

# What Is Quantitative EEG?

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**ABSTRACT.** This article provides a 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. doi:10.1300/J184v10n04\_05 [Article copies available for a fee from The Haworth Document Delivery Service: 1-800-HAWORTH. E-mail address: <docdelivery@haworthpress.com> Website: <<http://www.HaworthPress.com>> © 2006 by The Haworth Press, Inc. All rights reserved.]

**KEYWORDS.** EEG, electroencephalography, assessment, principles, introduction, QEEG report

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 and it communicates with itself and with the body by means of these electrical changes. Our emotions, perceptions, thoughts, and behaviors are the result of the totality of these electrochemical activities, 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 sinusoidal 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 (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

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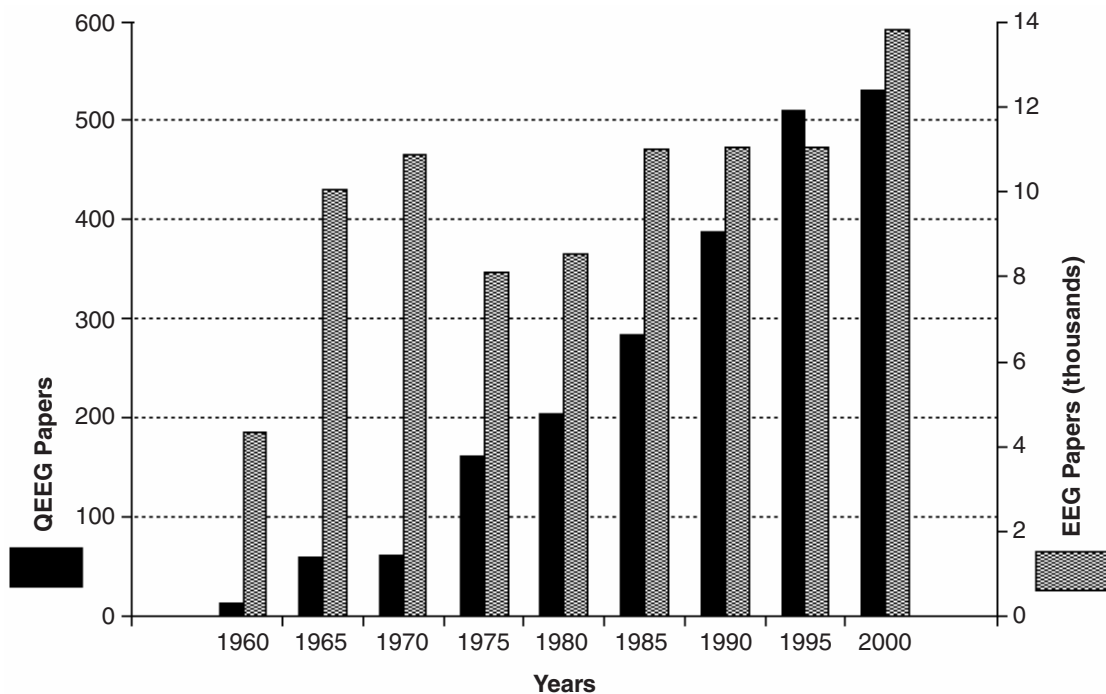
on a computer screen, and store the digital data, all within microseconds. The rapid development of inexpensive desktop computers in the 1990s placed QEEG technology in the hands of clinicians. The powerful desktop computers of today have paved the way for new and faster methods of analysis such as combining QEEG and functional magnetic resonance imaging (fMRI) for a three-dimensional view of brain activity. As Figure 1 shows, the advent of inexpensive powerful computers continues to accelerate the popularity of quantitative EEG analysis.

### **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: approximately 13,000 pyramidal neurons, 24,000 glial cells, 100 billion synapses, and one-tenth of a kilometer of axons (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 &

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.



Okada, in press), each electrode itself spans an area containing five 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 as shown in the Appendix. 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 the Appendix. 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.

## 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 uses 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 tend to 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 (Pfurtscheller & Klimesch, 1990).

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 dispersed high-amplitude EEG rhythms at the cortex. This work eventually led to a general physiological model of rhythmic activity (Andersen & Andersson, 1968; Steriade, Gloor, Llinas, Lopes da Silva, & Mesulam, 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, Mann, Kaiser, & Suyenobu, 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, 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 re-

placed by fast low-amplitude waveforms, or beta rhythm. [When eyes are opened in a dark room, alpha blocking does not generally occur (Bohdanecky, Indra, Lansky, & Radil-Weiss, 1984).] The degree and localization of blocking or desynchronization is associated with stimulus intensity, complexity, novelty, and meaningfulness (Gale & Edwards, 1983; 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).

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 times 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 be included in condition averages. The effect of undeleted state transitions on spectral values is shown in Table

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

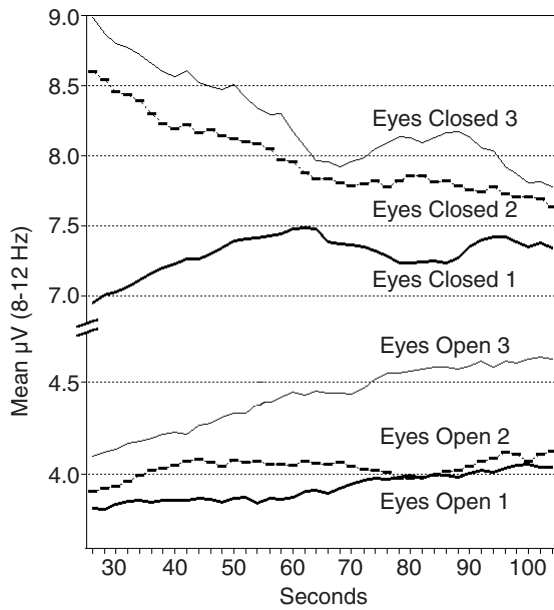


TABLE 1. Posterior alpha activity during replicated baselines.

	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

1. 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.

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 two minute baseline recordings for 20 adults (10 male, 10 female, all right-handed, mean age 28.2 years). The first column contains a state parameter familiar to most clinicians: mean

TABLE 2. Posterior alpha activity with increasing challenge.

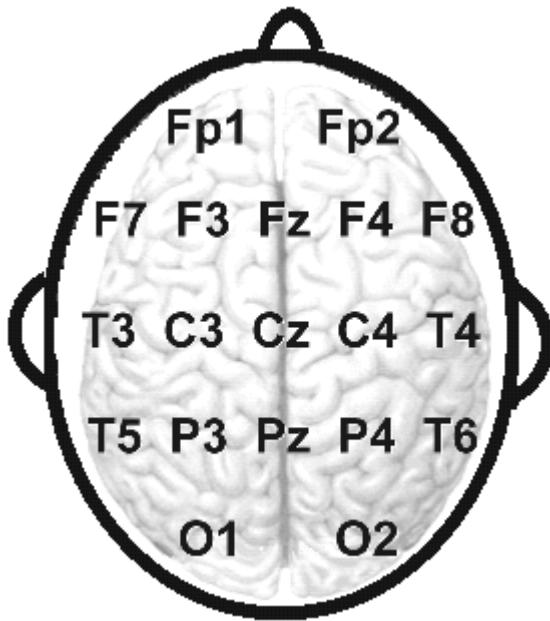
	Mean Magnitude	Standard Deviation	Slope Coefficient	Residual Variance
Eyes Closed	7.4	3.4	1.2	2.3
Eyes Open	4.1	1.9	1.0	1.3
Motor task	4.1	1.8	0.7	4.5
Visual task	3.9	1.6	0.2	1.3
Motor & Visual	3.8	1.5	0.5	1.3

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 ( $\mu\text{V}$ ) and slope and residual variance are mean microvolt difference per second or epoch ( $\delta \mu\text{V}$ ). Physiological engagement is associated with stable states of low alpha activity, and to a lesser degree, stable negative trends as shown in Table 2.

### WHAT ARE ELECTRODES?

Electrodes are sensors 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 ex-

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



tended to 74 electrodes to allow better coverage (Chatrian, Lettich, & Nelson, 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 3 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 Figure 4 and Table 3).

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 con-

taminated 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.

### **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 (see Figure 5), 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 6 presents a referential montage of 19 channels in such a chart. Most software programs allow examination of the raw data across

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

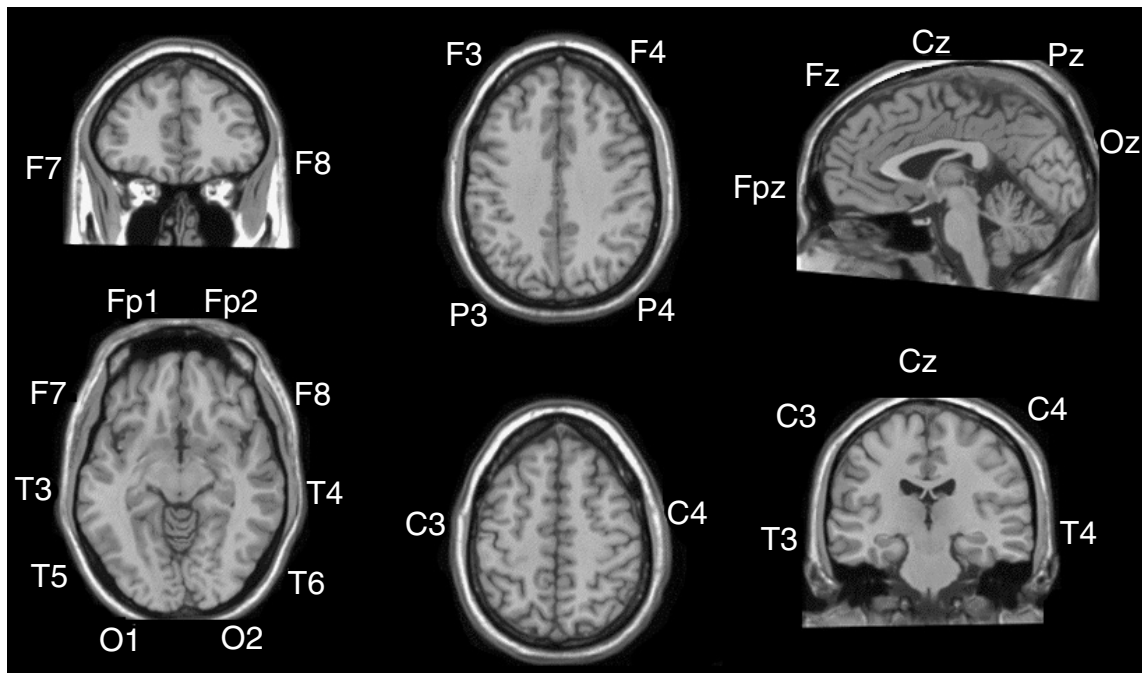
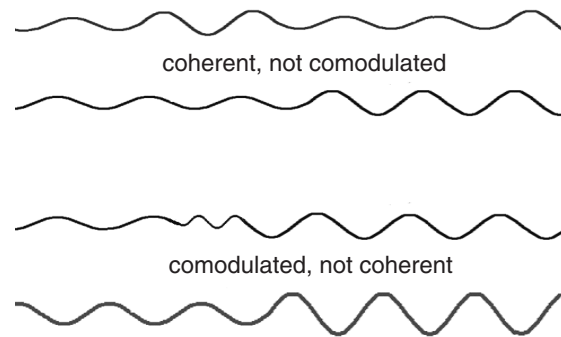


TABLE 3. Cortical gyrus below each electrode position, adapted from Okamoto et al. (2004).

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
Temporal	Superior	6	Cz
	Medial	21	T3/4
Parietal	Medial	37	T5/6
	Inferior	7	P3/4
Occipital	Precuneus	7	Pz
	Medial	19	O1/2

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

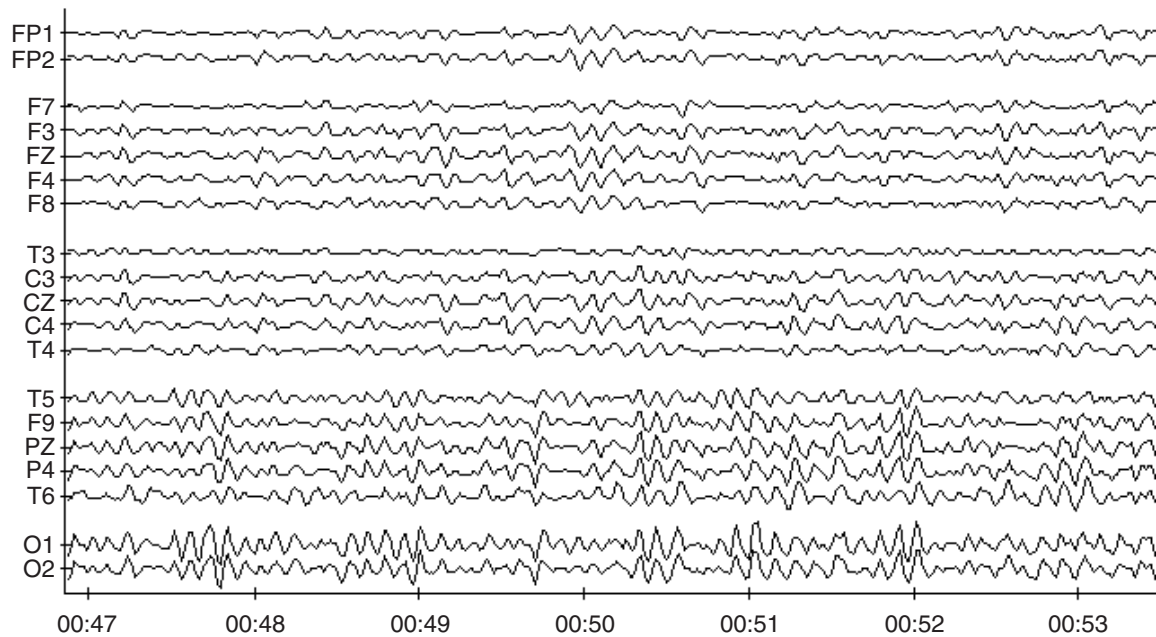
FIGURE 5. Conceptual depictions of the difference between two aspects of functional connectivity.



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

FIGURE 6. EEG data from 19 channels recorded from an adult.



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.

#### **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; see Table 4). 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

TABLE 4. Rhythm maturation: Alpha and sleep spindle frequency range by age group (modified from Niedermeyer, 1987).

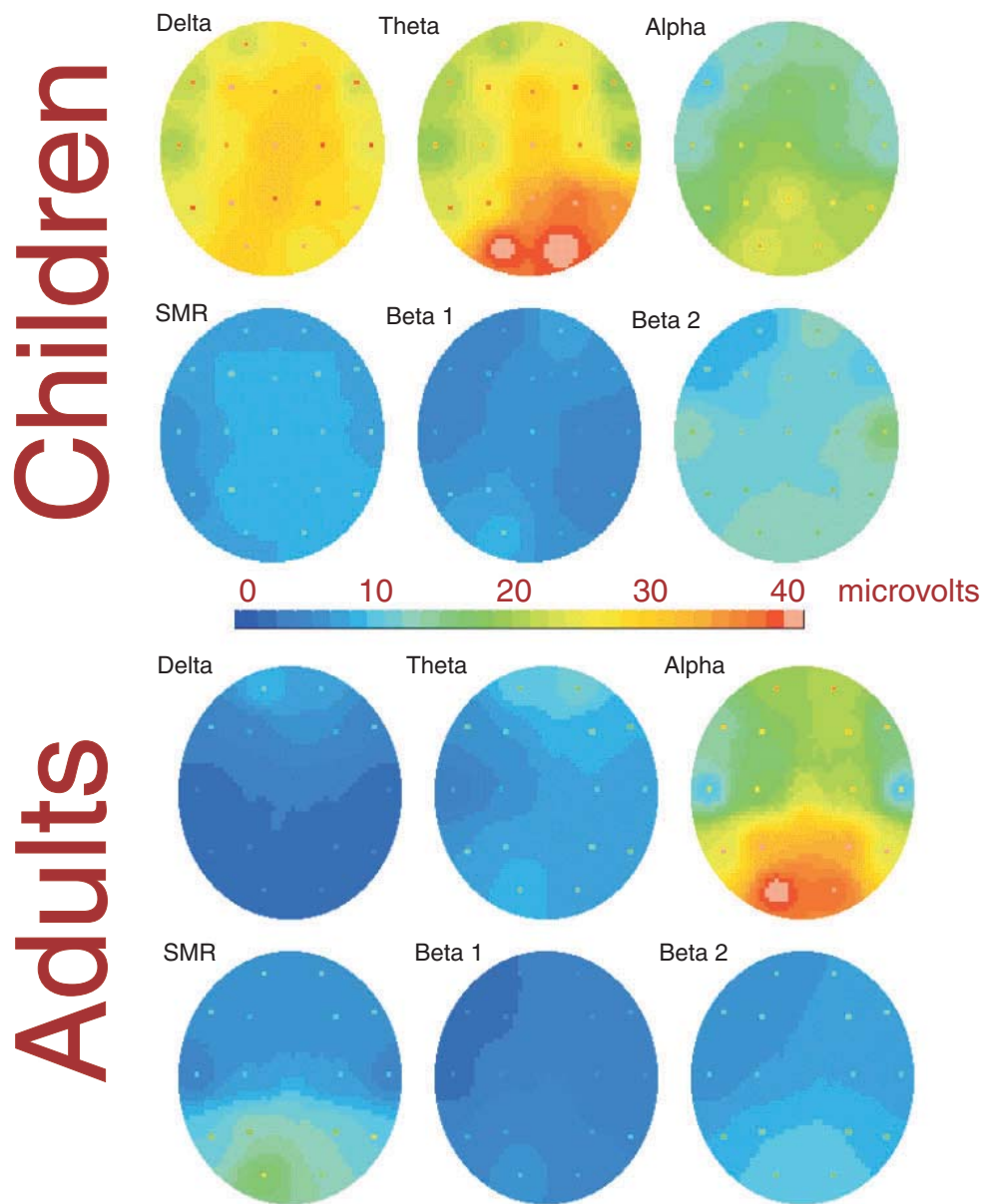
Rhythm	Newborn	Infant	Toddler	Preschooler	Preteen
Alpha	Not present	4-6 Hz	5-8 Hz	7-9 Hz	9-10 Hz
Sleep spindle	Not present	12-14 Hz	12-14 Hz	12-14 Hz	12-14 Hz

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; see Figure 7).

Besides age, gender and handedness should be considered during assessment. Left-handedness is associated with different functional laterality patterns than right handedness (Galín, Ornstein, Herron, & Johnstone, 1982; Provins & Cunliffe, 1972). Left-handed individuals may show abnormal hemispheric specialization



FIGURE 7. 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.



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; Trotman & Hammond, 1979; Tucker, 1976; Flor-Henry & Koles, 1982) due to stricter functional segregation for

males (Lake & Bryden, 1976; McGlone, 1978; Inglis & Lawson, 1982) or more bilateral representation of function for females (Turkheimer & Farace, 1992). Not everyone finds gender differences (Herring & Reitan, 1986, 1992) 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).

### 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 (see Figure 8) 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.

#### Example (Fictional) Report

**HISTORY:** J.D. was referred to our clinic 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 became 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 than 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 three minutes. These included three replications of (a) eyes closed relaxation, (b) eyes open relaxation, (c) reading for comprehension, and (d) a mathematics test of graded difficulty.

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.

**FINDINGS:** With eyes closed J.D. showed a dominant frequency of 8-10 Hz, prominent in posterior cortex and bilaterally symmetrical (see Figure 9). 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 (see Figure 10). Comodulation analysis also disclosed hyper-

FIGURE 8. Statistical deviation (z-score from normative database) for six frequency bands.

	Delta	Theta	Alpha	SMR	Beta1	Beta2
FP1	0.3	-0.3	-0.4	-0.3	-0.1	-1.2
FPS	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	-0.13	-1.9
FB	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	0A	-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 9. Spectral magnitudes of 19 channels during eyes closed relaxation.

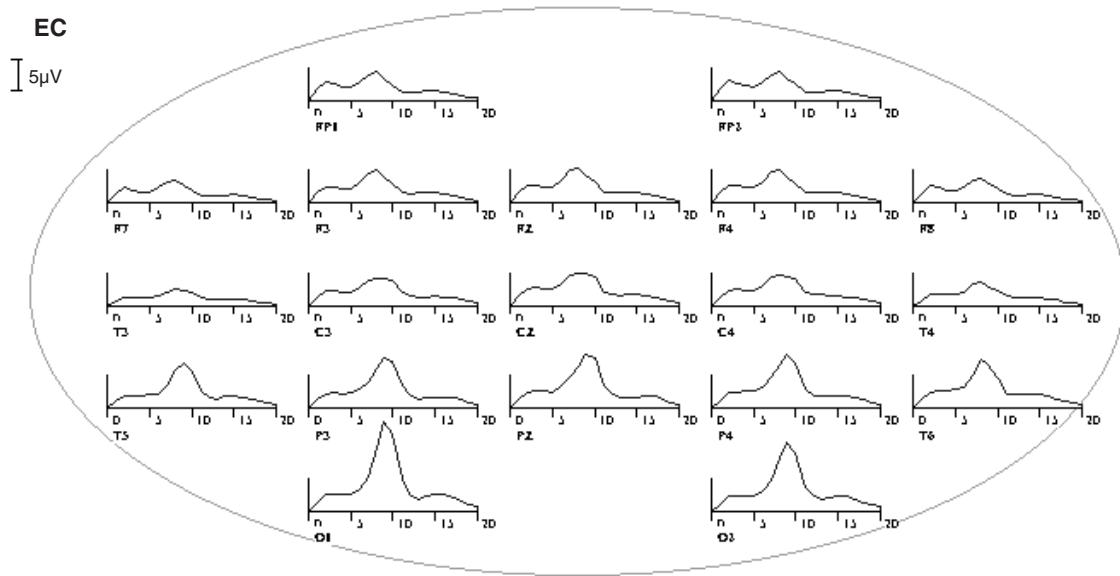
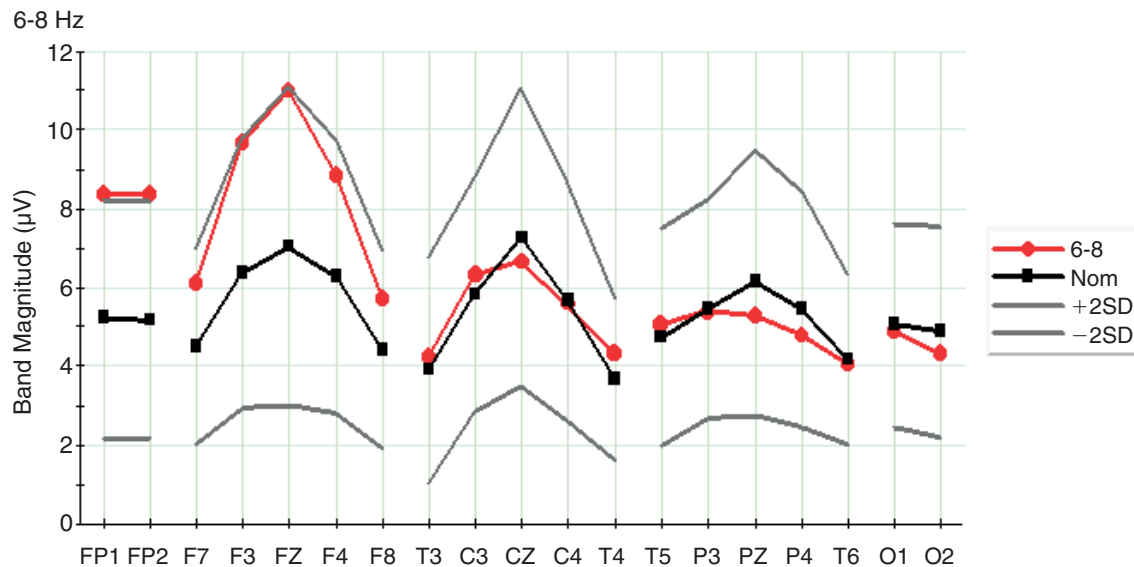


FIGURE 10. Topometric display of individual's data compared to adult normative values during mathematical processing.

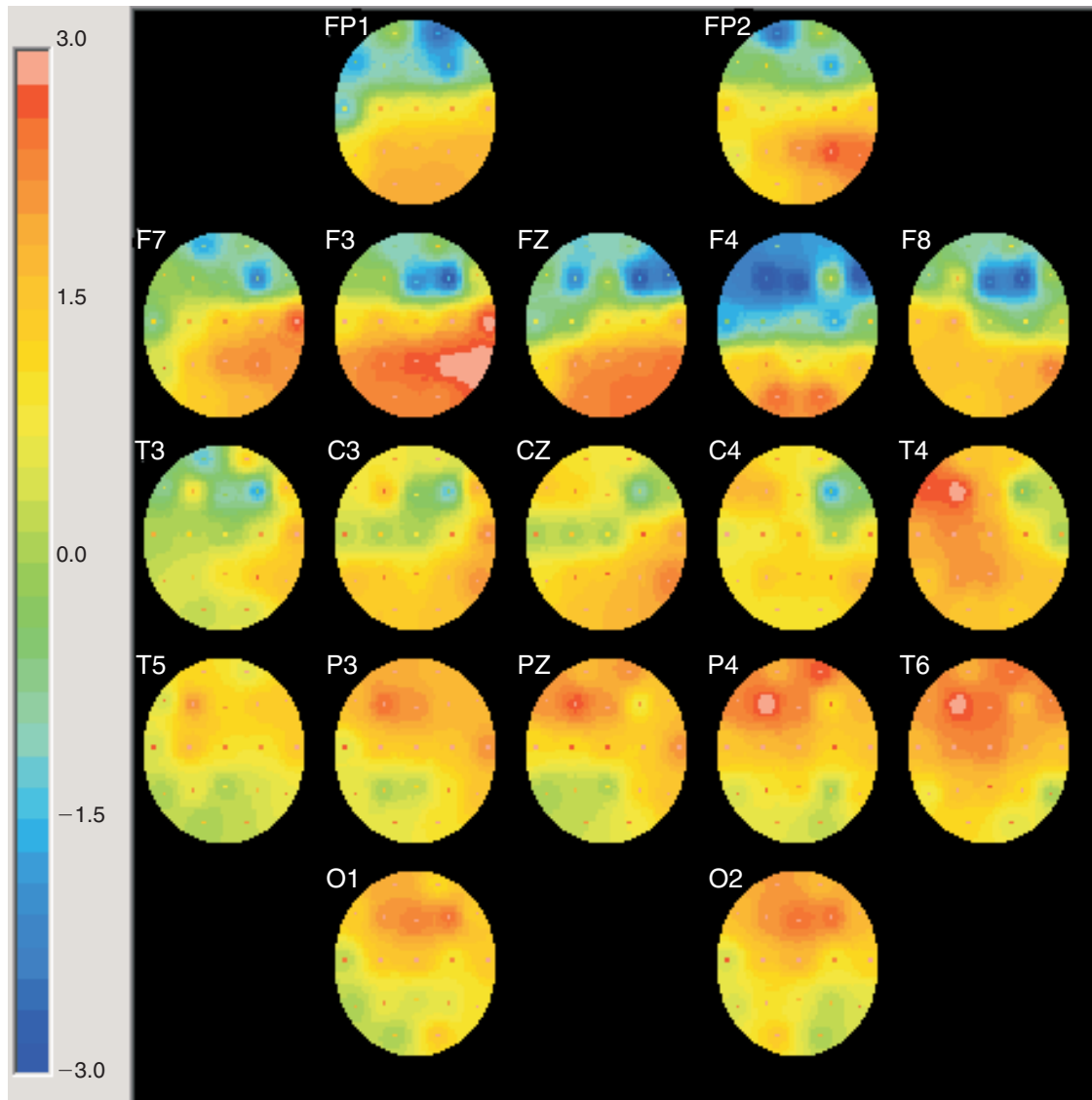


modulation of left medial frontal cortex (F3) with right posterior sites (P4, T4, T6), and hypomodulation of anterior cortex, primarily on the right side for the dominant frequency (see Figure 11).

**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

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).



posterior sites is recommended. Secondly, 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 intro-

duction 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: Brazier, (1980); Davidson, Jackson, and Larson, (2000); Gevins, (1984); Holschneider and Leuchter, (2002); Nuwer, (1988); Pfurtscheller and Lopes da Silva, (1999); Steriade, Gloor, Llinas, Lopes de Silva, and Mesulam, (1990); and Zappulla, (1991).

## REFERENCES

- Aboitiz, F., Scheibel, A. B., Fisher, R. S., & Zaidel, E. (1992). Individual differences in brain asymmetries and fiber composition in the human corpus callosum. *Brain Research*, *598*, 154-161.
- American Electroencephalographic Society (1994). Guideline thirteen: Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, *11*, 111-113.
- Andersen, P., & Andersson, S. A. (1968). *Physiological basis of the alpha rhythm*. New York: Appleton-Century-Crofts.
- Baker, G., & Franken, R. (1967). Effects of stimulus size, brightness and complexity on EEG desynchronization. *Psychonomic Science*, *7*, 289-290.
- Bohdanecky, Z., Indra, M., Lansky, P., & Radil-Weiss, T. (1984). Alternation of EEG alpha and non-alpha periods does not differ in open and closed eye condition in darkness. *Acta Neurobiologia Experimental*, *44*, 230-232.
- Boiten, F., Sergeant, J., & Geuze, R. (1992). Event-related desynchronization: The effects of energetic and computational demands. *Electroencephalography & Clinical Neurophysiology*, *82*, 302-309.
- Brazier, M. A. B. (1961). Computer techniques in EEG analysis. *Electroencephalography & Clinical Neurophysiology*, *S20*, 2-6.
- Brazier, M. A. B. (1980). The early development of quantitative EEG analysis: The roots of modern methods. In R. Sinz & M. R. Rosenzweig (Eds.), *Psychophysiology*. Amsterdam: Elsevier.
- Brown, J. W., & Grober, E. (1983). Age, sex, and aphasia type: Evidence for a regional cerebral growth process underlying lateralization. *Journal of Nervous & Mental Disease*, *171*, 431-434.
- Chapotot, F., Jouny, C., Muzet, A., Buguet, A., & Brandenberger, G. (2000). High frequency waking EEG: Reflection of a slow ultradian rhythm in daytime arousal. *Neuroreport*, *11*, 2223-2227.
- Chatrian, G. E., Lettich, E., & Nelson, P. L. (1985). Ten percent electrode system for topographic studies of spontaneous and evoked EEG activity. *American Journal of EEG Technology*, *25*, 83-92.
- Clarke, J. M. (1990). Interhemispheric functions in humans: Relationships between anatomical measures of the corpus callosum, behavioral laterality effects, and cognitive profiles. Unpublished doctoral dissertation, University of California, Los Angeles.
- Cooley, J. W., & Tukey, J. W. (1965). An algorithm for the machine computation of the complex Fourier series. *Mathematics of Computation* *19*, 297-301.
- Davidson, R. J., Jackson, D.C., & Larson, C. L. (2000). Human electroencephalography. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (2nd ed., pp. 27-52). Cambridge, UK: Cambridge University Press.
- Dietsch, G. (1932). Fourier-analyse von elektrenkephalogrammen des Menschen. *Pflugers Archive. European Journal of Physiology*, *230*, 106-112.
- Dumermuth, G., & Fluhler, H. (1967). Some modern aspects in numerical spectrum analysis of multichannel electroencephalographic data. *Medical and Biological Engineering*, *5*, 319-331.
- Earle, J. B., & Pikus, A. A. (1982). The effect of sex and task difficulty of EEG alpha activity in association with arithmetic. *Biological Psychology*, *15*, 1-14.
- Faber-Clark, M. M., & Moore, W. H. (1983). Sex task and processing strategy effects in hemispheric alpha asymmetries for the recall and recognition of arousal words: Results from perceptual and motor tasks in males and females. *Brain & Cognition*, *2*, 233-250.
- Flor-Henry, P., & Koles, Z. J. (1982). EEG characteristics of normal subjects: A comparison of men and women and of dextrals and sinistrals. *Research Communications in Psychology, Psychiatry, and Behavior*, *7*, 21-38.
- Gale, A., & Edwards, J. (1983). The EEG and human behavior. In E. Gale & C. A. Edwards (Eds.), *Physiological correlates of human behavior* (pp. 99-127). London: Academic Press.
- Galin, D., Ornstein, R., Herron, J., & Johnstone, J. (1982). Sex and handedness differences in EEG measures of hemispheric specialization. *Brain and Language*, *16*, 19-55.
- Gevins, A. S., & Schaffer, R. E. (1980). A critical review of electroencephalographic (EEG) correlates of higher cortical functions. *CRC Critical Reviews in Bioengineering*, *4*, 113-164.
- Gevins, A. S. (1984). Analysis of the electromagnetic signals of the human brain: milestones, obstacles, and goals. *IEEE Transactions in Biomedical Engineering*, *31*, 833-850.
- Goodman, N. R. (1957). On the joint estimation of the spectra, cospectrum and quadrature spectrum of a two-dimensional stationary Gaussian process. Unpublished doctoral dissertation, Princeton University.
- Grass, A. M., & Gibbs, F. A. 1938. A Fourier transform of the electroencephalogram. *Journal of Neurophysiology*, *1*, 521-526.
- Gratton, G., Villa, A. E., Fabiani, M., Colombis, G., Palin, E., Bolcioni, G., et al. (1992). Functional correlates of a three-component spatial model of the alpha rhythm. *Brain Research*, *582*, 159-162.
- Grillon, C., & Buchsbaum, M. S. (1986). Computed EEG topography of response to visual and auditory stimuli. *Electroencephalography and Clinical Neurophysiology*, *63*, 42-53.
- Harmony, T., Marosi, E., Becker, J., Rodriguez, M., Reyes, A., Fernandez, T., et al. (1995). Longitudinal quantitative EEG study of children with different performances on a reading-writing test. *Electroencephalography and Clinical Neurophysiology*, *95*, 426-433.

- Herring, S., & Reitan, R. M. (1986). Sex similarities in verbal and performance IQ deficits following unilateral cerebral lesions. *Journal of Consulting & Clinical Psychology, 54*, 537-541.
- Herring, S. L., & Reitan, R. M. (1992). Gender influence on neuropsychological performance following unilateral cerebral lesions. *Clinical Neuropsychologist, 6*, 431-442.
- Holschneider, D. P., & Leuchter, A. F. (2002). Quantitative electroencephalography: Neurophysiological alterations in normal aging and geriatric neuropsychiatric disorders. In C. E. Coffey & J. L. Cummings (Eds.), *Textbook of geriatric neuropsychiatry* (2nd ed., pp. 285-310). Washington, DC: American Psychiatric Press.
- Inglis, J., & Lawson, J. S. (1982). A meta-analysis of sex differences in the effects of unilateral brain damage on intelligence test results. *Canadian Journal of Psychology, 36*, 670-683.
- Jasper, H. H. (1958). The 10-20 system of the international federation. *Electroencephalography and Clinical Neurophysiology, 10*, 371-375.
- Kaiser, D. A. (1994). Interest in films as measured by ratings and topographic EEG. Unpublished doctoral dissertation, University of California, Los Angeles.
- Kaiser, D. A. (2006, April). Comodulation and coherence in normal and clinical populations. Paper presented at 37th Association for Applied Psychophysiology and Biofeedback conference, Portland, OR.
- Kinsborne, M. (1980). If sex differences in brain lateralization exist, they have yet to be discovered. *Behavioral and Brain Sciences, 3*, 231-232.
- Lake, D. A., & Bryden, M. P. (1976). Handedness and sex differences in hemispheric asymmetry. *Brain & Language, 3*, 266-282.
- Lopes da Silva, F. H. (1991). Neural mechanisms underlying brain waves: From neural membranes to networks. *Electroencephalography and Clinical Neurophysiology, 79*, 81-93.
- McGlone, J. (1978). Sex differences in functional brain asymmetry. *Cortex, 14*, 122-128.
- McGlone, J. (1980). Sex differences in human brain asymmetry: A critical survey. *Behavioral and Brain Sciences, 3*, 215-263.
- Millett, D. (2001). Hans Berger: From psychic energy to the EEG. *Perspectives in Biology and Medicine, 44*, 522-542.
- Moruzzi, G., & Magoun, H. W. (1949). Brain stem reticular formation and activation of EEG. *Electroencephalography and Clinical Neurophysiology, 1*, 455-473.
- Murakami, S., & Okada, Y. (in press). Contributions of principal neocortical neurons to magnetoencephalography (MEG) and electroencephalography (EEG) signals. *Journal of Physiology*.
- Niedermeyer, E. (1987). Maturation of the EEG: Development of waking and sleep patterns. In E. Niedermeyer & F. Lopes da Silva (Eds.), *Electroencephalography: Basic principles, clinical applications and related fields* (pp. 133-157). Baltimore, MD: Urban and Schwarzenberg.
- Nunez, P. L. (1981). *Electric fields of the brain: The neurophysics of EEG*. New York: Oxford University Press.
- Nuwer, M. R. (1988). Quantitative EEG: I. Techniques and problems of frequency analysis and topographic mapping. *Journal of Clinical Neurophysiology, 5*, 1-43.
- Okamoto, M., Dan, H., Sakamoto, K., Takeo, K., Shimizu, K., Kohno, S., et al., (2004). Three-dimensional probabilistic anatomical cranio-cerebral correlation via the international 10-20 system oriented for transcranial functional brain mapping. *Neuroimage, 21*, 99-111.
- Oldfield, R. C. (1971). The assessment and analysis of handedness, the Edinburgh inventory. *Neuropsychologia, 9*, 97-113.
- Pakkenberg, B., Pelvig, D., Marner, L., Bundgaard, M. J., Gundersen, H. J., Nyengaard, J. R., et al. (2003). Aging and the human neocortex. *Experimental Gerontology, 38*, 95-99.
- Peniston, E. G., & Kulkosky, P. J. (1989). Alpha-theta brainwave training and beta-endorphin levels in alcoholics. *Alcoholism, Clinical and Experimental Research, 13*, 271-279.
- Pfurtscheller, G. (1992). Event-related synchronization (ERS): An electrophysiological correlate of cortical areas at rest. *Electroencephalography & Clinical Neurophysiology, 83*, 62-69.
- Pfurtscheller, G., & Klimesch, W. (1990). Topographical display and interpretation of event-related desynchronization during a visual-verbal task. *Brain Topography, 3*, 85-93.
- Pfurtscheller, G., & Lopes da Silva, F. H. (1999). Event-related EEG/MEG synchronization and desynchronization: Basic principles. *Clinical Neurophysiology, 110*, 1842-1857.
- Pfurtscheller, G., Maresh, H., & Schuy, S. (1977). Inter- and intra-hemispheric differences in the peak frequency of rhythmic activity within the alpha band. *Electroencephalography and Clinical Neurophysiology, 42*, 77-83.
- Provins, K. A., & Cunliffe, P. (1972). The relationship between EEG activity and handedness. *Cortex, 8*, 136-146.
- Rasmussen, T., & Milner, B. (1977). The role of early left-brain injury in determining lateralization of cerebral speech functions. *Annals of the New York Academy of Sciences, 299*, 355-369.
- Rebert, C. S., & Mahoney, R. (1978). Functional cerebral asymmetry and performance III. Reaction time as a function of task, hand, sex, and EEG asymmetry. *Psychophysiology, 15*, 9-16.
- Shearer, D. E., Cohn, N. B., Dustman, R. E., & LaMarche, J. A. (1984). Electrophysiological correlates of gender differences: A review. *American Journal of EEG Technology, 24*, 95-107.

- Shepherd, R. (1982). EEG correlates of sustained attention: Hemispheric and sex differences. *Current Psychological Research*, 2, 1-20.
- Steriade, M., Gloor, P., Llinas, R. R., Lopes da Silva, F. H., & Mesulam, M. M. (1990). Basic mechanisms of cerebral rhythmic activities. *Electroencephalography and Clinical Neurophysiology*, 76, 481-508.
- Sterman, M. B., Mann, C. A., Kaiser, D. A., & Suyenobu, B. Y. (1994). Multiband topographic EEG analysis of a simulated visuomotor aviation task. *International Journal of Psychophysiology*, 16, 49-56.
- Trotman, S. C., & Hammond, G. R. (1979). Sex differences in task-dependent EEG asymmetries. *Psychophysiology*, 16, 429-431.
- Tucker, D. M. (1976). Sex differences in hemispheric specialization for synthetic visuospatial functions. *Neuropsychologia*, 14, 447-454.
- Turkheimer, E., & Farace, E. (1992). A reanalysis of gender differences in IQ scores following unilateral brain lesions. *Psychological Assessment*, 4, 498-501.
- Zappulla, R. A. (1991). Fundamentals and applications of quantified electrophysiology. *Annals of the New York Academy of Science*, 620, 1-21.

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## APPENDIX

Topical history of EEG investigation by initial year of publication. The references below correspond to the topic.

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		Delinquency	1943
in children	1937	Multiple sclerosis	1944
Mental deficiency	1937	OCD	1947
Schizophrenia	1937	Anxiety	1948
Brain lesions	1938	Operant	
Personality	1938	conditioning	1969

1. Head injury: Berger (1931) and Jasper, H. H., Kershman, J., & Elvidge, A. R. (1940). EEG studies of injury to the head. *Archives of Neurology and Psychiatry*, 44, 328-348.

2. Epilepsy: Berger (1933) and Gibbs, F. A., Davis, H. & Lennox, W. G. (1935). The electro-encephalogram in epilepsy and in conditions of impaired consciousness. *Archives of Neurology and Psychiatry*, 34, 1133-1148.

3. Heredity: Perkins, F. T. (1934) Genetic study of cerebral action currents. *Science*, 79, 418.

4. Sleep: Loomis, A. L., Harvey, E. N., & Hobart, G. A. (1935). Potential rhythms of the cerebral cortex during sleep. *Science*, 81, 597-598.

5. Hypnosis: Loomis, A. L., Harvey, E. N., & Hobart, G. (1936). Brain potentials during hypnosis. *Science*, 83, 239.

6. Behavior problems in children: Solomon, P., Jasper, H. H., & Braley, C. (1937). Studies in behav-

ior problem children. *American Neurology and Psychiatry*, 8, 1350-1351.

7. Consciousness: Travis, L. E. (1937). Brain potentials and the temporal course of consciousness. *Journal of Experimental Psychology*, 21, 302-309.

Mental deficiency: Kreezer, G., & Smith, F. W. (1937). Brain potentials in the hereditary type of mental deficiency. *Psychological Bulletin*, 34, 535-536.

8. Schizophrenia: Travis, L. E., & Malamud, W. (1937). Brain potentials from normal subjects, stutterers, and schizophrenics. *American Journal of Psychiatry*, 93, 927-936 and Hoagland, H. (1937). Encephalography in schizophrenia. *Archives of Neurology and Psychiatry*, 39, 210-213.

9. Brain lesions: Case, T. J., & Bucy, P. C. (1938). Localization of cerebral lesions by EEG. *Journal of Neurophysiology*, 1, 245-261.

10. Personality: Gottlob, A. B. (1938). The relationship between brain potentials and personality. *Journal of Experimental Psychology*, 22, 67-74.

11. Narcolepsy: Janzen, R. (1939). Hiernbioelektrische Untersuchungen über den physiologischen Schlaf und den Schlaganfall bei Kranken mit genuiner Narkolepsie. *Deutsch. Z. Nervenheilk.* 149, 93-106.

12. Alcoholism: Davis, P. A., Gibbs, F. A., Davis, H., Jetter, W. W., & Trowbridge, L. S. (1941). The effects of alcohol upon the electroencephalogram (brain waves). *Quarterly Journal of Studies on Alcohol*, 1, 626-637.

13. Migraine: Strauss, H., & Selinsky, H. (1941). EEG changes in patients with migrainous syndrome. *Transactions of the American Neurological Assoc.*, 67, 205-208.

14. Peak performance: Minderman, E. (1941). Pilots tested by brain wave analysis. *Medical Records*, 153, 292.

15. Deafness: Bagchi, B. K. (1941). The brain potentials of the deaf and dumb. *Psychological Bulletin*, 38, 591.
16. Aggression: Gibbs, F. A., Bloomberg, W., & Bagchi, B. K. (1942). An EEG study of adult criminals. *Transactions of the American Neurological Assoc.*, 68, 87-90
17. Delinquency: Jenkins, R. L., & Pacella, B. L. (1943). EEG studies of delinquent boys. *American Journal of Orthopsychiatry*, 13, 107-120.
18. Multiple sclerosis: Hofer, P. F. A., & Guttman, S. A. (1944). The EEG in multiple sclerosis. *Transactions of the American Neurological Assoc.*, 70, 70-73.
19. OCD: Rockwell, F. V., & Simons, D. J. (1947). The electroencephalogram and personality organization in the obsessive-compulsive reactions. *Archive of Neurology and Psychiatry*, 57, 71-77.
20. Anxiety: Schipp, E., Dugan, P., Kennard, M. A., & Welsh, L. (1948). Effects of pathological anxiety in childhood on EEG and conditioned PGR. *American Psychologist*, 3, 371.
21. Operant conditioning: Kamiya, J., Callaway, E., & Yeager, C. L. (1969). Visual evoked responses in subjects trained to control alpha rhythms. *Psychophysiology*, 5, 683-695.