A case analysis of a person with a traumatic brain injury (TBI) is presented in detail. The analysis employs the coordination allocation of resource (CAR) model of brain functioning and the activation quantitative EEG analysis of brain response patterns. This model states that individual cognitive tasks involve specific frequencies and locations for successful performance and employs a flashlight metaphor for conceptualization of spectral correlation coefficient relationships between locations. The employment of this model in this specific case resulted in dramatic improvements in auditory memory (+5.4 standard deviations) as well as other improvements in cognitive functioning, albeit not all cognitive functioning skills.

**Introduction: Traumatic Brain Injury**

Traumatic brain injury (TBI) is a major medical, social, and financial problem in the United States. The annual cost estimate of the annual 1.5 million cases is $60 billion. Causes of TBI include motor vehicle accidents, assaults, sports activities, falls, and blast injuries in the Iraq war. The most prevalent type of TBI is a mild TBI (MTBI). Mild cases constitute up to 90% of the TBI cases (Torg, 1991). The Centers for Disease Control and Prevention (CDC, 2008) defines TBI as a blow or jolt to the head or a penetrating head injury that disrupts the normal function of the brain, which results in concussion (functional deficits) or contusion (bruising). The CDC defines mild TBI as an injury to the head as a result of blunt trauma or acceleration or deceleration forces that result in either observed or self-reported conditions of confusion, disorientation, memory dysfunction, or loss of consciousness. Traditional cognitive rehabilitation programs and medication approaches have not achieved their initial goals and, by and large, are ineffective (Thornton & Carmody, 2008). The electroencephalography (EEG) biofeedback treatment used in the single TBI case reported in this article offers a viable, effective alternative to traditional interventions. The individual analysis of deficit quantitative electroencephalography (QEEG) patterns in 19 MTBI patients with subsequent activation database-guided EEG biofeedback interventions have demonstrated an average of 2.61 standard deviation (SD) units in auditory memory improvement, the single most prevalent complaint and ecologically relevant of the TBI group (Thornton & Carmody, 2008). The “activation database approach,” described in detail elsewhere (Thornton, 2001), performs EEG biofeedback training that is customized for this individual based on QEEG patterns of cortical activation.

**Case Study: Traumatic Brain Injury in a Motor Vehicle Accident**

A 30-year-old man was driving his Ford Explorer at 50 mph when another car drove through a red light and hit the right front of the Ford, causing the car to flip over two times. The man’s car ended up on the side of the road with the roof caved in. During the accident, he hit his head on the posterior and superior region but was not rendered unconscious. Initially he felt dazed, dizzy, in shock, and had a headache and a “huge” bump. He was unable to recall events of that morning (retrograde amnesia). His memory of events following the accident is spotty (anterograde amnesia). He was in the intensive care unit for 5 days and was diagnosed with a lacerated liver. At the time of the initial intake, he was reporting pain throughout his back as well as in his neck and shoulders. He also reported problems seeing objects in the distance, numbness in his arms and lower back, occasional dizziness, ringing in his ear, and headaches (posterior/superior region that radiate to the front) about five times a week. Subjective emotional symptoms included a moderate increase in anxiety while driving that was accompanied by sweaty palms and physical shaking. He stated that as a passenger, he nags the driver and hits an imaginary brake with his foot. He reported flashbacks (especially when in similar situations to the original accident) and nightmares of the accident. He also reported the onset of depression, a significant increase in irritability, vacillation in appetite, decrease in energy level (“always tired”), and sleeping problems (“wake up every
few hours’). He found that his memory and concentration ability were “very much affected,” because he couldn't recall what he does or comprehend what he reads. He underwent an electromyogram (EMG) and an epidural and was diagnosed with four bulging disks in his neck, three herniated disks in his lower back, and carpal tunnel syndrome in his left hand.

A neuropsychological evaluation was conducted 6 months after the accident; the evaluation revealed problems in reaction time, memory (working memory, memory for word lists and paragraphs), and set shifting (Wisconsin Card Sorting). An activation QEEG evaluation was performed. The evaluation involves 10 tasks (an eyes-closed condition and 9 cognitive tasks directed toward auditory and visual [reading] memory and problem solving). Of specific interest in this patient are the auditory and reading tasks. The auditory task requires the patient to listen (with eyes closed) to four seventh-grade reading level stories one at a time, with a recall of the story to the self initially (about 40 seconds) and then out loud to the evaluator for scoring purposes. The reading task requires the patient to read a page of sixth-grade level material and then quietly recall the information before verbalizing the information to the evaluator. Memory scores are based upon the sum of the immediate and delayed (20 to 30 minutes later) recall tasks. The reevaluation occurred 2 years later and involved similar equivalent cognitive measures during the QEEG evaluation (auditory and reading memory, problem solving).

The initial evaluation revealed

1. Significant deficits in the spectral correlation coefficient (SCC; Lexicor’s coherence algorithm) in the alpha frequency under auditory input conditions.
2. Significant deficits in the SCC beta2 (32–64 Hz) frequency under reading recall and problem-solving conditions from right frontal locations (F8, F4).
3. Elevated values (average of 2.08 SD) above the normative group in the delta frequency during auditory input conditions in left posterior locations (T3, P3).
4. Above-normal values of beta1 (13–32 Hz) relative power values (1–2 SD) across almost all locations, but especially higher in frontal locations during all of the 10 tasks administered.

This generally elevated (compared with the norm) and frontally elevated beta activation pattern is characteristic in a sample of the author’s 80 TBI subjects under a number of cognitive activation conditions and is also reflected in functional MRI studies of brain functioning (Christodoulou et al., 2001; Gross, Kling, Henry, Herndon, & Lavretsky, 1996; McAllister et al., 1999). The TBI’s impairing effect on the SCC values can be inferred from the damage to the myelinated white fibers of the brain. Diffusion tensor imaging research has documented a surprising 19.3% of the 249 white-matter fiber bundles examined showing disruption in mild TBI cases (Rutgers et al., 2008).

The patient underwent 167 sessions of EEG biofeedback, guided by the results of the evaluation. Given that each session was 33 minutes, the total intervention time was approximately 92 hours. The intervention model employed a coordinated allocation of resource (CAR) model of brain functioning, which states that specific cognitive skills are a result of the relevant operation of multiple, specific locations and frequencies. The metaphor of a flashlight is employed to conceptualize the SCC relationships between locations. The flashlight metaphor asserts that each location is capable of sending out a “beam,” within a frequency, to all other locations. The flashlight metaphor has some similarities to the “generator” concept employed in the EEG literature and statistically reduces the number of SCC variables by a factor of 18. For example, auditory memory is predominantly related to SCC alpha flashlights in the left hemisphere and right frontal locations (Thornton, 2000, 2006) and is the focus of the intervention if the patient’s values are in the low functioning range (<−.50 SD below norm) and correspondingly, SCC beta flashlight relationships are predominantly involved in effective reading. Knowledge of basic neuroanatomy and neuropsychology was also employed in the determination of the intervention protocols.

Of particular interest is the change in the QEEG values under the different conditions. The auditory interventions involved the patient listening to stories on audio CDs while the treatment session was occurring, whereas the reading interventions were conducted while reading. The main treatment focus was on auditory memory. The initial focus was on reducing the delta relative power (RPD) and increasing beta (13–64 Hz) at T5 and P3 and secondarily increasing SCC alpha values from T3 initially and then from F7, F8, P3, C3, and F4. The comparison between the pre- and post-QEEG evaluations employed the patient’s SD value from the normative group. For example, if the patient was −.50 SD below the norm at the initial evaluation and +1.2 SD above the norm during the reevaluation, his SD change was considered to be +1.7 SD. For this patient, the auditory memory reevaluation indicated a RPD reduction at T5 and P3 of −2.08 SD (the desired direction) and an increase of +1.27 SD in beta1 (13–32 Hz) and +.60 SD of beta2 (32–64 Hz) at T5 and P3. The change in the SCC alpha flashlight values...
were +.97 SD (T3), +.60 SD (F7), +.32 SD (F8), +.81 SD (P3), +.76 SD (C3), and +.81 SD (F4). The overall average SD change (across all connections) for SCC alpha was +.68 SD. His auditory memory score on paragraph recall improved from a raw score of 4.87 to 18 (269% improvement). Employing the mean (18) and SD (2.45) of the control group indicated that his paragraph recall memory performance improved some 5.4 SD. On the California Verbal Learning test, raw score improved from 43 to 53.

The interventions for reading recall involved increasing SCC beta flashlight values from frontal and posterior locations. The pre- and post-QEEG comparison indicated SCC flashlight beta increases from F4 (beta1, +1.78 SD; beta2, +2.42 SD) and from F8 (beta1, +2.35; beta2, +2.38 SD). The overall average (across all locations) of coherence beta1 increases was +1.21 SD, whereas beta2 averaged +1.71 SD. The postreading memory evaluation indicated improvement from a raw score of 5.5 to 18 (227% improvement) or .60 SD, employing the control group’s SD of 20.8. The left posterior levels of relative power of beta1 was addressed in the auditory interventions but not in the reading interventions, and the levels increased +.69 SD in the auditory condition and decreased −.07 SD in the reading condition.

It would be expected that as the individual’s QEEG response pattern to specific tasks is improved, there should be some improvement in the overall system, because the improved QEEG variables would also be relevant to other cognitive tasks, a fact allowed for in the CAR model. This generalization of cognitive improvement was evident on several of the readministered tests that included a decrease in errors on the Category test (77 to 56), the Shipley Institute of Living Scale IQ estimate increase (99 to 113), and decreased time (10 minutes to 7 minutes) and errors (13 to 5) on a visual scanning test developed by the author.

However, there are limitations to the generalization of improvement concept as there was no change on the California Computerized Assessment Package (CALCAP) reaction time test or the Michigan Serial recall test of working memory and the patient had a poorer performance on the Wisconsin Card Sorting test (Miller, 1990; Watkin, Craig, & Gallagher, 1990; Heaton, Chelona, Talloy, Kay, & Curtis, 1993). The CALCAP reaction time test is a series of 10 tasks requiring rapid responses (tapping a spacebar) based upon conceptual rules provided to the participant by the software. At present, it is not known what the critical QEEG variables relevant to these tasks are. The author is currently collecting the data to address the question of the QEEG critical correlates of the Wisconsin Card Sorting test as well and the Digit Symbol subtest of the Wechsler IQ tests (Wechsler, 1997). The Wisconsin is frequently used in neuropsychology with the TBI patient to assess executive function and set shifting abilities. The Digit Symbol is considered a sensitive measure of general cognitive integration and is the lowest scale score in two independent samples of high-functioning autistic patients (Goldstein, Johnson, & Minshew, 2001; Majiviona & Prior, 1999). Results from both of these research studies should help elucidate the electrophysiological problems in these two groups.

The patient’s own report of improvement was as follows: He reported that following his deposition, his lawyer commented that his response behavior was the best that he had ever seen from a client. The patient was acutely aware of the improvements in his cognitive functioning to the point of pursuing and winning a lawsuit to protect the clinician’s bill. The New Jersey legal arbitration system decided that the EEG biofeedback treatment immediately following the trauma was not medically necessary, although it was necessary some 12 months following the injury. This decision was upheld upon appellate court review, reflective of the problem of the judicial system in understanding scientific evidence and logic.

**Conclusions**

The functional mapping of the electrophysiology of the human brain is a complex problem and it is unlikely that the CAR model will provide the eventual model. However, a systems approach, which the CAR model strives for, does allow for the complexity of the human mind to be addressed. There are many unanswered questions and questions that remain to be asked. We cannot assume that one or two QEEG variables can successfully address all elements of a cognitive skill.

**References**


Correspondence: Kirtley Thornton, PhD, 203C Ethel Road, Edison, NJ 08817, Web: chp-neurotherapy.com, email: ket@chp-neurotherapy.com.