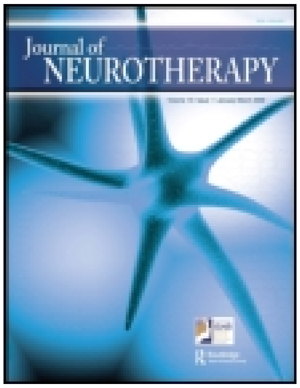

Journal of Neurotherapy: Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/wneu20

A Modular Activation/Coherence Approach to Evaluating Clinical/QEEG Correlations and for Guiding Neurofeedback Training: Modular Insufficiencies, Modular Excesses, Disconnections, and Hyperconnections

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Version of record first published: 08 Sep 2008

A Modular Activation/Coherence Approach to Evaluating Clinical/QEEG Correlations and for Guiding Neurofeedback Training: Modular Insufficiencies, Modular Excesses, Disconnections, and Hyperconnections

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ABSTRACT. Current approaches to QEEG-guided neurofeedback involve efforts to normalize the abnormalities seen, without reference to the functional localization of the cortical areas involved. Recent advances in cortical neurophysiology indicate that specific brain areas are developed to perform certain functions (cortical modules). Complex brain functions require cooperation between modules, particularly during a learning situation. For example, the left prefrontal "activation module" must cooperate with one or both occipital "visual modules" to attend *and* see something on a chalkboard. To remember what has been seen, both temporal "memory modules" must cooperate with the visual modules for the image to be retained in short-term memory. If the connections between these modules are not functioning optimally, visual learning will be impaired. Decreased coherence (hypocoherence) indicates a decrease in functional connectivity between these modules, and increased coherence (hypercoherence) indicates an increase in functional connectivity between the modules. Neurofeedback can be used to normalize coherence between these modules, thereby improving the efficiency of their cooperation in the learning process. If coherence is less than normal, it is trained up. If coherence is more than normal, it is trained down. Three cases are presented where this approach has succeeded in remediating the client's symptoms. doi:10.1300/J184v11n01_03 *[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> © 2007 by The Haworth Press, Inc. All rights reserved.]*

KEYWORDS. Activation, coherence, connectivity, neurofeedback, QEEG, disconnections, excess, hyperconnections, insufficiencies, module

INTRODUCTION

This paper provides motivation and a detailed rationale for the use of power and coherence metrics in the assessment and training of a variety of clinical cases, and presents individual case outcomes. Our findings provide a foundation for further development and application of coherence and related metrics in practical clinical scenarios, based upon a functional model of the brain and EEG.

There are four major ways in which information is coded and processed in the cerebral cortex:

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Journal of Neurotherapy, Vol. 11(1) 2007
Available online at http://jn.haworthpress.com

doi:10.1300/J184v11n01_03

1. Frequency coding (cycles/second)
2. Intensity coding (amplitude)
3. Spatial coding (connections)
4. Tim binding (simultaneous or asynchronous activation)

The only technology that gives us information with which to adequately evaluate cortical function is the quantitative electroencephalogram (QEEG). Further, the time course of EEG information (milliseconds) is the only technology that is in real time, i.e., what is happening as it is happening. Localization of brain functions based on the study of brain lesions is a time-honored tradition in neurology (Mesulam, 2000). Gradually over time the concept of modules subserving distinct brain processes has gained widespread acceptance (Fodor, 1983). With the advent of QEEG it has become possible to evaluate localized brain dysfunctions, and to correlate those abnormalities with neuropsychological test abnormalities (Shenal, Rhodes, Moore, Higgins, Harrison, 2001). A problem with this approach is that there may be several functions associated with a given area delimited by the 10/20 system (e.g., FP2). On the other hand, a functional module may involve several areas of the 10/20 system. For example, the process of reading involves FP1, 01, 02, T3, T5, and P3 (at a minimum), as well as connections between those areas (Walker & Norman, 2006). The commercially available QEEG databases (Lubar, 2003) are restricted to the 10/20 system, so we cannot train all the elements of such complicated modules at the same time. However, we can evaluate the connectivity of the different areas represented in the 10/20 system. These areas may be viewed as having a central role in the various brain processes. Neurofeedback can then normalize the connections with coherence training. If the modules are under-activated or over-activated, neurofeedback can restore normal activation. Once the modules are activated and connections are normalized, normal brain activity can take place.

DEFINITIONS FOR THIS PAPER

1. Module–an area of the cerebral cortex, lying under an electrode location defined by the 10/20 system, which has a characteristic or principal function (e.g., 01, which has the principal function of analyzing visual information from the right half of visual space). There may be other functions within that module (e.g., color perception). Several modules may be needed to subserve complex brain functions, such as reading.
2. Coherence–the degree of cooperation between two brain areas (modules). Normal coherence leads to optimal cooperation. Decreased coherence results in less cooperation than normal, leading to reduced efficiency, longer processing time, and mistakes. Increased coherence leads to excessive cross-talk between the two areas involved and less cooperation with other brain areas, leading to stereotypic or stuck responses, decreased flexibility, and decreased creativity in cortical processing.

Table 1 is information we gathered from our clinical experience and from other resources (Brownback et al., 2003; Joseph, 1990; & Mesulam, 2000). It indicates the principal functions of the different modules, as delineated by the 10/20 system. Other functions in which the modules seem to be important are listed in the third column. Table 2 indicates the coherence pairs involved in functions requiring cooperation of activity between those two sites to produce that activity (Walker, 2003).

This model emphasizes the roles of specialized areas (modules) and their connections in normal brain function. Brain disease commonly results in modular insufficiencies, modular excesses, disconnections, and hyperconnections. Neurofeedback training to normalize these abnormalities is proving to be an effective way to normalize the functions of the cerebral cortex. At this point, only a few examples of each type of abnormality have been found, but this approach is proving to be a reliable way to restore normal brain functions in patients with stable deficits involving cortical areas and their connections, as assessed by QEEG.

TABLE 1. Cortical Modules

10/20 Territory Modules	Principal Function	Some Other Functions Involving this Area
FP1	Logical attention	Orchestrate network interactions Planning Decision making Task completion Working memory
FP2	Emotional attention	Judgment Sense of self Self-control Restraint of impulses
F7	Verbal expression	Speech fluency Mood regulation (cognitive)
F8	Emotional expression	Drawing (right hand) Mood regulation (endogenous)
F3	Motor planning right upper extremity (RUE)	Fine motor coordination Mood elevation
F4	Motor planning of left extremity (LUE)	Fine motor coordination (left hand)
FZ	Motor planning of both lower extremities (BLE) and midline	Running Walking Kicking
T3	Logical (verbal) memory formation and storage	Phonologic processing Hearing (bilateral) Suppression of tinnitus
T4	Emotional (non-verbal) memory formation and storage	Hearing (bilateral) Suppression of tinnitus Autobiographical memory storage
C3	Sensorimotor integration right upper extremity (RUE)	Alerting responses Handwriting (right hand)
10/20 Territory	**Principal Function**	**Some Other Functions Involving this Area**
C4	Sensorimotor integration left upper extremity (LUE)	Calming Handwriting (left hand)
CZ	Sensorimotor integration both lower extremities (BLE) and midline	Ambulation
T5	Logical (verbal) understanding	Word recognition Auditory processing
T6	Emotional understanding	Facial recognition Symbol recognition Auditory processing
P3	Perception (cognitive processing) right half of space	Spatial relations Sensations Multimodal sensations Calculations Praxis Reasoning (verbal)

TABLE 1 (continued)

P4	Perception (cognitive processing) left half of space	Spatial relations Multimodal interactions Praxis Reasoning (non-verbal)
PZ	Perception midline	Spatial relations Praxis Route finding
01	Visual processing right half of space	Pattern recognition Color perception Movement perception Black/white perception Edge perception
02	Visual processing left half of space	Pattern recognition Color perception Movement perception Black/white perception Edge perception

TABLE 2. Coherence Pairs Involved in Specific Functions

FPI Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) FP1/FP2	**Less efficient integration of** logical/emotional attention	**Lack of flexibility in** integrating logical/emotional attention
2) FP1/F7	logical attention/verbal expression	Lack of flexibility in integrating logical attention/verbal expression
3) FP1/F3	logical attention/RUE motor actions	Lack of flexibility of logical attention/RUE motor actions
4) FP1/FZ	logical attention/midline motor actions	Lack of flexibility of logical attention/midline motor actions
5) FP1/F4`	logical attention/LUE motor actions	Lack of flexibility of logical attention/LUE motor actions
6) FP1/F8	logical attention/emotional expression	Lack of flexibility of logical attention/emotional expression
7) FP1/T3	logical attention/logical memory (e.g., word recall)	Lack of flexibility of logical attention/logical memory
8) FP1/T4	logical attention/emotional memory	Lack of flexibility of logical attention/emotional memory
9) FP1/T5	logical attention/logical understanding (e.g., empathy)	Lack of flexibility of logical attention/logical understanding
10) FP1/T6	logical attention/emotional understanding	Lack of flexibility of logical attention/emotional understanding
11) FP1/C3	logical attention/sensorimotor integration RUE	Lack of flexibility of logical attention/sensorimotor integration RUE
12) FP1/C4	logical attention/sensorimotor integration LUE	Lack of flexibility of logical attention/sensorimotor integration LUE
13) FP1/CZ	logical attention/sensorimotor integration legs, midline	Lack of flexibility of logical attention/sensorimotor integration legs, midline
14) FP1/P3	logical attention/R perception	Lack of flexibility of logical attention/R perception
15) FP1/P4	logical attention/L perception	Lack of flexibility of logical attention/L perception
16) FP1/PZ	logical attention/midline perception	Lack of flexibility of logical attention/midline perception
17) FP1/O1	logical attention/R visual sensations	Lack of flexibility of logical attention/R visual sensations
18) FP1/O2	logical attention/L visual sensations	Lack of flexibility of logical attention/L visual sensations

FP2 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) FP2/FP7	Less efficient emotional attention/verbal expression	Lack of flexibility of emotional attention/verbal expression
2) FP2/F8	Less efficient emotional attention/emotional expression	Lack of flexibility of emotional attention/emotional expression
3) FP2/F3	Less efficient emotional attention/motor actions RUE	Lack of flexibility of emotional attention/motor actions RUE
4) FP2/F4	Less efficient emotional attention/motor actions LUE	Lack of flexibility of emotional attention/motor actions LUE
5) FP2/F2	Less efficient emotional attention/motor actions midline	Lack of flexibility of emotional attention/motor actions midline
6) FP2/C3	Less efficient emotional attention/sensorimotor integration RUE	Lack of flexibility of emotional attention/sensorimotor integration RUE
7) FP2/C4	Less efficient emotional attention/sensorimotor integration LUE	Lack of flexibility of emotional attention/sensorimotor integration LUE
8) FP2/CZ	Less efficient emotional attention/sensorimotor integration midline	Lack of flexibility of emotional attention/sensorimotor integration midline
9) FP2/P3	Less efficient emotional attention/perception R	Lack of flexibility of emotional attention/perception R
10) FP2/P4	Less efficient emotional attention/perception L	Lack of flexibility of emotional attention/perception L
11) FP2/PZ	Less efficient emotional attention/midline perception	Lack of flexibility of emotional attention/midline perception
12) FP2/O1	Less efficient emotional attention/R visual sensations	Lack of flexibility of emotional attention/R visual sensations
13) FP2/O2	Less efficient emotional attention/L visual sensations	Lack of flexibility of emotional attention/L visual sensations
14) FP2/T3	Less efficient emotional attention/logical memory	Lack of flexibility of emotional attention/logical memory
15) FP2/T4	Less efficient emotional attention/emotional memory	Lack of flexibility of emotional attention/emotional memory
16) FP2/T5	Less efficient emotional attention/logical understanding	Lack of flexibility of emotional attention/logical understanding
17) FP2/T6	Less efficient emotional attention/emotional understanding	Lack of flexibility of emotional attention/emotional understanding

TABLE 2 (continued)

F7 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) F7/F8	Less efficient verbal/emotional expression	Lack of flexibility of verbal/emotional expression
2) F7/F3	Less efficient verbal/motor actions R	Lack of flexibility of verbal/motor actions R
3) F7/F4	Less efficient verbal/motor actions L	Lack of flexibility of verbal/motor actions L
4) F7/T3	Less efficient verbal/logical memory	Lack of flexibility of verbal/logical memory
5) F7/T4	Less efficient verbal/emotional memory	Lack of flexibility of verbal/emotional memory
6) F7/C3	Less efficient verbal/sensorimotor integration RUE	Lack of flexibility of verbal/sensorimotor integration RUE
7) F7/C4	Less efficient verbal/sensorimotor integration LUE	Lack of flexibility of verbal/sensorimotor integration LUE
8) F7/T5	Less efficient verbal/logical understanding	Lack of flexibility of verbal/logical understanding
9) F7/T6	Less efficient verbal/emotional understanding	Lack of flexibility of verbal/emotional understanding
10) F7/P3	Less efficient verbal/perception R	Lack of flexibility of verbal/perception R
11) F7/P4	Less efficient verbal/perception L	Lack of flexibility of verbal/perception L
12) F7/O1	Less efficient verbal/visual sensations R	Lack of flexibility of verbal/visual sensations R
13) F7/O2	Less efficient verbal/visual sensations L	Lack of flexibility of verbal/visual sensations L
14) F7/FZ	Less efficient verbal/motor midline, legs	Lack of flexibility of verbal/motor midline, legs
15) F7/CZ	Less efficient verbal/sensorimotor integration midline	Lack of flexibility of verbal/sensorimotor integration midline
16) F7/PZ	Less efficient verbal perception midline	Lack of flexibility of verbal/perception midline

F3 Coherences

Coherences	Result of Hypocoherence	Result of Hypercoherence
1) F3/F4	Less efficient motor actions RUE/motor actions LUE	Lack of flexibility motor actions RUE/motor actions LUE
2) F3/T3	Less efficient motor actions RUE/logical memory	Lack of flexibility motor actions RUE/logical memory
3) F3/T4	Less efficient motor actions RUE/emotional memory	Lack of flexibility motor actions RUE/emotional memory
4) F3/C3	Less efficient motor actions RUE/sensorimotor integration RUE	Lack of flexibility motor actions RUE/sensorimotor integration RUE
5) F3/Cr	Less efficient motor actions RUE/sensorimotor integration LUE	Lack of flexibility motor actions RUE/sensorimotor integration LUE
6) F3/T5	Less efficient motor actions RUE/logical understanding	Lack of flexibility motor actions RUE/logical understanding
7) F3/T6	Less efficient motor actions RUE/emotional understanding	Lack of flexibility motor actions RUE/emotional understanding
8) F3/P3	Less efficient motor actions RUE/perception R	Lack of flexibility motor actions RUE/perception R
9) F3/P4	Less efficient motor actions RUE/perception L	Lack of flexibility motor actions RUE/perception L
10) F3/O1	Less efficient motor actions RUE/visual sensations R	Lack of flexibility motor actions RUE/visual sensations R
11) F3/O2	Less efficient motor actions RUE/visual sensations L	Lack of flexibility motor actions RUE/visual sensations L
12) F3/FZ	Less efficient motor actions RUE/midline motor actions	Lack of flexibility motor actions RUE/midline motor actions
13) F3/CZ	Less efficient motor actions RUE/midline sensorimotor integration	Lack of flexibility motor actions RUE/midline sensorimotor integration
14) F3/PZ	Less efficient motor actions RUE/midline perceptions	Lack of flexibility motor actions RUE/midline perceptions

TABLE 2 (continued)

F4 Coherences

Coherences	Result of Hypocoherence	Result of Hypercoherence
1) F4/T3	Less efficient motor actions LUE/logical memory	Lack of flexibility motor actions LUE/Logical memory
2) F4/T4	Less efficient motor actions LUE/emotional memory	Lack of flexibility motor actions LUE/emotional memory
3) F4/C3	Less efficient motor actions LUE/sensorimotor integration RUE	Lack of flexibility motor actions LUE/sensorimotor integration RUE
4) F4/C4	Less efficient motor actions LUE/sensorimotor integration LUE	Lack of flexibility motor actions LUE/sensorimotor integration LUE
5) F4/T5	Less efficient motor actions LUE/logical understanding	Lack of flexibility motor actions LUE/logical understanding
6) F4/T6	Less efficient motor actions LUE/emotional understanding	Lack of flexibility motor actions LUE/emotional understanding
7) F4/P3	Less efficient motor actions LUE/perception R	Lack of flexibility motor actions LUE/perceptions R
8) F4/P4	Less efficient motor actions LUE/perceptions L	Lack of flexibility motor actions LUE/perceptions L
9) F4/O1	Less efficient motor actions LUE/visual sensations R	Lack of flexibility motor actions LUE/visual sensations R
10) F4/O2	Less efficient motor actions LUE/visual sensations L	Lack of flexibility motor actions LUE/visual sensations L
11) F4/FZ	Less efficient motor actions LUE/midline motor actions	Lack of flexibility motor actions LUE/midline motor actions
12) F4/CZ	Less efficient motor actions LUE/midline sensorimotor integration	Lack of flexibility motor actions LUE/midline sensorimotor integration
13) F4/PZ	Less efficient motor actions LUE/midline perception	Lack of flexibility motor actions LUE/midline perception

F8 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) F8/F3	Less efficient emotional expression/motor actions RUE	Lack of flexibility of emotional expression/motor actions RUE
2) F8/F4	Less efficient emotional expression/motor actions LUE	Lack of flexibility of emotional expression/motor actions LUE
3) F8/T3	Less efficient emotional expression/logical memory	Lack of flexibility of emotional expression/logical memory
4) F8/T4	Less efficient emotional expression/emotional memory	Lack of flexibility of emotional expression/emotional memory
5) F8/C3	Less efficient emotional expression/sensorimotor integration RUE	Lack of flexibility of emotional expression/sensorimotor integration RUE
6) F8/C4	Less efficient emotional expression/sensorimotor integration LUE	Lack of flexibility of emotional expression/sensorimotor integration LUE
7) F8/T5	Less efficient emotional expression/logical understanding	Lack of flexibility of emotional expression/sensorimotor integration LUE
8) F8/T6	Less efficient emotional expression/emotional understanding	Lack of flexibility of emotional expression/emotional understanding
9) F8/P3	Less efficient emotional expression/perception R	Lack of flexibility of emotional expression/perception R
10) F8/P4	Less efficient emotional expression/perception L	Lack of flexibility of emotional expression/perception L
11) F8/O1	Less efficient emotional expression/visual sensations R	Lack of flexibility of emotional expression/visual sensations R
12) F8/O2	Less efficient emotional expression/visual sensations L	Lack of flexibility of emotional expression/visual sensations L
13) F8/FZ	Less efficient emotional expression/midline motor actions	Lack of flexibility of emotional expression/midline motor actions
14) F8/CZ	Less efficient emotional expression/midline sensorimotor integration	Lack of flexibility of emotional expression/midline sensorimotor integration
15) F8/PZ	Less efficient emotional expression/midline perception	Lack of flexibility of emotional expression/midline perception

TABLE 2 (continued)

T3 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) T3/T4	Less efficient logical memory/emotional memory	Lack of flexibility of logical memory/emotional memory
2) T3/C3	Less efficient logical memory/sensorimotor integration RUE	Lack of flexibility of logical memory/sensorimotor integration RUE
3) T3/C4	Less efficient logical memory/sensorimotor integration LUE	Lack of flexibility of logical memory/sensorimotor integration LUE
4) T3/T5	Less efficient logical memory/logical understanding	Lack of flexibility of logical memory/logical understanding
5) T3/T6	Less efficient logical memory/emotional understanding	Lack of flexibility of logical memory/emotional understanding
6) T3/P3	Less efficient logical memory/perception R	Lack of flexibility of logical memory/perception R
7) T3/P4	Less efficient logical memory/perception L	Lack of flexibility of logical memory/perception L
8) T3/O1	Less efficient logical memory/visual sensations R	Lack of flexibility of logical memory/visual sensations R
9) T3/O2	Less efficient logical memory/visual sensations L	Lack of flexibility of logical memory/visual sensations L
10) T3/FZ	Less efficient logical memory/midline motor actions	Lack of flexibility of logical memory/midline motor actions
11) T3/CZ	Less efficient logical memory/midline sensorimotor integration	Lack of flexibility of logical memory/midline sensorimotor integration
12: T3/PZ	Less efficient logical memory/midline perception	Lack of flexibility of logical memory/midline perception

C3 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) C3/C4	Less efficient sensorimotor integration RUE/sensorimotor integration L	Lack of flexibility of sensorimotor integration RUE/sensorimotor integration L
2) C3/T5	Less efficient sensorimotor integration RUE/logical memory	Lack of flexibility of sensorimotor integration RUE/logical memory
3) C3/T6	Less efficient sensorimotor integration RUE/emotional memory	Lack of flexibility of sensorimotor integration RUE/ emotional memory
4) C3/P3	Less efficient sensorimotor integration RUE/perceptions R	Lack of flexibility of sensorimotor integration RUE/perceptions R
5) C3/P4	Less efficient sensorimotor integration RUE/perceptions L	Lack of flexibility of sensorimotor integration RUE/perceptions L
6) C3/O1	Less efficient sensorimotor integration RUE/visual sensations R	Lack of flexibility of sensorimotor integration RUE/visual sensations R
7) C3/O2	Less efficient sensorimotor integration RUE/visual sensations L	Lack of flexibility of sensorimotor integration RUE/visual sensations L
8) C3/FZ	Less efficient sensorimotor integration Rue/midline motor actions	Lack of flexibility of sensorimotor integration RUE/midline motor actions
9) C3/CZ	Less efficient sensorimotor integration RUE/midline sensorimotor integration	Lack of flexibility of sensorimotor integration RUE/midline sensorimotor integration
10) C3/PZ	Less efficient sensorimotor integration RUE/midline perception	Lack of flexibility of sensorimotor integration RUE/midline perception

C4 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) C4/T5	Less efficient sensorimotor integration LUE/logical memory	Lack of flexibility of sensorimotor integration LUE/logical memory
2) C4/T6	Less efficient sensorimotor integration LUE/emotional memory	Lack of flexibility of sensorimotor integration LUE/emotional memory
3) C4/P3	Less efficient sensorimotor integration LUE/perceptions R	Lack of flexibility of sensorimotor integration LUE/perceptions R
4) C4/P4	Less efficient sensorimotor integration LUE/perceptions	Lack of flexibility of sensorimotor integration LUE/ perceptions
5) C4/O1	Less efficient sensorimotor integration LUE/visual sensations	Lack of flexibility of sensorimotor integration LUE/visual sensations R
6) C4/O2	Less efficient sensorimotor integration LUE/visual sensations	Lack of flexibility of sensorimotor integration LUE/visual sensations
7) C4/FZ	Less efficient sensorimotor integration LUE/midline motor actions	Lack of flexibility of sensorimotor integration LUE/midline motor actions
8) C4/CZ	Less efficient sensorimotor integration LUE/midline sensorimotor integration	Lack of flexibility of sensorimotor integration LUE/midline sensorimotor integration
9) C4/PZ	Less efficient sensorimotor integration LUE/midline perception	Lack of flexibility of sensorimotor integration LUE/midline perception

TABLE 2 (continued)

T4 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) T4/C3	Less efficient emotional memory/sensorimotor integration RUE	Lack of flexibility of emotional memory/sensorimotor integration RUE
2) T4/C4	Less efficient emotional memory/sensorimotor integration LUE	Lack of flexibility of emotional memory/sensorimotor integration LUE
3) T4/T5	Less efficient emotional memory/logical understanding	Lack of flexibility of emotional memory/logical understanding
4) T4T6	Less efficient emotional memory/emotional understanding	Lack of flexibility of emotional memory/emotional understanding
5) T4/P3`	Less efficient emotional memory/perception R	Lack of flexibility of emotional memory/perception R
6) T4/P4	Less efficient emotional memory/perception L	Lack of flexibility of emotional memory/perception L
7) T4/O1	Less efficient emotional memory/visual sensations R	Lack of flexibility of emotional memory/visual sensations R
8) T4/O2	Less efficient emotional memory/visual sensations L	Lack of flexibility of emotional memory/visual sensations L
9) T4/FZ	Less efficient emotional memory/midline motor actions	Lack of flexibility of emotional memory/midline motor actions
10) T4/CZ	Less efficient emotional memory/midline sensorimotor integration	Lack of flexibility of emotional memory/midline sensorimotor integration
11) T4/PZ	Less efficient emotional memory/midline perception	Lack of flexibility of emotional memory/midline perception

T5 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) T5/T6	Less efficient logical memory/emotional memory	Lack of flexibility of logical memory/emotional memory
2) T5/P3	Less efficient logical memory/perception R	Lack of flexibility of logical memory/perception R
3) T5/P4	Less efficient logical memory/perception L	Lack of flexibility of logical memory/perception L
4) T5/O1	Less efficient logical memory/visual sensations R	Lack of flexibility of logical memory/visual sensations R
5) T5/O2	Less efficient logical memory/visual sensations L	Lack of flexibility of logical memory/visual sensations L
6) T5/FZ	Less efficient logical memory/midline motor actions	Lack of flexibility of logical memory/midline motor actions
7) T5/CZ	Less efficient logical memory/midline sensorimotor integration	Lack of flexibility of logical memory/midline sensorimotor integration
8) T5/PZ	Less efficient logical memory/midline perception	Lack of flexibility of logical memory/midline perception

P3 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) P3/P4	Less efficient perceptions R/perceptions L	Lack of flexibility of perceptions R/perceptions L
2) P3/O1	Less efficient perceptions R/visual sensations R	Lack of flexibility of perceptions R/visual sensations R
3) P3/O2	Less efficient perceptions R/visual sensations L	Lack of flexibility of perceptions R/visual sensations L
4) P3/FZ	Less efficient perceptions R/midline motor actions	Lack of flexibility of perceptions R/midline motor actions
5) P3/CZ	Less efficient perceptions R/midline sensorimotor integration	Lack of flexibility of perceptions R/midline sensorimotor integration
6) P3/PZ	Less efficient perceptions R/midline perception	Lack of flexibility of perceptions R/midline perception

P4 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) P4/O1	Less efficient perceptions L/visual sensations R	Lack of flexibility of perceptions L/visual sensations R
2) P4/O2	Less efficient perceptions L/visual sensations L	Lack of flexibility of perceptions L/visual sensations L
3) P4/FZ	Less efficient perceptions L/midline motor actions	Lack of flexibility of perceptions L/midline motor actions
4) P4/CZ	Less efficient perceptions L/midline sensorimotor integration	Lack of flexibility of perceptions L/midline sensorimotor integration
5) P4/PZ	Less efficient perceptions L/midline perception	Lack of flexibility of perceptions L/midline perception

T6 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) T6/P3	Less efficient emotional memory/perceptions R	Lack of flexibility of emotional memory/perceptions R
2) T6/P4	Less efficient emotional memory/perceptions L	Lack of flexibility of emotional memory/perceptions L
3) T6/O1	Less efficient emotional memory/visual sensations R	Lack of flexibility of emotional memory/visual sensations R
4) T6/O2	Less efficient emotional memory/visual sensations L	Lack of flexibility of emotional memory/visual sensations L
5) T6/FZ	Less efficient emotional memory/midline motor actions	Lack of flexibility of emotional memory/midline motor actions
6) T6/CZ	Less efficient emotional memory/midline sensorimotor integration	Lack of flexibility of emotional memory/midline sensorimotor integration
7) T6/PZ	Less efficient emotional memory/midline perception	Lack of flexibility of emotional memory/midline perception

TABLE 2 (continued)

O1 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) 01/O2	Less efficient visual sensations R/visual sensations L	Lack of flexibility of visual sensations R/visual sensations L
2) 01/FZ	Less efficient visual sensations R/midline motor actions	Lack of flexibility of visual sensations R/midline motor actions
3) 01/CZ	Less efficient visual sensations R/midline sensorimotor integration	Lack of flexibility of visual sensations R/midline sensorimotor integration
4) 01/PZ	Less efficient visual sensations R/midline perception	Lack of flexibility of visual sensations R/midline perception

O2 Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) O2/FZ	Less efficient visual sensations L/midline motor actions	Lack of flexibility of visual sensations L/midline motor actions
2) O2/CZ	Less efficient visual sensations L/midline sensorimotor integration	Lack of flexibility of visual sensations L/midline sensorimotor integration
3) O2/PZ	Less efficient visual sensations L/midline perception	Lack of flexibility of visual sensations L/midline perception

Midline Coherences

Coherence	Result of Hypocoherence	Result of Hypercoherence
1) FZ/CZ	Less efficient midline motor action/midline sensorimotor integration	Lack of flexibility of midline motor action/midline sensorimotor integration
2) FZ/PZ	Less efficient midline motor action/midline perception	Lack of flexibility of midline motor action/midline perception
3) CZ/PZ	Less efficient midline sensorimotor integration/midline perception	Lack of flexibility of midline sensorimotor integration/midline perception

UNDERLYING ASSUMPTIONS

A. The QEEG data bases (using the 10/20 system) represent a reasonable estimate of the optimal (normal) modular activity (amplitude) and connectivity (coherence).
B. The brain can learn to normalize the abnormalities with the use of neurofeedback.
C. Resolution of the abnormalities will result in remediation of the symptoms and normalization of brain functions.
D. Modules and connections not evaluated with available data bases are not likely to be detected on QEEG, nor to be improved by QEEG-based neurofeedback.

PATTERNS OF ABNORMALITIES ON QEEG

The six patterns so far delineated include:

1. Modular insufficiencies–Excessive slow activity or diminished fast activity in a module. The classical example is reduced verbal expression (fluency) with increased amplitudes of slow frequencies (delta, theta, alpha) in module F7 (Broca's area). Training to decrease slow frequencies at F7 would be associated with improvement in speech fluency. A second example: an increase in the amplitude of slow frequencies at FP1 is a common finding in attention deficit disorder (inattentive type). Training to decrease the amplitude of slow frequencies usually results in improved attention (Othmer & Othmer, 2005).
2. Diffuse insufficiencies–Excessive slow activity or diminished fast activity diffusely. This is seen with toxic encephalopathies, mental retardation, and severe (diffuse) head injuries. Normalizing these abnormalities results in improved cognitive functions.
3. Modular excesses–Excessive beta activity. For example, if there is an excess of beta activity at FP1, this is also likely to produce attentional difficulty, but of the hyper-focused or anxiety associated type rather than the inattentive type. A second example is tics, which are associated with excessive beta at C3 and C4. Training the beta down improves these problems.
4. Diffuse amplitude excesses–Excessive beta activity diffusely. This is seen in alcoholism and various anxiety disorders, including obsessive compulsive disorders. Training the beta down reduces anxiety, obsessive compulsive behavior, and craving for alcohol.
5. Disconnections–Decreased connectivity between two brain areas (modules). An example would be conduction aphasia, as elucidated by Geschwind (1965). The QEEG would show hypocoherence between F7 (Broca's area) and T5 (Wernicke's area). Training to increase coherence between those two modules would be expected to resolve the conduction aphasia. This kind of abnormality is commonly responsible for dyslexia, which is associated with one or more disconnections between left hemisphere language locations. Reading ability usually improves markedly with neurofeedback training to normalize coherence between these areas (Walker & Norman, 2006).
6. Hyperconnections–Increased connectivity between two brain areas (modules). The idea that hyperconnection between different areas could result in brain dysfunction is relatively new (Catani & ffythe, 2005). Rather than difficulty using two areas simultaneously, there is difficulty in getting and giving information from other brain areas. As a result, there is a decrease in flexibility and creativity secondary to less connection with other brain areas required to make varied approaches or responses. An example would be hyperconnection between FP1 (logical attention module) and F3 (motor planning module for the right upper extremity). This would result in inflexible or stereotyped responses to attentional stimuli (see Patient 3 below).

Table 3 lists other examples of disorders that have been successfully treated using this model, as well as disorders based on "off the map" modules.

TABLE 3. Quantitative EEG abnormalities and associated disorders.

Types of Abnormalities	Examples
Modular insufficiencies Excess slow (1-10 HZ) ± Insufficient beta (13-20 HZ)	ADD (FP1) Hyperactivity/Impulsivity (FP2) Expressive aphasia (F7) Receptive aphasia (T5)
Modular excesses Excess low beta (13-20 HZ) ± Excess high beta (21-30 HZ) ± Insufficient slow (1-10 HZ)	PTSD (T3, T4) Insomnia (FP2) Tics (C3,C4)
Diffuse or multifocal insufficiencies Excessive slow (1-10 HZ) ± Insufficient beta (13-20 HZ)	Mental retardation Toxic encephalopthies Severe (diffuse) head injuries
Diffuse or multifocal excesses Excess low beta ± Excess high beta	Alcoholism Anger control problems Neurogenic hypertension Anxiety Irritability
Disconnections (any frequency band)	Conduction aphasia (T5/F7) Most learning difficulties
Hyperconnections (any frequency band)	Neuroses Some learning difficulties Parkinsonism Decreased flexibility, creativity
Combinations of above	Autistic spectrum OCD Dyslexia Epilepsy Head injury Learning difficulties Memory disorders Strokes
"Off-the-map" abnormalities (not evaluated adequately by 10/20 reference data bases)	Some types of: Depression (FP02)*--decrease 2-7 Hz; increase 15-18Hz Fear states (FP02)—decrease 2-7 Hz, increase 8-12 Hz Reward deficiency syndrome, non-verbal aspects (FP02) Reward deficiency syndrome, cognitive aspects** Incontinence (I01, I02)***

* FPO2 (frontopolar/orbital) = right medial orbit just below eyebrow (Fisher, 2003) (Blum, et al 2005)
** FPO1 (frontopolar/orbital) = left medial orbit just below eyebrow
*** I01, I02 (inferior occipital left, right = below 01 and 02 (Hammond, 2005)

Note: This model predicts that individuals with the reward deficiency syndrome would be less sensitive to reward-based therapies, such as neurofeedback therapy. It suggests that more sessions of neurofeedback may be necessary to help these people with their addictions, which are largely determined by their insensitivity to reward (Blum et al., 2000). It also suggests that initial training to activate the reward module (decrease 2-7 Hz/ at FPO2 and FPO1) should make reward-based therapies, such as other neurofeedback protocols, more effective in ameliorating other problems in such patients (such as excessive high frequency beta). FPO1 and FPO2 beta training (decrease 2-7 Hz, increase 15-18 Hz) should also help with other addictions (drugs, food, sex, gambling, etc.) by sensitizing these individuals to cognitive (FPO1) and non-verbal (FPO2) reward, thereby reducing the amount of these rewards required to make them satisfied with the rewards into the normal range. QEEG would not be helpful in diagnosing reward deficiency syndrome, since the nucleus accumbens, where the abnormal dopamine receptors in these individuals is located, does not generate sufficient rhythmic activity to be detected with scalp electrodes. Still treatment with neurofeedback should be effective, since activity in the nucleus accumbens can be regulated by orbital frontal cortex (FPO1 and FPO2) (Kalivas, 2005).

This model also predicts that states of fear cannot be detected by QEEG, since these states are generated by amygdalar activity (LeDoux, 2003). Nevertheless, excessive amygdalar activity should be down-regulated by FPO1 alpha training for cognitive fears and FPO2 alpha training for non-verbal fears (including phobias).

METHODS

EEG's were recorded with a Cadwell® system (model Easy II) using standard recording techniques. QEEGs were evaluated with the Thatcher Neuroguide database®. Neurofeedback was done on Brainmaster® equipment (model 2.5 SE) using auto-thresholding.

Examples from Our Clinic

Patient #1 –15 y/o boy

Complaints: Difficulty concentrating, completing tasks

QEEG: Hypocoherence of theta F3/01 (Z = 3.16)

Hypocoherence of theta F3/02 (Z = 3.27)

Normal delta, theta, alpha, beta power

QEEG Abnormalities: Hypocoherence of theta F3/01

Hypocoherence of theta T3/02 (Z = 3.16)

QEEG/Clinical/ Correlations: Hypocoherence of theta F3/01. Disconnection between the right motor planning module and the right visual field processing module

Hypocoherence of theta F3/02. Disconnection between the right motor

planning module and the left visual field processing module

Normal delta, theta, alpha, and beta power–no modular or diffuse abnormalities

TOVA: Normal

Clinical Correlation: Not ADD. Visual/motor learning difficulty masquerading as ADD

Training: 5 sessions to increase coherence of theta F3/01

5 sessions to increase coherence of theta F3/02

Result: Marked improvement in school performance

Improved shooting ability when hunting

Batting average improved from .250 to .500

Discussion: This case represents a relatively simple disconnection syndrome involving the left motor planning module (F3) and both right and left visual processing areas (01 and 02). This disconnection resulted in a visual/motor learning difficulty and a performance difficulty. Both were rapidly remediated with neurofeedback. Visual/motor improvements resulted in better reading, better copying from the chalk board, improved accuracy in rifle shooting, and an improved batting average.

Patient #2–7 y/o boy

Complaints: Attentional problems, hyperactivity

QEEG: 1) Excessive absolute beta power T3 (Z = 3.33)

2) Excessive absolute beta power FP1 (Z = 2.52)

3) No excess delta, theta, or alpha power

4) Hypocoherence of beta at F4/C4 (Z = 3.01)

TOVA: First two quarters normal

Second two quarters no correct responses ("got tired and quit")

QEEG/Clinical Correlations: 1) Excess beta FP1 (attention module)–beta type ADD (hyperfocused, anxious)

2) Excess beta T3 (verbal memory module)–"hyper-

memory" (excess rumination)

3) Hypocoherence beta C4/F4–disconnection between sensorimotor interaction module for the left upper extremity and the motor planning module for the left hand, resulting in clumsiness of the left hand and performance errors

4) No excess of delta, theta, or alpha power–This implies the patient does not have classical ADD, which is associated with excess theta or alpha at FP1. Classical neurofeedback training to decrease theta and/or alpha probably would not have helped this child.

Training: 5 sessions to decrease beta power at FP1

5 sessions to decrease beta power at T3

5 sessions to increase coherence of theta C4/F4

Results: Doing well in school and at home

Discussion: This case represents a combination of problems. First is excess beta at FP1, an indicator of anxiety-associated attentional difficulty. The second is excess beta at T3, an indicatior of excess rumination. Third, there is a disconnection between the sensorimotor integration and motor planning areas for the left upper extremity, resulting in clumsiness and slowed reaction time with the left hand. Each problem was rapidly remediated with training to normalize each.

Patient #3–T.R., 10 y/o

Complaint: Dyslexia/ADHD, dysgraphia, Mathematics difficulty

QEEG: 1) Excess absolute alpha power C3 (Z = 3.35)

2) Excess absolute alpha power P4 (Z = 2.43)

3) Hypocoherence of delta T3/T5 (Z = 2.56)

4) Hypocoherence of beta O1//F3 (Z = 2.54)

5) Hypocoherence of alpha T4/T6 (Z = 3.11)

6) Hypercoherence of alpha FP2/F4 (Z = 2.32)

7) Hypercoherence of alpha FP1/F3 (Z = 3.23)

8) Hypercoherence of alpha O2/F4 (Z = 2.52)

9) Hypercoherence of theta FP2/F4 (Z = 2.63)

QEEG/Clinical Correlations: 1) Excess alpha at C3 (sensorimotor integration module for right upper extremity)–modular insufficiency, resulting in clumsy right hand, poor handwriting

2) Excess alpha at P4 (perceptual/cognitive processing module of the right hemisphere)–modular insufficiency, resulting in mathematics difficulty

3) Hypocoherence of delta at T3/T5 (disconnection between the verbal memory/phoneme recognition module and the verbal understanding/comprehension module)–resulting in difficulty with phoneme recognition and verbal memory (a left hemisphere auditory processing problem). This probably accounted for part of the child's difficulty reading.

4) Hypocoherence of beta at O1/F3 (right visual/right

motor upper extremity disconnection)–resulting in increased visual motor reaction time

5) Hypocoherence of alpha at T4/T6 (emotional memory/emotional understanding disconnection)–resulting in slow auditory/emotional processing, errors (right hemisphere auditory processing problem)

6) Hypercoherence of alpha at FP2/F4 (emotional attention/motor planning left upper extremity hyperconnection)– resulting in decreased flexibility and creativity in emotional attention/motor planning with left upper extremity

7) Hypercoherence of alpha at FP1/F3 (logical attention/ motor planning right upper extremity hyperconnection)– resulting in decreased flexibility and creativity in logical attention/motor planning with right upper extremity

8) Hypercoherence of alpha at O2/F4 (visual processing left visual field/motor planning left upper extremity hyperconnection)–resulting in decreased flexibility and creativity in visual/motor processing to the left

9) Hypercoherence of theta at FP2/F4 (emotional attention/motor planning right upper extremity hyperconnection)–resulting in decreased flexibility and creativity in emotional/motor processing

Training: 55 sessions:

1) Decrease alpha amplitude at C3 (10 sessions) to improve fine motor coordination with right hand and to improve handwriting

2) Decrease alpha amplitude at P4 (10 sessions) to improve visualization of mathematical problems and cognitive processing of them (reasoning)

3) Increase beta coherence at O1/F3 (5 sessions) to integrate visual processing of right visual information with motor planning for the right upper extremity and speed visual motor reaction times and reduce visual/motor errors

4) Increase alpha coherence at T4/T6 (5 sessions) to integrate emotional memory with emotional understanding and improve auditory processing and reading

5) Increase delta coherence at T3/T5 (5 sessions) to integrate verbal memory and phonological processing and improve auditory processing

6) Decrease alpha coherence FP2/F4 (5 sessions) to improve flexibility and creativity in coordinating emotional attention and motor activities of the left hand

7) Decrease alpha coherence at FP1/T3 (5 sessions) to improve flexibility and creativity in coordinating attention and verbal memory. This would be expected to improve reading.

8) Decrease alpha coherence O2/F4 (5 sessions) to improve flexibility and creativity in coordinating visual processing of right vi-

sual field information with motor planning for the left hand (for example, mimicking)

9) Decrease theta coherence FP2/F4 (5 sessions) to improve flexibility and creativity in coordinating emotional attention and judgment with motor planning for the left hand

Result: No improvement in reading ability with amplitude training alone

Reading at grade level after amplitude plus coherence training

Pre: reading at 1st grade level

Post: reading at 5th grade level (in 3 months)

Normally attentive

Not hyperactive or impulsive

CONCLUSION

A modular coherence model is presented, based on modern concepts of distributed networks and their role in cerebral dysfunctions. The model presented here has proven successful in using the QEEG to guide neurofeedback training in clients with static brain dysfunctions involving the cerebral cortex and the cortico-cortical connections. These include learning disabilities, residual problems from closed head injury, epilepsy, and autism.

The QEEG is less useful in guiding training in disorders with prominent subcortical pathology. These types of cases may respond better to empirical symptom-based protocols, such as those used by the Othmers (2005) for remediation of symptoms.

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RECEIVED: 03/21/06
REVISED: 08/23/06
ACCEPTED: 11/06/06

doi:10.1300/J184v11n01_03