategies, augmented by counseling on diet, sleep, and exercise. The objectives written out in the initial report of July 2007 were in five areas: improved memory, improved sleep and increased energy, completion of revisions to his thesis, improved mood and less irritability, plus regaining mental sharpness. Happily, these objectives have been achieved, and there has also been a decrease in headaches from twice a month to rarely (no more than he had preaccident). In effect, Mike has evolved from being someone with severe deficits that affected his functioning in everyday life into an optimal performance client.

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