What is Quantitative EEG

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Abstract

Basic description of quantitative electroencephalography (EEG) in the context of neurotherapeutic application. Issues associated with spectral analysis of human EEG are discussed and an example quantitative EEG assessment report is provided.

Introduction

The human brain is the most resilient and adaptable structure in nature, the source of all of our emotions, perceptions, thoughts, and behaviors. The brain is made up of hundreds of billions of microscopic elements called neurons which use chemical messages to regulate electrical activity throughout the brain. The brain communicates to itself and with the body by means of these electrical changes and our emotions, perceptions, thoughts, and behaviors are the result of the totality of these electrical and chemical changes, although the exact mechanism of how brain becomes mind is not understood. The purpose of this paper is to provide a description of the brain's electrical activity, how it can be measured and how a quantitative EEG (QEEG) report can be used to guide neurofeedback treatment.

What is the History of QEEG?

The first report on electrical brain activity in humans, published in 1929, allowed clinicians and scientists to peek into the skull and watch the brain in action for the first time in a meaningful way. It was recognized early on that the brain's electrical signals or electroencephalogram (EEG) contained regular patterns that might be better understood by their spectral (frequency) content. Bursts of sinuosoidal waves occurred and reoccurred in a predictable fashion and these bursts corresponded with mental states, primarily inattention or inactivity. Initial attempts to quantify brain activity with Fourier analysis were promising (Berger, 1932; Dietsch, 1932; Grass & Gibbs, 1938) but the field of quantitative electroencephalography itself would not emerge until machines could assist us in our analysis (Brazier, 1961). The Fast Fourier Transformation (FFT) algorithm, invented in 1965, deserves much of the credit for early progress in this field as it significantly simplified computation of spectral coefficients (Cooley & Tukey, 1965; Dumermuth & Fluhler 1967). Computers allow us to digitize signals recorded from the scalp, identify specific electrical wave patterns within each signal, display these patterns on a computer screen, and store the digital data, all within microseconds. The rapid development of inexpensive desktop computers in the 1990's placed QEEG technology in the hands of clinicians. The powerful desktop computers of today has paved the way for new and faster methods of analysis such as combining QEEG and functional magnetic resonance imaging (fMRI) for a 3-dimensional view of brain activity. As Figure 1 shows, the advent of inexpensive powerful computers continues to accelerate the popularity of quantitative EEG analysis.

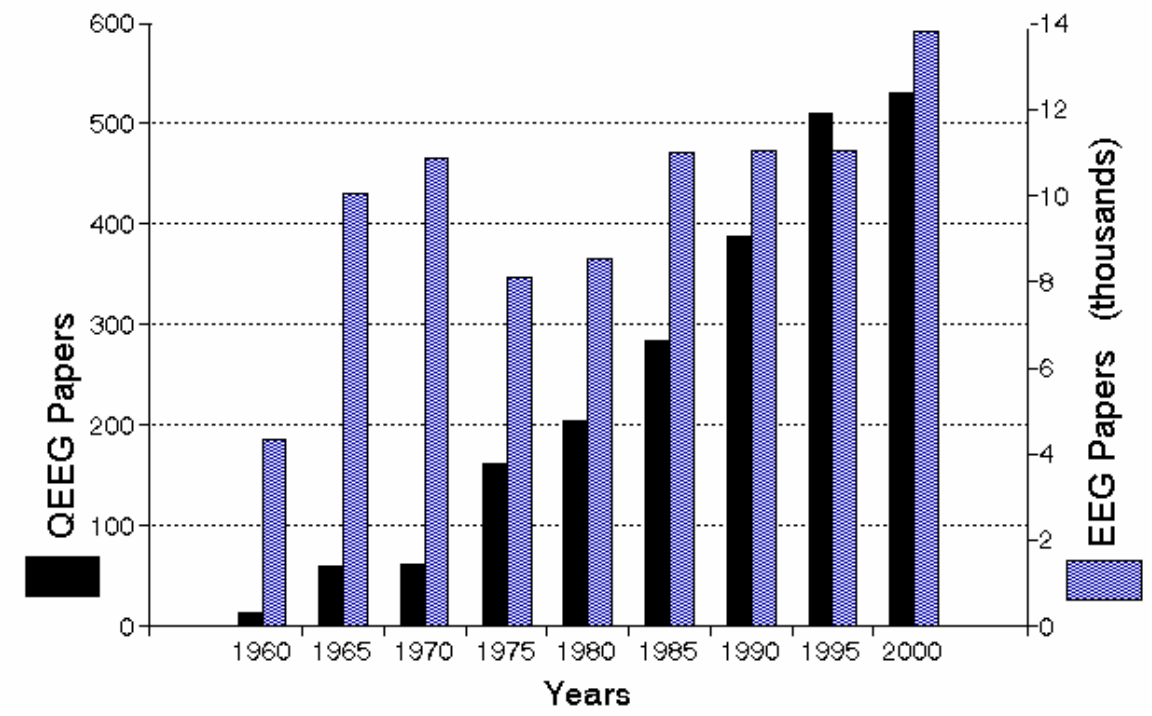

Figure 1. Journal publications indexed in PubMed as "quantitative EEG" or "EEG" since 1960. Note that many EEG papers may rely on quantitative methods without using the QEEG moniker.

What is the Difference between QEEG and other Neuroimaging Techniques?

Functional neuroimaging is the hottest field in science with every major psychology, psychiatry, and neurology department vying for the newest technologies. More than half a dozen techniques can now be used to visualize brain activity including functional magnetic resonance imaging (fMRI), positron emission tomography (PET), single-photon emission computed tomography (SPECT), magnetic resonance spectroscopy (MRS), hemoencephalography (HEG), magnetoencephalography (MEG), transcranial magnetic stimulation (TMS), event-related optical signals (EROS) as well as continuous and event-related EEG. The most popular technologies (fMRI, PET, SPECT) assess metabolic correlates of neurons (blood flow, blood volume, oxygenation) and they have two distinct advantages over EEG analysis: better spatial resolution and an ability to

detect cellular activity in structures that do not contribute to scalp EEG including the cerebellum and most of the subcortex. Still, a single cubic millimeter of cortex -- the spatial resolution of current fMRI technology – contains an astounding array of energy-regulating equipment: 13,000 pyramidal neurons, 24,000 glial cells, 100 billion synapses, and one-tenth of a kilometer of axons, approximately (Pakkenberg et al, 2003). As for EEG, although electrical activity from as few as 10,000 pyramidal cells acting synchronously may be detectable at the scalp (Murakami & Okada, 2006), each electrode itself spans an area containing 5 million pyramidal neurons or more beneath it (Okamoto et al., 2004). But the electroencephalogram and its partner in force, the magnetoencephalogram, can detect changes in brain activity a thousand times faster than most biochemical indices, and they are not measures of cell metabolism but the summation of cortical postsynaptic potentials themselves, a distant eavesdrop on the brain's inner workings (Lopes da Silva, 1991). Recording with EEG and fMRI machinery simultaneously, which is called co-registration, complements strengths and cancels weaknesses of each approach and is increasingly popular in neuroscience though not yet economically viable for most clinical work.

EEG technology has in its favor portability, facility, inexpensiveness, and a 75-year history of investigation. Facility refers to psychological and physical convenience. Functional MRI machines are noisy enclosures which can frighten or intimidate young children or mentally-impaired individuals whereas EEG involves wearing a simple cap or string of electrodes and is commonly acquired from infants, hyperactive children, and autistic children, populations not well known for tolerating containment or noise. Advances in telemetry and dry electrodes should eventually eliminate the greatest

inconveniences associated with this technology. In terms of portability EEG may be recorded for hours or even days from ambulatory patients and has been recorded from pilots flying planes and even skydiving. Wearable fMRI is but a dream at this point in time. In terms of expense the annual cost of running a PET scanner is $2 million, which translates to capital costs of $800 per scan. MRI and MEG machines cost about the same, SPECT a little less, but EEG equipment is one-tenth to one-hundredth the expense. The greatest asset EEG has is a 75-year history of investigation, as shown in Table 1. Hans Berger, the German psychiatrist who pioneered human EEG acquisition and analysis, investigated EEG correlates of attention, epilepsy, brain injury, and sleep prior to World War II (Millett, 2001). MEG and PET technologies were invented during the Vietnam War and fMRI reached prominence during the first Gulf War, to place a military time-line on events.

Table 1. Topical history of EEG investigation by initial year of publication[2]

Head injury	1931	Narcolepsy	1939
Epilepsy	1933	Alcoholism	1941
Heredity	1934	Deafness	1941
Sleep	1935	Migraine	1941
Hypnosis	1936	Peak performance	1941
Consciousness	1937	Aggression	1942
Behavioral problems in children	1937	Delinquency	1943
Mental deficiency	1937	Multiple sclerosis	1944
Schizophrenia	1937	OCD	1947
Brain lesions	1938	Anxiety	1948
Personality	1938	Operant conditioning	1969

What is EEG?

EEG is a measure of electrical changes in our brain that present as spikes, transients, or seemingly random events and rhythms. During Neurotherapy, a clinician

use knowledge of brain anatomy, psychological testing, behavioral measurement, symptoms and QEEG to apply the principles of Learning and as a result, specified brain activity patterns can be taught established or extinguished (i.e. learned or unlearned). Neurotherapists focus upon rhythms and activity within conventional frequency bands such as delta (0.1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), sensorimotor rhythm or SMR (12-15 Hz), beta (15-40 Hz), and gamma (40-300+ Hz). Beta activity is usually divided into sub-bands such as beta 1 for lower frequencies (e.g., 12-16 Hz, or 15-18 Hz), beta 2 for middle frequencies (e.g., 18-24 Hz), and beta 3 for higher frequencies (e.g., 24-30 Hz, 30-40 Hz). Frequency bands may vary across clinics (e.g., theta as 4-7 Hz, 5-7 Hz) and the SMR label may be restricted to spindle activity over sensorimotor cortex only. Because wider frequency bands encompass a variety of physiological processes, narrow bands (e.g., 6-8 Hz, 9-10 Hz) or bands tailored for an individual are commonly analyzed as well (Klimesch et al., 1993).

Moruzzi and Magoun (1949) were the first to shed light on the origin of EEG rhythms. Working in cats they determined that stimulating the reticular formation of the brainstem aroused the animal behaviorally and any dispersed high-amplitude EEG rhythms at the cortex. This work eventually led to a general physiological model of rhythmic activity (Andersen & Andersson, 1968; Steriade et al. 1990). According to the model, isolated thalamocortical neurons fire rapidly at their own pace due to metabolic characteristics but in an intact brain, a sheath of cells known as the reticular thalamic nucleus (RTN) inhibits intrinsic or random firing of thalamocortical neurons and unites individual discharges into simultaneous volleys. These volleys propagate to the cortex and synchronize pyramidal cell activity, whose synchronization can be detected at the

scalp as high-amplitude oscillations (e.g., alpha bursts, sleep spindles). Corticothalamic feedback influences these volleys by inhibiting RTN's inhibitory action so that neuronal ensembles may break free of reticular thalamic influence and fire in response to specific processing demands. When this occurs, large slow waveforms (theta, alpha) are replaced by faster frequencies of lower amplitude (beta, gamma), a process originally called alpha blocking and now called EEG desynchronization. Desynchronization may be localized to a single electrode as uncommitted cortical areas remain "idling" or synchronized, or it may involve several brain areas or electrodes (Pfurtscheller, 1992; Sterman et al. 1994). Regional patterns of simultaneous desynchronization and synchronization characterize specific cognitive and behavioral states (Pfurtscheller & Klimesch, 1990) and it is by measuring the mix of slow and fast rhythms across the head that we identify the nature and extent of cortical engagement.

How is QEEG Related to Human Behavior?

Behavioral and mental states such as mathematical processing, reading, or relaxed wakefulness are assumed to be distinct and uniform in nature, consisting of similar perceptual and cognitive operations whenever they occur. It is also assumed that distinct mental operations present distinct EEG and biochemical profiles which are reproduced reliably whenever a task or mental state occurs. These assumptions lay the foundation to functional MRI as well as EEG assessment and are the rationale for EEG normalization training. In other words, a clinicians may train brain activity toward a population norm because any deficit or excess is conceived as evidence of an abnormal neurophysiological and mental state (e.g., Peniston & Kulkosky, 1989).

Running on a treadmill helps a physician determine how well a patient's heart handles work. Running through a test battery of reading, math, and problem-solving during the acquisition of QEEG helps a neurotherapist determine how well a client's brain handles work. The most reliable finding in EEG research occurs when an individual resting with eyes closed opens his or her eyes in a well-lit room: alpha blocking occurs. The alpha rhythm is replaced by fast low-amplitude waveforms, or beta rhythm. (When eyes are opened in a dark room, alpha blocking does not generally occur; Bohdanecky et al., 1984.) The degree and localization of blocking or desynchronization is associated with stimulus intensity, complexity, novelty, and meaningfulness (Gale & Edwards, 1983; Berlyne & McDonnell, 1965; Baker & Franken, 1967; Boiten, Sergeant, & Geuze, 1992; Gevins & Schaffer, 1980). Topographic analysis reveals whether EEG desynchronization is nonspecific (many or all sites) or selective (few sites). Nonspecific arousal is modulated by drugs, drowsiness, drive, and time of day, whereas sensory and strategic demands activate specific brain areas such as parietal and occipital cortex to visual stimulation and temporal cortex to acoustic stimulation (e.g., Grillon & Buchsbaum, 1986; Pfurtscheller, Maresh, & Schuy, 1977; Chapotot, Jouny, Muzet, Buguet, & Brandenberger, 2000).

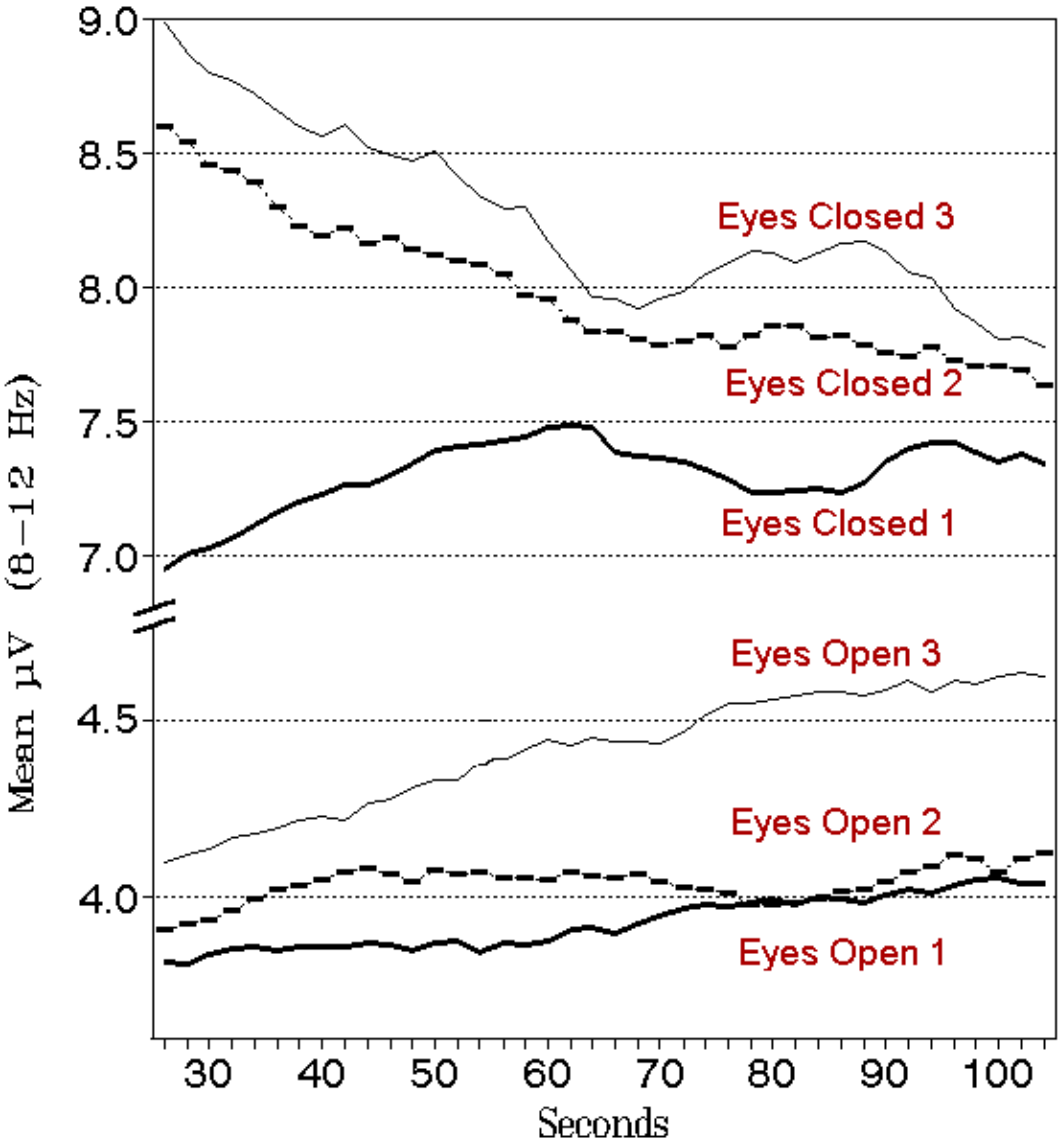

Figure 2. Posterior alpha activity of baseline replications across time (50 s smooth, 20 adults).

Eyes closed relaxation or simply opening the eyes may reveal functional shortcomings in some individuals while others require challenges such a general test battery (age-appropriate reading, mathematical computation) or tests tailored to suspected or known deficits (e.g., continuous performance tasks for ADHD, social cognition tasks for autism). Baseline and challenge conditions should be replicated two or three during assessment and spaced apart in time so as to be likely to acquire representative data for each condition. Figure 2 shows posterior alpha activity for eyes closed and eyes open relaxation (baseline) conditions recorded an hour apart for 20 adults. The first recording during the EEG session (here, Eyes Closed 1) was more activated than latter recordings of the same condition, which is not uncommon as individuals acclimate and habituate themselves to novel settings and procedures (Rebert & Mahoney, 1978). The final recording of the session (here, Eyes Open 3) included fatigue, perhaps even drowsiness, which would have been overlooked without examining EEG trends.

Eyes closed recordings and two of three eyes open recordings converged after a minute or so. Activity prior to convergence, what we call a state transition, should not included in condition averages. The effect of undeleted state transitions on spectral values is shown in Table 2. Eyes Closed 1 and Eyes Open 3 differ from other replications as Eyes Closed 1 transitions toward moderate relaxation and Eyes Open 3 transitions out of a modestly attentive state. As a rule of thumb, deleting the first 30 seconds of each recording eliminates most state transitions.

Table 2 Posterior alpha activity during replicated baselines

	Mean Magnitude	Standard Deviation	Slope Coefficient	Residual Variance
Eyes Closed 1	6.8*	3.1*	1.4*	2.1*
Eyes Closed 2	7.6	3.5	-2.5	2.3
Eyes Closed 3	7.9	3.6	-2.4	2.5
Eyes Open 1	3.9	1.7	0.4	1.2
Eyes Open 2	4.0	1.9	1.2	1.3
Eyes Open 3	4.5*	2.2*	1.6+	1.6*

- * $p<.01$, all other replications + $p<.01$, compare to first replication

Few clinicians examine trend dynamics, which is unfortunate as measures of variability and trend can provide information not otherwise obvious in overall means. Table 2 presents alpha activity (8-12 Hz, 7 posterior sites) during 2 min baseline recordings for 20 adults (10 male, 10 female, all right-handed, mean age 28.2 yr). The first column contains a state parameter familiar to most clinicians: mean spectral magnitude. Absolute or relative power, or log power (natural or base-10 logarithm) are also common state descriptors. Standard deviation is a measure of variability of epoch magnitude and it denotes *state stability*. Slope coefficient of a linear regression (here, scaled by a factor of 100) encapsulates rate of change in spectral magnitude across time and residual variance is its error term (similarly scaled). Residual variance is moment-to-moment variability not accounted for by a linear trend, or *trend stability*. Slope is harder to interpret functionally because it is sensitive to initial conditions at recording onset as well as record duration. Mean magnitude and standard deviation are measured in microvolt (μV) and slope and residual variance are mean microvolt difference per second

or epoch (δ μV). Physiological engagement is associated with stable states of low alpha activity, and to a lesser degree, stable negative trendsm as shown in Table 3.

Table 3. Posterior alpha activity with increasing challenge

	Mean Magnitude	Standard Deviation	Slope Coefficient	Residual Variance
Eyes Closed	7.4	3.4	-1.2	2.3
Eyes Open	4.1	1.9	1.0	1.3
Motor task	4.1	1.8	0.7	4.5
Visual task	3.9	1.6	0.2	1.3
Motor & Visual	3.8	1.5	0.5	1.3

How many electrodes are used and where?

Electrodes are positioned on the scalp and labeled according to the International 10-20 system which divides the skull into proportional distances based on four prominent landmarks: dent of the nose (nasion), protrusion in the back of the head (inion), and preauricular points directly in front of each ear (Jasper, 1958). Labels reflect underlying brain areas: FP for frontal pole, F for frontal, P for parietal, C for central, T for temporal, and O for occipital. Sites are numerically sequenced from midline, which is set as zero or Z, with odd numbers on the left hemisphere alternating with even numbers on the right (see Figure 3). This system spaces electrodes 6 or 7 cm apart on most heads so the nomenclature has been extended to 74 electrodes to allow better coverage (Chatrian et al. 1985). Some channels have also been renamed: T7/8 for T3/4 and P7/8 for T5/6 (American EEG Society, 1994), although not everyone has yet adopted these changes, as Figure 2 attests. The International 10-20 system owes its endurance to its simplicity and fortuitous division of the scalp into corresponding brain regions that remain relevant to cognitive and psychiatric research (see Table 4).

Table 4. Cortical gyrus below each electrode position, based on Mokotoma et al (2004)

Lobe	Gyrus	Brodmann Area	Site (Left/Right)
Frontal	Superior	10	Fp1/2
	Inferior	47	F7/8
	Medial	9	F3/4
	Medial	8	Fz
	Precentral	6	C3/4
	Superior	6	Cz
Temporal	Medial	21	T3/4
	Medial	37	T5/6
Parietal	Inferior	7	P3/4
	Precuneus	7	Pz
Occipital	Medial	19	O1/2

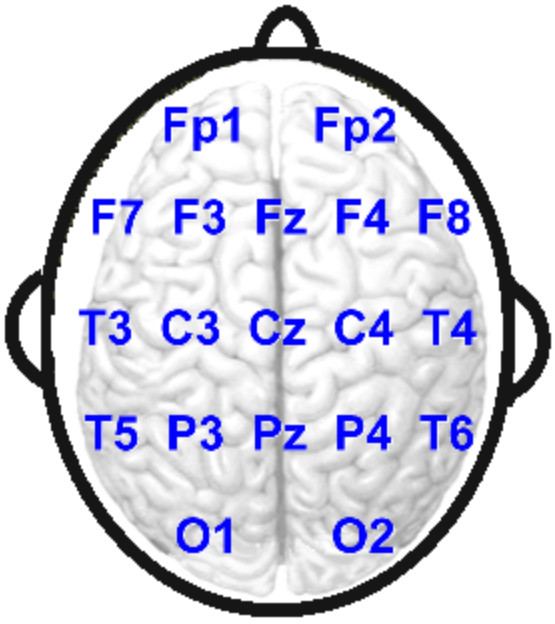

Figure 3. International 10-20 system for electrode placement on the scalp.

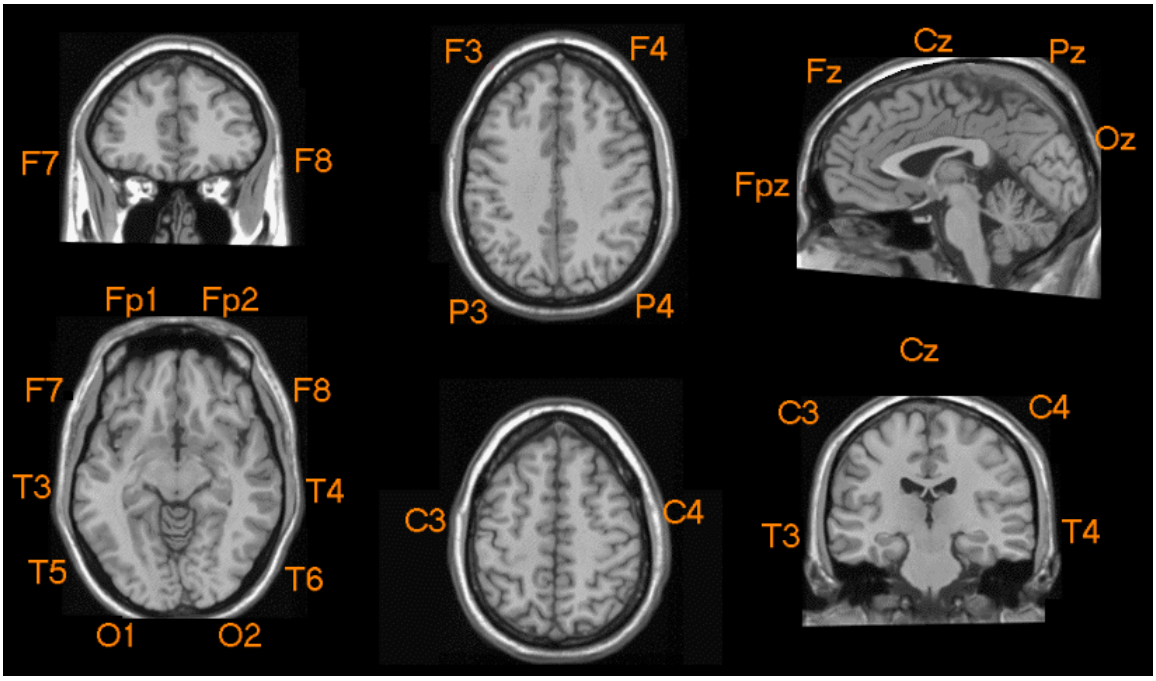

Figure 4. MRI slices nearest the International 10-20 EEG positions

Electrical activity is detected as a difference in potential between two electrodes in a grounded system. In referential recordings all electrodes are paired to the same physical reference such as vertex (site Cz) or the ears. In bipolar recordings electrodes are paired together in series and there is no common reference across pairings (e.g., site F3 is linked to C3; C3 to P3, P3 to O1). Reference-free techniques such as common average or source derivation do not suffer from problems associated with a physical reference such as local contamination but are sensitive to artifact anywhere in the network. Referential linked-ears are commonly used in neurotherapy assessment and training in spite of the fact that linked ears can be contaminated by nearby temporal lobe activity. Some clinicians will run several references in succession such as linked-ears followed by a nose reference in order to identify whether a physical reference is contaminated. The main advantage with physical references is simplicity as only two

electrodes are needed plus ground. Linked-ears provide a non-lateralized reference when properly connected and will remain popular until multiple-channel training becomes commonplace.

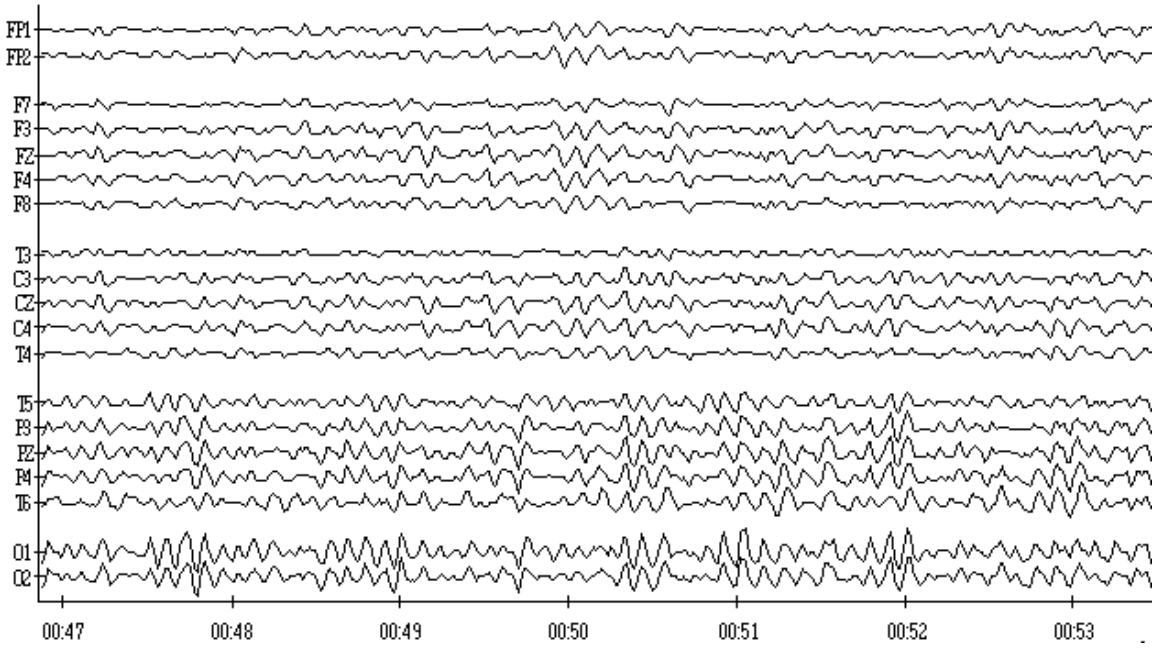

Figure 5. EEG data from 19 channels recorded from an adult.

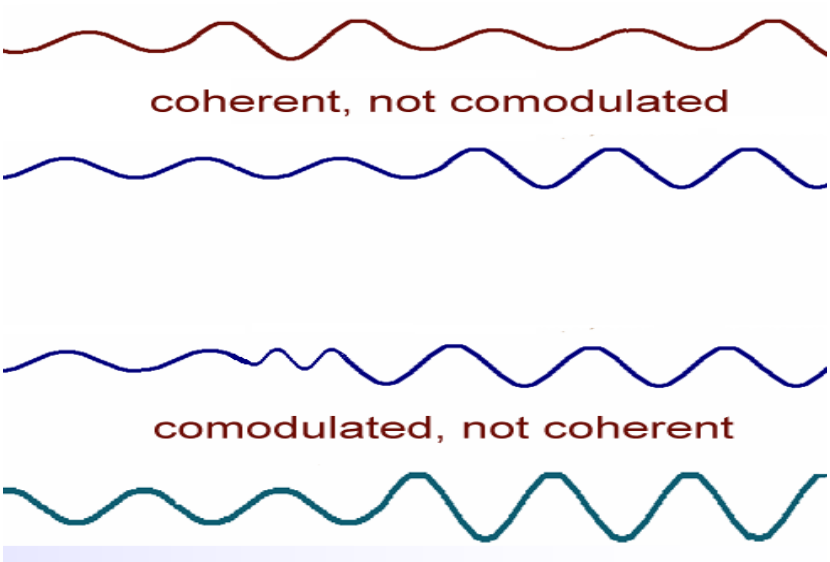

Figure 7. Conceptual depictions of the difference between two aspects of functional connectivity.

What is Functional Connectivity?

In addition to evaluating site abnormalities -- deviant amounts of spectral magnitude or power -- clinicians may also evaluate network abnormalities. This may be achieved by determining whether shared activity between brain areas is excessive or deficient. Functional homogeneity, differentiation, or topographic reciprocities may be revealed through coherence analysis, comodulation analysis, or both. Coherence analysis quantifies phase consistency between signals and comodulation analysis quantifies magnitude consistency (Goodman, 1957; Kaiser, 1994). Two signals are said to be coherent when their phase relationship is stable, even if signals are entirely out of phase with each other. Two signals are said to comodulate when their magnitude relationship is stable, regardless of absolute difference between signals. Although it is possible for EEG signals to be hypercoherent but hypomodulating, or vice versa, we commonly observe similar coherence and comodulation values in EEG analysis, presumably due to the nature of cortical networks being investigated (Kaiser, 2006).

What is Artifact Management?

The more we quantify data, the more we distance ourselves from it. Clinicians should always start an analysis by examining the raw data, EEG voltages in a standard strip chart. Figure 5 presents a referential montage of 19 channels in such a chart. Most software programs allow examination of the raw data across different montages. Visual inspection in different montages may assist in artifact identification. Electrodes do not differentiate electrical activity generated by cortical tissue from those generated by muscle movements (eye, tongue, face, neck, or heart), changes in skin conductance, or equipment problems. Eyes blinks and eye movements cast energies into the lower end of the frequency spectrum and at many times the size of cortical scalp potentials and the heart may cast energies in the middle of the spectrum. Some artifacts may be detected algorithmically and with low- or high-pass filters but others require human intervention – that is, visual inspection and manual deletion.

Artifact management is followed by data review and selection. A minute of EEG contains incredible information in both time (voltage amplitude, time lag) and frequency (magnitude, phase). Frequency analysis, the most popular analytical approach in this field, reduces EEG to a manageable number of coefficients. While information is necessarily lost during any analytical procedure, what's lost may not be pertinent to our interests. Spectral information can be presented in a number of formats, from numerical tables to histograms to line graphs to brain maps. Brain maps convert numbers into colors (values on a color scale) and provide user-friendly depictions of large data sets.

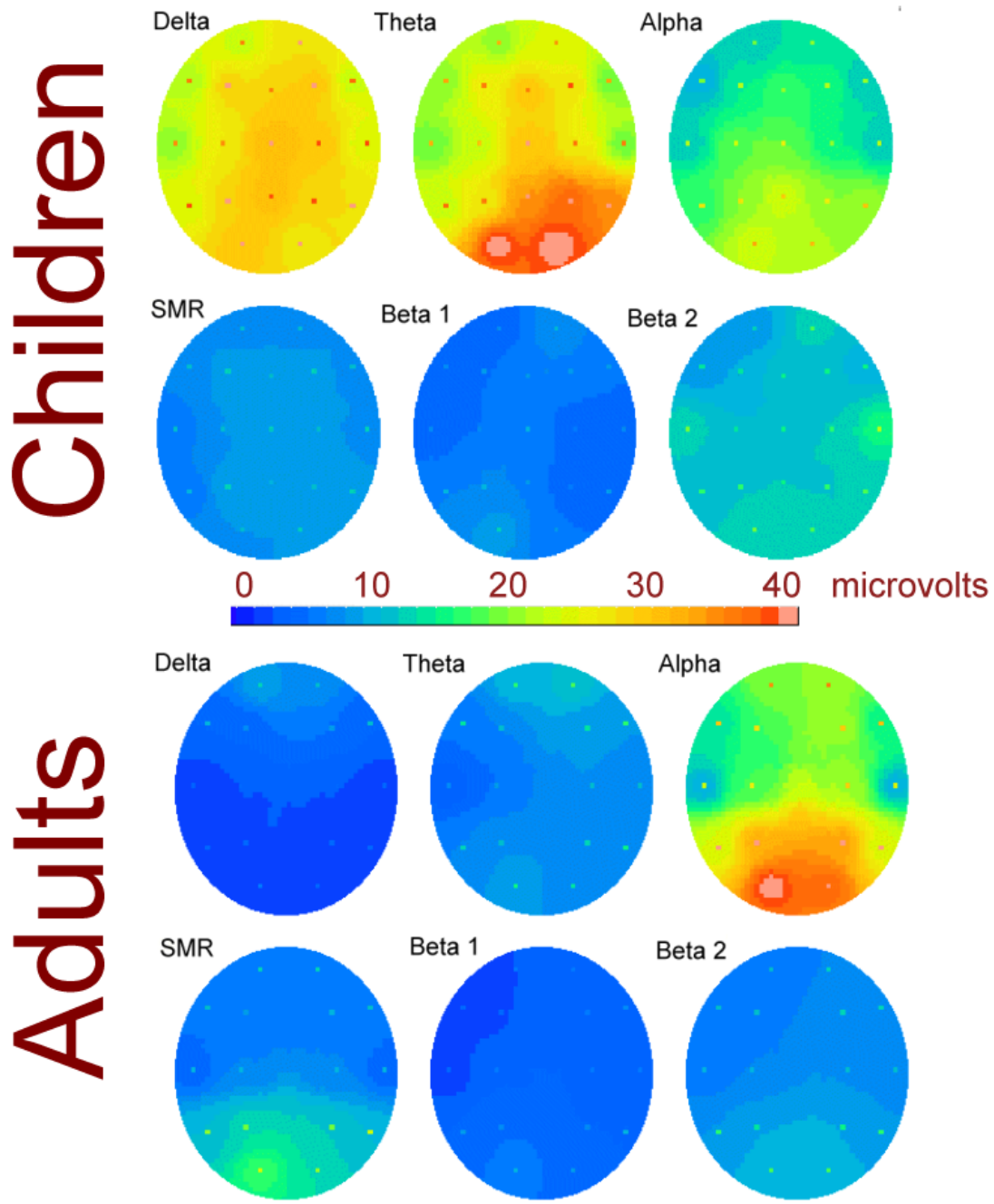

Figure 6. During eyes closed baseline rest, the theta rhythm (4-8 Hz) dominates the spectral energies of a child's brain whereas the alpha rhythm (8-12 Hz) dominates the adult brain.

What about Age, Handedness, and Gender?

The previous discussion referred to the alpha rhythm for a normal adult population. When we evaluate children we must take into account a degree of neurological immaturity.

The alpha rhythm emerges as a slow 3-4 Hz rhythm in infancy, and it takes a decade of development before an adult rhythm at 10 Hz is established (Niedermeyer, 1987). Prominent 4-7 Hz activity in children diagnosed with attention deficit hyperactivity disorder, for instance, may reflect an immature manifestation of the dominant thalamocortical rhythm (Harmony et al., 1995) whereas similar slowing of the dominant frequency in adults may indicate brain-injury or disease. Dominant frequency is an important feature of a client's EEG profile. The term “dominant frequency” refers to the frequency range that contains the most energy in the spectrum. Peak frequency, as it is sometimes called, may exhibit topographic variability with higher peak frequencies toward the back of the head and lower peak frequencies toward the front (Gratton et al, 1992). Nearly all healthy adults present peak frequencies between 8 and 12 Hz during eyes closed (Nunez, 1981).

Table 5. Rhythm Maturation: Alpha & Sleep Spindle Frequency Range by Age Group (modified from Niedermeyer, 1987)

Rhythm	Newborn	Infant	Toddler	Preschooler	Preteen
Alpha	Not present	4-6 Hz	5-8 Hz	7-9 Hz	9-10 Hz
Sleep spindle	Not present	12-14 Hz	12-14 Hz	12-14 Hz	12-14 Hz

Besides age, gender and handedness should be considered during assessment. Left-handedness is associated with different functional laterality patterns than right handedness (Galin, Ornstein, Herron, & Johnstone, 1982; Provins & Cunliffe, 1972). Left-handed individuals may show abnormal hemispheric specialization such as speech functions in the right hemisphere (Rasmussen & Milner, 1977). Handedness can be

readily assessed by simple questionnaire such as the Edinburgh Handedness Inventory (Oldfield, 1971) or by writing samples from each hand. As for gender, males typically exhibit greater functional asymmetry than females (McGlone, 1980; Rippon, 1990; Trotman & Hammond, 1979; Tucker, 1976; Beaumont, Mayes, & Rugg, 1978; Flor-Henry & Koles, 1982) due to stricter functional segregation for males (Lake & Bryden, 1976; McGlone, 1978; Sundet, 1986; Inglis & Lawson, 1982) or more bilateral representation of function for females (Turkheimer & Farace, 1992). Not everyone finds gender differences (Herring & Reitan, 1992; Herring & Reitan, 1986; Scarpa et al., 1987) although neuroanatomical differences do exist (Aboitiz, Scheibel, Fisher, & Zaidel, 1992; Clarke, 1990). Gender effects, when present, may also signify differences in development (Shearer, Cohn, Dustman, & LaMarche, 1984; Brown & Grober, 1983), task characteristics (Earle & Pikus, 1982; Shepherd, 1982), or cognitive strategy (Kinsbourne, 1980; Faber-Clark & Moore, 1983; Inglis & Lawson, 1982; Sundet, 1986).

What is a Quantitative EEG Report?

A quantitative EEG assessment report typically includes displays of a client's mean spectral magnitude or power for multiple frequency bands. This information may be provided as means, percent change from another condition, or as statistical database comparisons and presented in numerical tables or line graphs (spectral plots, topometrics), brain maps, or functional connectivity maps, as well as samples of typical and atypical EEG data, are used to support one's conclusions and training recommendations, the culmination of a report.

	Delta	Theta	Alpha	SMR	Beta1	Beta2
FP1	0.3	-0.3	-0.4	-0.3	-0.1	-1.2
FP2	0.4	-0.3	-0.3	0.3	0.7	-0.6
F7	0.8	-0.2	-0.4	-0.2	0.9	-1.1
F3	0.3	-0.4	-0.6	-0.8	-0.7	**-2.3**
FZ	0.3	-0.5	-0.6	-0.8	-0.8	**-2.2**
F4	0.2	-0.5	-0.6	-0.8	-0.6	-1.9
F8	1.0	-0.2	-0.6	-0.2	0.0	-1.1
T3	0.1	-0.7	-0.7	-0.4	0.3	-1.2
C3	0.3	-0.6	-0.8	-0.9	-0.9	**-2.6**
CZ	0.5	-0.7	-1.0	-0.9	-0.9	**-2.5**
C4	0.3	-0.7	-0.8	-0.6	-0.9	**-2.1**
T4	0.3	-0.5	-0.8	-0.5	-0.5	-1.2
T5	0.3	-0.7	-0.7	-0.5	0.3	-1.7
P3	0.3	-0.6	-0.7	-0.8	-0.5	**-2.3**
PZ	0.3	-0.7	-0.8	-0.9	-0.6	**-2.7**
P4	0.3	-0.7	-0.8	-0.8	-0.4	**-2.2**
T6	0.5	-0.4	-0.7	0.2	1.5	-1.2
O1	1.3	-0.3	-0.4	-0.1	1.0	-1.4
O2	0.8	-0.4	-0.6	0.0	0.7	-1.2

Figure 6. Statistical deviation (z-score from normative database) for six frequency bands.

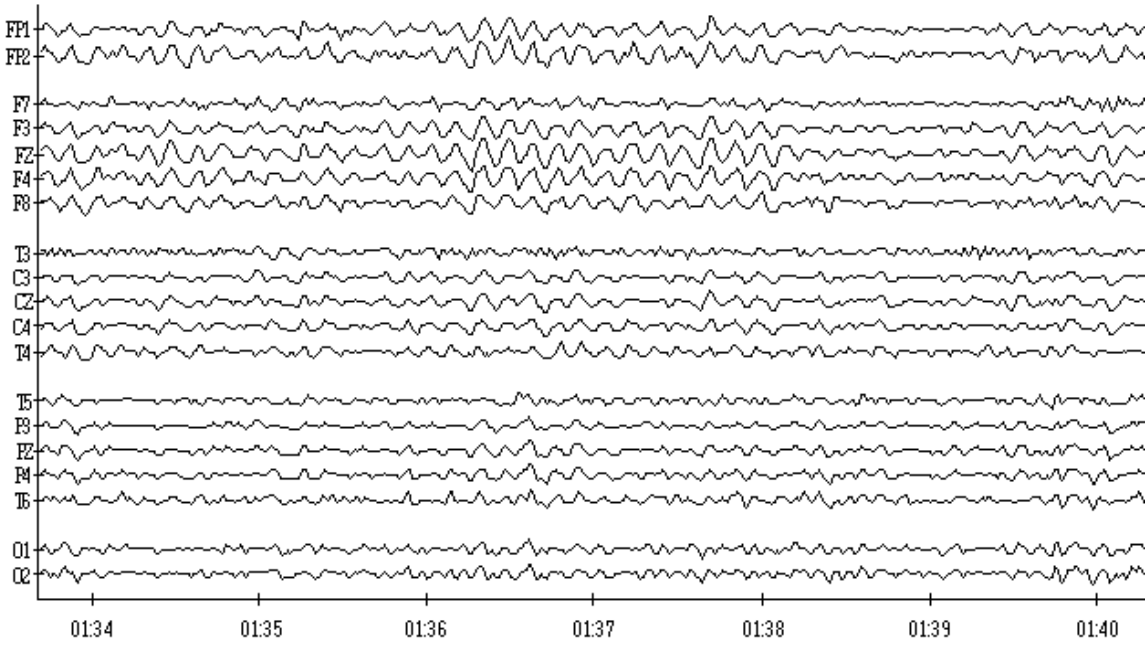

Figure 8. EEG during challenge (math problems)

Example (fictional) report:

HISTORY: J.D. was referred to our clinician after an outburst at school. J.D. is a 22-year-old right-handed male with a history of impulsive control problems and aggression. He is intelligent and attends a local community college, but last Wednesday he become very angry at his professor and threatened him physically...etc. [The more information about a client's past and present behavior, the better chance of understanding the relevance of any functional deviations found during an assessment.]

METHODOLOGY: A fitted electrode cap with leads placed according to the International 10/20 System was applied to achieve a standardized 19 channel EEG recording. A referential recording with linked earlobes was performed. Electrode

impedance of less then 5 Kohms was required at all sites prior to initiation of recording. EEG signals were digitized at a rate at or above 256 samples per second, band-pass filtered between 0.5 and 35 Hz and stored on a hard disk for subsequent analysis.

J.D. was seated in a comfortable reclining chair and underwent a series of standardized tests, each lasting approximately 3 minutes. These included three replications of 1) eyes closed relaxation, 2) eyes open relaxation, 3) reading for comprehension, and 4) a mathematics test of graded difficulty.

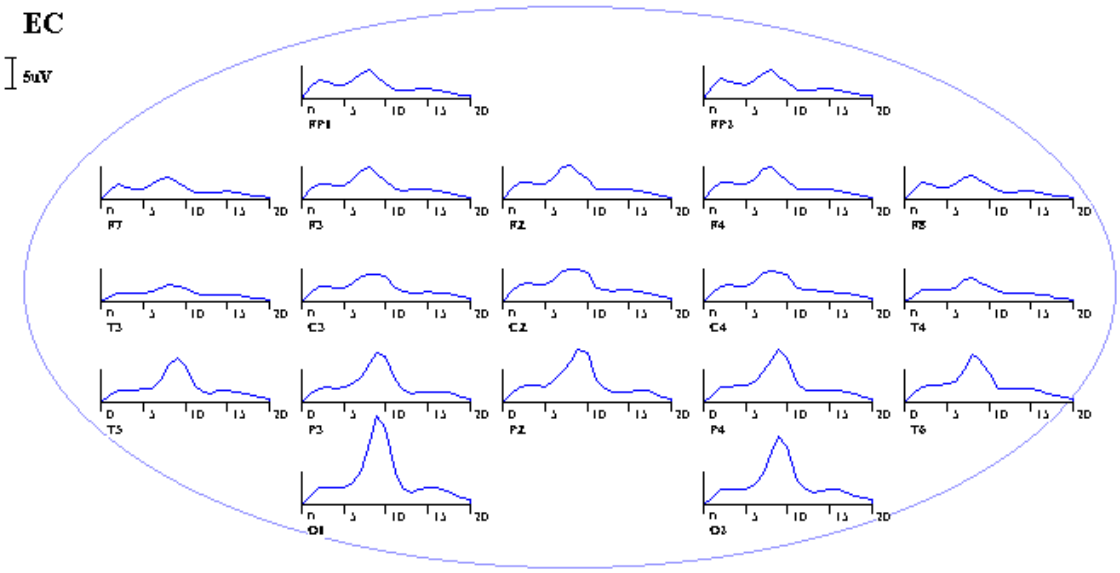

Figure 9. Spectral magnitudes of 19 channels during eyes closed relaxation.

Digitized data were subjected to an automatic artifact detection routine and supplemented by visual review. Atypical transients in the EEG signal were noted for subsequent analysis during this procedure. Representative samples of EEG data for each of the four conditions (EC, EO, Reading, and Math) were analyzed for frequency content using discrete Fourier transformation. Evaluation of these data employed various descriptive and statistical displays with a variety of frequency band formats including

data tables, spectral maps, individual frequency band, topometric analysis, topographic maps, and comodulation analysis. Statistical analysis compared client data with an adult normative database corrected for time-of-day variations and state transitions.

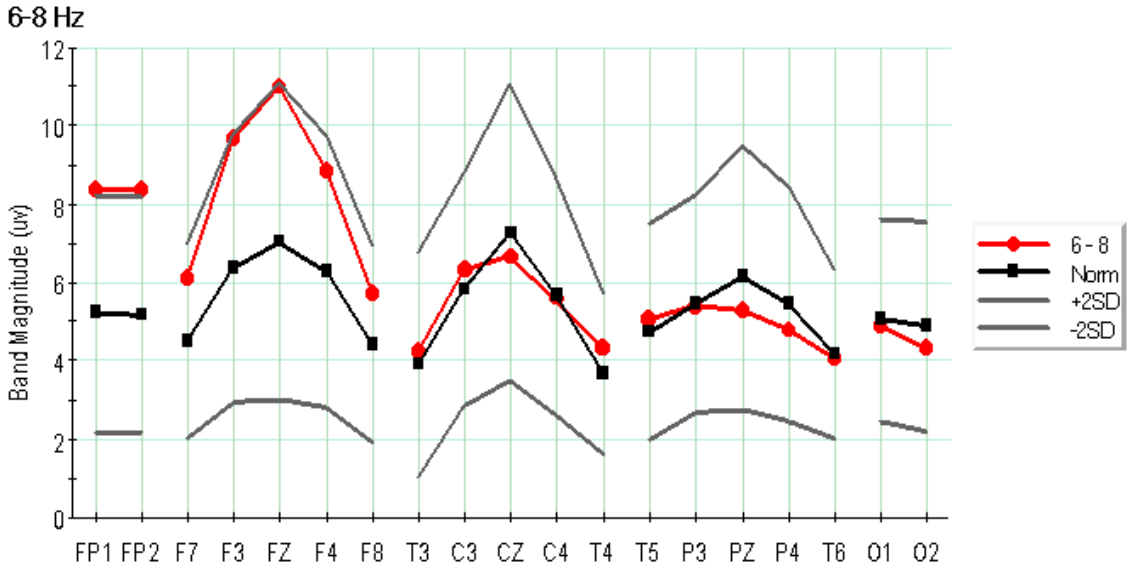

Figure 10. Topometric display of individual's data compared to adult normative values during mathematical processing.

FINDINGS With eyes closed J.D. showed a dominant frequency of 8-10 Hz , prominent in posterior cortex and bilaterally symmetrical. His dominant frequency was effectively suppressed with attentional demand and was statistically normal for all conditions in this band. However 6-8 Hz activity during challenge (mathematics) was abnormal across frontal sites in all three replications. Comodulation analysis also disclosed hypermodulation of left medial frontal cortex (F3) with right posterior sites (P4, T4, T6), and hypomodulation of anterior cortex, primarily on the right side for the dominant frequency.

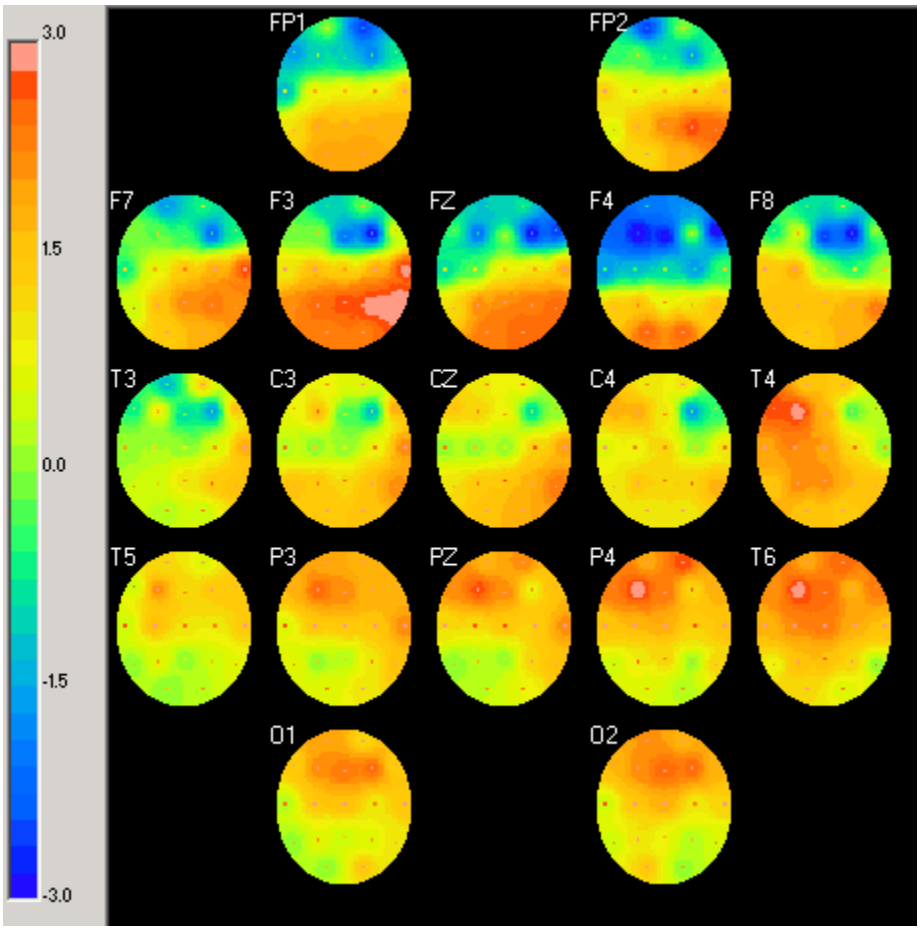

Figure 11. Comodulation map during math processing for dominant frequency (8-10 Hz). Note the hypermodulation of F3 and T4, T6, and P3 (red splotches indicating a 3 standard deviation difference above the norm) along with the hypomodulation of frontal cortex (blue splotches which indicate 3 standard deviation below norm).

CONCLUSIONS: Findings are consistent with a clinical history of impulse control problems. The deviant increase in anterior cortex during cognitive challenge is a pattern common to ADHD children. The unusual connectivity pattern reveals a functional disturbance relatively unique to adults of his age. The anterior hypomodulation is often seen for college-age adults, but the hypermodulation pattern is suggestive of a possible injury. Dispersion training to reduce connectivity between F3 and right posterior sites is recommended. Secondarily, neurofeedback training to suppress frontal/central slowing, along with conventional SMR reward training, are also recommended.

Conclusion

Quantitative EEG is a powerful and sensitive tool for identifying maladaptive brain activity patterns – that is, bad brain habits. This introduction has touched on the multitude of issues surrounding this technology and its clinical application in neurofeedback.

The following publications are recommended reading for further information on specific aspects of this technology:

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