History of Coherence Based Neurofeedback Training

Robert Coben, PhD., Neuropsychologist, Co-Director, Integrated Neuroscience Services

Presented on March 16, 2019


\[ \gamma_{xy}(f) = \frac{|G_{xy}(f)|^2}{G_x(f) G_y(f)} \]

Gxy(f) is the cross-spectral density between x and y and Gx(f) and Gy(f) are the autospectral density of x and y respectively.
Variation in amplitude and phase. Sometimes referred to as synchrony.

Similarity of amplitudes across time. Sometimes referred to as pure coherence as it is independent of phase and amplitudes.

\[ \tau_{xy}^2(f) = \frac{(G_{xy}(f))^2}{(G_{xx}(f)G_{yy}(f))} \]

Where: \( G_{xy}(f) \) = cross power spectral density and 
\( G_{xx}(f) \) and \( G_{yy}(f) \) = auto power spectral densities

The final normalized coherence value is given by Equation (2):

\[ \tau_{xy}^2(f) = \frac{r_{xy}^2 + q_{xy}^2}{G_{xx}G_{yy}} \]

Where: \( r_{xy} \) = real cospectrum and \( q_{xy} \) = imaginary quadrature 
\( G_{xx}(f) \) and \( G_{yy}(f) \) = as in Equation (1)

Phase: \( 159.1549 \tan^{-1}(r_{xy}/q_{xy})/\pi \)

Where: \( r \) and \( q \) = as in Eq. 2, \( fc \) = center frequency of fiber

\[
COHERENCE = \frac{|H_{xy}|^2}{|H_{xx}||H_{yy}|}
\]

\[
SPECTRALCORRELATION = \frac{\sum |x_i||y_i|^2}{\sum |x_i|^2 \sum |y_i|^2}
\]

\[
COMODULATION = \frac{\sum |x_i||y_i|^2}{\sum |x_i|^2 \sum |y_i|^2}
\]

\[
SIMILARITY_{[\alpha,\beta]} = \frac{2AB}{A^2+B^2}
\]

\[
PHASE = \arctan\left(\frac{b}{a}\right)
\]

Sometimes referred to as synchrony.

Similarity of the FFT spectra regardless of phase.

Similarity of amplitudes across time.

Variation in amplitude and phase. Sometimes referred to as synchrony.
Different approaches to neurofeedback have used all of these approaches. Coherence has received the most attention due to it’s pureness of measurement (not without it’s problems). Virtually every neurofeedback system allows you to do coherence training between pairs of sites, some do comodulation (EEGer etc.) and others synchrony.

Coherence training as a new form of Neurofeedback first began about 18 years ago. The originators included Joseph Horvat, Jonathan Walker and Kirt Thornton. All of them started these attempts with persons with closed head injuries. Horvat and Walker used coherence training and Thornton spectral correlation (even though it is called coherence on the Lexicor machine).
**Improvement/Rehabilitation of Memory Functioning with Neurotherapy/QEEG Biofeedback**

*Kirby Thornton, PhD  J Head Trauma Rehabil 2000;15(6):1-13*

![Graphs showing improvement in memory functioning](image)

**Impact of qEEG-Guided Coherence Training for Patients with a Mild Closed Head Injury**

Jonathan E. Walker, MD
Charles A. Norman, PhD
Ronald K. Weiser, PhD

*Journal of Neurotherapy, Vol. 6(2) 2002*

**TABLE 3. Electrode Placement for Coherence Scores**

<table>
<thead>
<tr>
<th>Intrahemispheric</th>
<th>Interhemispheric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fp1/F3</td>
<td>Fp1/Fp2</td>
</tr>
<tr>
<td>Fp2/F4</td>
<td>F3/F4</td>
</tr>
<tr>
<td>T3/T5</td>
<td>F7/F8</td>
</tr>
<tr>
<td>T4/T6</td>
<td>C3/C4</td>
</tr>
<tr>
<td>C4/P4</td>
<td>T5/T6</td>
</tr>
<tr>
<td>F3/O1</td>
<td>P3/P4</td>
</tr>
<tr>
<td>F4/O2</td>
<td>O1/O2</td>
</tr>
</tbody>
</table>

**TABLE 4. Mean and Range for Age, Time Since MHI, Number of Sessions and Global Improvement**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>38.6 ± 13.5</td>
<td>15-55</td>
<td></td>
</tr>
<tr>
<td>Time Since MHI (months)</td>
<td>12.7 ± 18.5</td>
<td>3-70</td>
<td></td>
</tr>
<tr>
<td>Number of Sessions</td>
<td>19.1 ± 9.7</td>
<td>5-40</td>
<td></td>
</tr>
<tr>
<td>Global Improvement</td>
<td>72.7 ± 27.6</td>
<td>0-100</td>
<td></td>
</tr>
</tbody>
</table>
Thornton’s work has focused on TBI and Reading Disability.

**Modular insufficiencies**
- Diffuse insufficiencies
- Modular excesses
- Diffuse excesses
- Disconnections
- Hyperconnections
Neurofeedback treatment of epilepsy
Jonathan E. Walker, MD, PhD
Gerald P. Kozlowski, PhD
Child Adolesc. Psychiatr Clin N Am

The Neurophyiology of Dyslexia:
A Selective Review with Implications
for Neurofeedback Remediation and Results
of Treatment in Twelve Consecutive Patients
Jonathan E. Walker, MD
Charles A. Neumeier, PhD
Journal of Neurotherapy, Vol. 10(1) 2006

Clinical EEG and Neuroscience
Power Spectral Frequency and Coherence Abnormalities in Patients
with Intractable Epilepsy and their Usefulness in Long-Term
Remediation of Seizures Using Neurofeedback
Jonathan E. Walker, MD
Published Online: 10.2008 - Research Article

Following our previous study in 2005, we report an additional 25 patients on treatment.
We also report an analysis of the frequency of QEEG abnormalities in this patient
group. All of the intractable epilepsy patients had one or more slow frequencies
(zeta or delta) compared with the normal database. One third had a relative deficiency
of beta power. One fourth had a deficiency of absolute delta. Eighteen percent had
excessive absolute alpha power. Fifteen percent had decreased absolute alpha power.
Fifteen percent had increased absolute beta power, and 16% percent had decreased absolute beta
power. Hypocoherence of theta was found in 70%, and decreases in alpha coherence
were noted in 40%. Hypocoherence of beta was found in 55%, and hypocoherence of
delta was found in 35%. Increases in alpha coherence were noted in 33%. Seventeen
percent had no coherence abnormalities.

When most of the power and coherence abnormalities were normalized with
neurofeedback training; all the patients became seizure-free, 75% no longer required
an anticonvulsant for seizure control.

Neurofeedback training of alpha-band coherence enhances motor
performance
Anaïs Montar, Marco Solé, Cécile Magnin, Tiffany Corbet, Armin Schneider, Adrian G. Guggerberg
Clinical Neurophysiology
Clinical Neurophysiology xx (2014) xxx–xxx

Fig. 2. Near-chron of delta-band coherence evolution during neurofeedback.
Training of 10 healthy subjects. Subjects stood to naturally enhance alpha-band
covenance by looking at their own hand and the use of the hands to
a single sensor. Subjects with right target are flipped left for visualization.
A: The target area is marked in red. B: The color indicates regions which global alpha
coherence decreased across the sessions. C: The coherence significant areas are
marked with blue contour lines. For interpretation of the references to color in this figure legend,
the reader is referred to the web version of this article.
The Effectiveness of Neurofeedback Training on EEG Coherence and Neuropsychological Functions in Children With Reading Disability

Mohammad Ali Nazari1, Elnaz Mozaffari1, Touraj Hashemi1, and Ali Jahan2,3
Clinical EEG and Neuroscience
14(4) 315-322
2012

Table 4. Z Scores: FFT Coherence for Pre- and Posttreatment

<table>
<thead>
<tr>
<th></th>
<th>Delay (1-4 Hz)</th>
<th>Total (4-8 Hz)</th>
<th>Beta (10-32 Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FoCo pre</td>
<td>FoCo post</td>
<td>FoCo post</td>
</tr>
<tr>
<td>Case 1</td>
<td>-2.31</td>
<td>0.18</td>
<td>2.30</td>
</tr>
<tr>
<td>Case 2</td>
<td>-1.40</td>
<td>-1.09</td>
<td>2.14</td>
</tr>
<tr>
<td>Case 3</td>
<td>-1.13</td>
<td>-0.14</td>
<td>2.03</td>
</tr>
<tr>
<td>Case 4</td>
<td>-3.08</td>
<td>5.77</td>
<td>5.11</td>
</tr>
<tr>
<td>Case 5</td>
<td>-4.15</td>
<td>-3.62</td>
<td>0.61</td>
</tr>
<tr>
<td>Case 6</td>
<td>-1.17</td>
<td>0.75</td>
<td>2.06</td>
</tr>
<tr>
<td>Mean</td>
<td>-1.95</td>
<td>0.92</td>
<td>2.30</td>
</tr>
</tbody>
</table>

Figure 3. Phonological awareness scores across baseline, treatment, 6-month, 12-month, and 18-month follow-up assessments conducted for all patients.

The Impact of Coherence Neurofeedback on Reading Delays in Learning Disabled Children: A Randomized Controlled Study

Robert Coppen1, Emma Kate Wright1, Scott L. Decker2, and Tina Morgan1
www.neuronregulation.org
doi:10.15540/vr 2.4.168

Table 2. Reading delay in years for the total sample, experimental (coherence) and control (resourced) groups.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
<th>95% Confidence Interval for Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading Delay</td>
<td>21</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.55</td>
<td>0.55</td>
<td>-0.55</td>
</tr>
<tr>
<td>Resourced</td>
<td>21</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.55</td>
<td>0.55</td>
<td>-0.55</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>0.00</td>
<td>0.00</td>
<td>-0.55</td>
<td>0.55</td>
<td>-0.55</td>
</tr>
</tbody>
</table>

Figure 2. Change in age equivalent reading scores by group.

Figure 3. Change in percentage reading delay by group.

FIGURE 2. Change in age equivalent reading scores by group.
Processing of Coherence Data
Assessment-Guided Neurofeedback for Autistic Spectrum Disorder

Robert Cohen, PhD
Team Paderbom, PhD
Journal of Neurotherapy, Vol. 11 (1) 2007

TABLE 2. Demographics of Neurofeedback Group

<table>
<thead>
<tr>
<th>Group</th>
<th>Age</th>
<th>Gender</th>
<th>Race</th>
<th>Residence</th>
<th>Number of Male</th>
<th>ATSC Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>25.0</td>
<td>M = 66</td>
<td>M = 66</td>
<td>M = 66</td>
<td>M = 66</td>
<td>M = 66</td>
</tr>
<tr>
<td>SD</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Range</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

TABLE 3. Demographics of Control Group

<table>
<thead>
<tr>
<th>Group</th>
<th>Age</th>
<th>Gender</th>
<th>Race</th>
<th>Residence</th>
<th>Number of Male</th>
<th>ATSC Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>25.0</td>
<td>M = 66</td>
<td>M = 66</td>
<td>M = 66</td>
<td>M = 66</td>
<td>M = 66</td>
</tr>
<tr>
<td>SD</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Range</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

TABLE 7. Percent Ratings for Neurofeedback Group

<table>
<thead>
<tr>
<th>Rating</th>
<th>Total ATEC</th>
<th>Pre-ATEC Total</th>
<th>Post-ATEC Total</th>
<th>Percent Change</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>75%</td>
<td>123.0</td>
<td>105.0</td>
<td>12.5</td>
<td>p &lt; .05</td>
</tr>
<tr>
<td>Fair</td>
<td>25%</td>
<td>30.0</td>
<td>22.5</td>
<td>12.5</td>
<td>p &lt; .05</td>
</tr>
</tbody>
</table>

TABLE 8. Neuropsychological Testing* for Neurofeedback Group

<table>
<thead>
<tr>
<th>Test</th>
<th>Pre-Attention</th>
<th>Post-Attention</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-VisuAl</td>
<td>Mean = 1.25</td>
<td>Mean = 1.20</td>
<td>p &lt; .05</td>
</tr>
<tr>
<td>Pre-Motor</td>
<td>Mean = 1.00</td>
<td>Mean = 0.95</td>
<td>p &lt; .05</td>
</tr>
<tr>
<td>Pre-Language</td>
<td>Mean = 1.00</td>
<td>Mean = 0.95</td>
<td>p &lt; .05</td>
</tr>
</tbody>
</table>

*Note: All neuropsychological testing consisted of composite scores for index of attention, visual perceptual, executive, and language domains.

The Relative Efficacy of Connectivity Guided and Symptom Based EEG Biofeedback for Autistic Disorders

Robert Cohen • Thomas E. Myers

Table 4. Percent change per session

<table>
<thead>
<tr>
<th>Session</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>r</th>
<th>df</th>
<th>Sig. (2 tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session 1</td>
<td>12</td>
<td>1.13</td>
<td>1.08</td>
<td>-3.05</td>
<td>22</td>
<td>0.005</td>
</tr>
<tr>
<td>Session 2</td>
<td>12</td>
<td>1.83</td>
<td>1.02</td>
<td>-3.05</td>
<td>22</td>
<td>0.005</td>
</tr>
<tr>
<td>Session 3</td>
<td>12</td>
<td>1.01</td>
<td>1.06</td>
<td>-3.05</td>
<td>22</td>
<td>0.005</td>
</tr>
<tr>
<td>Session 4</td>
<td>12</td>
<td>2.15</td>
<td>1.00</td>
<td>-3.05</td>
<td>22</td>
<td>0.005</td>
</tr>
<tr>
<td>Session 5</td>
<td>12</td>
<td>5.55</td>
<td>0.37</td>
<td>-3.05</td>
<td>22</td>
<td>0.005</td>
</tr>
<tr>
<td>Session 6</td>
<td>12</td>
<td>2.12</td>
<td>1.00</td>
<td>-3.05</td>
<td>22</td>
<td>0.005</td>
</tr>
<tr>
<td>Session 7</td>
<td>12</td>
<td>2.05</td>
<td>1.15</td>
<td>-3.05</td>
<td>22</td>
<td>0.005</td>
</tr>
<tr>
<td>Session 8</td>
<td>12</td>
<td>8.44</td>
<td>1.15</td>
<td>-3.05</td>
<td>22</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Percent Change Per Session Total ATEC Score

Percent Change in ATEC

Fig. 1. The amount of change in Total ATEC scores per session was significant in Cohen and Paderbom (2007) but not in the amount of change per session in Parent (2003).

Fig. 2. Percent Change in ATEC Scores Per Session

Fig. 3. The amount of change which occurred per session in Cohen and Paderbom (2007) was significantly greater than the amount of change which occurred per session in Parent (2003) for all subscores of the ATEC.
Efficacy of Connectivity Guided Neurofeedback on Language Functions and Intelligence in Autism

Robert Coben, Ph.D., N. Kyle Jamison, B.S., Nicholas Lofthouse, Ph.D., Aishwarya Balasubramaniyan, B.S., Elizabeth Hurt, Ph.D., & L. Eugene Arnold, M.D., M.Ed.

1NeuroRehabilitation & Neuropsychological Services, NY
2The Ohio State University Wexner Medical Center
3University of Illinois

Abstract

Due to the limitations of current Autism Spectrum Disorder (ASD) treatment (Tx) options and established evidence for its neurological basis, specifically neural connectivity abnormalities, we examined the efficacy of neurofeedback (NF) training as a Tx for language deficits in autism. We administered up to 20 sessions of quantitative electroencephalography-(QEEG) guided NF coherence training, targeting the brain’s language centers, to 18 children with autism. When compared to a waitlist control group of children with autism matched for age and IQ, significant improvements were found in measures of language, intelligence, and ratings of autistic behavioral symptoms. Pending further research, NF may be considered an effective Tx option to improve language functioning in those with autism.

Verbal IQ Change

![Verbal IQ Change Diagram](image-url)
Neurofeedback for social skills deficits in Autism Spectrum Disorders

Robert Coben, Ph.D.¹, Aishwarya Balasubramanivan, M.S.², Nicholas Lofthouse, Ph.D.², N. Kyle Jamison, B.S.², Elizabeth Hurt, Ph.D.², & L. Eugene Arnold, M.D., M.Ed.²
¹Integrated Neuroscience Services
²The Ohio State University Wexner Medical Center

Abstract

Due to the limitations of existing treatments for autism spectrum disorders (ASD) and strong evidence for neurological deficits in ASD, the complementary/alternative and neural connectivity-based intervention of neurofeedback (NF) was examined. QEEG coherence-based training targeting social skills deficits was administered to 25 children with ASD and compared to 25 randomized matched waitlist controls. Relative to the latter, the NF group had significant pre-post treatment improvements, with medium-large effect sizes in social skills, visual processing and overall behaviors. Significant EEG NF-related improvements were also shown in the neural substrates related to visual/facial/emotional processing.
Types of connectivity

- Structural connectivity
- Functional connectivity
- Effective connectivity
Comparing DTI to Coherence measurements
Review of the methods of determination of directed connectivity from multichannel data

Katarzyna J. Blinowska

Fig. 1. Comparison of bivariate and multivariate methods of estimation of directed connectivity. Top: simulation scheme (1) driving scheme (2) driven scheme (3), addition of each step while noise is added. Bottom: connectivity measures, in the left section on the right multivariate propagation from channel 1 to channel 5. The top row (SP) is shown as a function of frequency. In the bottom row, the time series are shown as a function of time step.
Using quantitative and analytic EEG methods in the understanding of connectivity in autism spectrum disorders: a theory of mixed over- and under-connectivity

Robert Cohen 1,2, Imran Mohammed Reazuddah 1,2 and Rex L. Conner 1

1 Department of Pediatrics, Children's Hospital, Boston, MA, USA
2 Department of Neurology, Boston Children's Hospital, Boston, MA, USA

Frontiers in Human Neuroscience
February 2014 | Volume 8 | Article 45 | 1
Comparing levels of connectivity

- Delta (1.0 - 4.0 Hz)
- Theta (4.0 - 8.0 Hz)
- Alpha (8.0 - 12.0 Hz)
- Beta (12.0 - 25.0 Hz)
Exemplar: Major Depression
Four Channel Multivariate Coherence Training: Development and Evidence in Support of a New Form of Neurofeedback

QPS: Averaging coherences

- A method of combining averaged psync values.
- 4 channels of EEG
- Each pair has a running psync calculation
- For each channel, the 3 pairs of psync values are computed, averaged and this is used as the output reward value
- If a raw channel is in artifact condition, the channel is not used in the averaging calculation

\[
\begin{align*}
A & = \frac{(AB + AC + AD)}{3} \\
B & = \frac{(BA + BC + BD)}{3} \\
C & = \frac{(CA + CB + CD)}{3} \\
D & = \frac{(DA + DB + DC)}{3} \\
QPS \ Ave & = \frac{(A + B + C + D)}{4}
\end{align*}
\]
QPS Average

- 3 modes:
  - Avg: average value (sum/samples)/number of samples
  - Dev: difference in the range of values
  - Mod: simultaneous combination of avg and dev

\[ \text{Avg} = \left( \sum_{i=1}^{n} v_i \right) / n \]

\[ n = \text{number of values NOT in artifact} \]
\[ v = \text{sync value} \]
\[ \text{Avg} = \text{average value result} \]
\[ \text{compute Avg like submode AVG} \]
\[ \text{answer} = \sqrt{\left( \sum_{i=1}^{n} (v_i - \text{Avg})^2 \right)} \]
Anecdotal evidence

- Obsessive-Compulsive Disorder
- Seizures
- Autism
- TBI
- Dyslexia
- Speech/Language
- Emotional regulation
- Depression
- Developmental trauma/PTSD

Efficacy Studies in Support of 4 channel MVCNF (N = 591)

<table>
<thead>
<tr>
<th>Population</th>
<th>Sample</th>
<th>Design</th>
<th>Findings 1</th>
<th>Findings 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Population</td>
<td>N = 174</td>
<td>MVCNF v 2 Ch CNF</td>
<td>MVCNF &gt; 2 Ch CNF</td>
<td>Enhanced coherence and reduced power</td>
</tr>
<tr>
<td>Traumatic Brain Injury</td>
<td>N = 20</td>
<td>Compared time since injury in 3 groups</td>
<td>Improvements in symptoms and NP testing</td>
<td>Changes associated with increases in coherence</td>
</tr>
<tr>
<td>Epilepsy</td>
<td>N = 52</td>
<td>MVCNF v 2 Ch CNF</td>
<td>MVCNF &gt; 2 Ch CNF</td>
<td>81% reduction in seizures</td>
</tr>
<tr>
<td>Learning Disabilities</td>
<td>N = 63</td>
<td>MVCNF v 2 ch CNF v resource room</td>
<td>MVCNF &gt; 2 Ch CNF &gt; RR</td>
<td>1.6 year increase in reading</td>
</tr>
<tr>
<td>Autism</td>
<td>N = 110</td>
<td>MVCNF v 2 Ch CNF</td>
<td>MVCNF &gt; 2 Ch CNF</td>
<td>98% success rate</td>
</tr>
<tr>
<td>Autism MND</td>
<td>N = 78</td>
<td>MVCNF v 2 Ch CNF v Bipolar</td>
<td>MVCNF &gt; 2 Ch CNF &gt; Bipolar</td>
<td>Mu suppression with coherence changes</td>
</tr>
<tr>
<td>Depression</td>
<td>N = 54</td>
<td>MVCNF Psychotherapy v WLC</td>
<td>MVCNF &gt; both groups</td>
<td>94% success rate, crossover and 2 yr f/u</td>
</tr>
<tr>
<td>Developmental Trauma</td>
<td>N = 40</td>
<td>MVCNF v. Psychotherapy</td>
<td>Exp &gt; controls on clinical ratings</td>
<td>Δ in power, sources and connectivity</td>
</tr>
</tbody>
</table>
Controlled Analysis of EEG Coherence and it’s impact on Learning Disabilities
Robert Coben, PhD
Co-Founder/Neuropsychologist, integrated neuroscience services, LLC
Presented at ISNR 2015, Denver, Colorado

Number above 1 month per session

The Use of Four Channel Multivariate coherence Training on Mild Traumatic Brain Injury:
A comparison of newly concussed and remotely concussed individuals
Presented at the 25th Annual ISNR Conference, September, 2017, Foxwoods, CT
Anne Stevens, Ph.D., Morgan Middlebrooks, BA
Integrated Neuroscience Services, Fayetteville, Arkansas
Relative efficacy of two different forms of Coherence Neurofeedback for Seizure Disorders
Morgan Middlebrooks, BA, Robert Cohen, PhD, Janease Traylor, MS

Comparing Bivariate and Multivariate Coherence Neurofeedback for Autism Spectrum Disorder
Robert Cohen, PhD and Morgan Middlebrooks, BA
Exploring the Impact of single channel, bivariate and multichannel coherence training on Mu suppression deficits in Autism Spectrum Disorders

Janease Traytor, MS and Robert Cohen, PhD

![Graph 1: Boxplot showing distribution of Mu suppression deficits across different conditions.]

- Bipolar
- Bivariate
- 4 ch mv

![Graph 2: Bar chart comparing Coherence values across different conditions.]

- 25%
- 50%
- 75%

![Graph 3: Bar chart comparing Mu Suppression values across different conditions.]

- 25%
- 35%
- 45%
Depression Two Years Post Four Channel Multivariate Coherence Neurofeedback Treatment

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**MVCNF for Developmental Trauma: Study Methodology**

- Subjects were assigned to one of two groups (N = 40). Age range 10 – 65.
- These included an experimental group that received the active treatment (four channel multivariate coherence neurofeedback (20), and an alternate treatment comparison group (N = 20) that received individual psychotherapy. All subjects had experienced significant developmental trauma.
- All subjects in the experimental groups received four channel multivariate coherence training over 12-15 sessions.
- Clinical ratings and therapist ratings (0-20) were derived at the completion of their treatment regimen.
- Client ratings were largely subjective and based on self-ratings only or parental ratings at the completion of training and during the process.
- Therapist ratings were performed at the completion of training and were based on objective test findings including neuropsychological, behavioral and qeeg findings that reflected change over time.
- We also tracked the presence of negative symptoms, their severity and resolution during the training/treatment periods.
- QEEG analysis of change included measures of power at the component level, dipole sources, spectral properties, and multiple measures of graph theory connectivity.
Graph Theory Connectivity Findings

### Paired Samples T-Test

<table>
<thead>
<tr>
<th></th>
<th>statistic</th>
<th>df</th>
<th>p</th>
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<tbody>
<tr>
<td>Clust Coeff 2</td>
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<td>0.419</td>
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<td>Clust Coeff 1</td>
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<td>Redius 2</td>
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Conclusions

◎ MVCNF leads to enhanced client and therapist ratings of outcome and to a greater degree than traditional psychotherapy.

◎ Client and therapist outcome ratings correlate but disagree with therapist ratings being higher (more accurate?).

◎ Mild, negative symptoms are possible but often can be resolved. These do not differ from psychotherapy and are often related to medication usage.

◎ Positive response to MVCNF in DT leads to decreases in delta, theta and beta activity over left temporal, precuneus (midline parietal), and right parietal brain regions. There were also increases in alpha and high beta over midline frontal (anterior cingulate) and right parietal-temporal regions.

◎ Positive responses are also seen with increases in multivariate connectivity, especially long range connectivity.
Using Effective Connectivity in Guiding NF: Study Methodology

- Subjects were assigned to one of three groups (N = 45). Age ranges 10 – 70.
- These included an effective connectivity (15), functional connectivity within group (15) and a functional connectivity between group (15) comparison. Group 1 and 2 were the same subjects (within groups) that received different interventions at different time points (FC always first).
- All subjects received four channel multivariate coherence training over 12-15 sessions.
- Clinical ratings and therapist ratings (0-20) were derived at the completion of their treatment regimen.
- Client ratings were largely subjective and based on self-ratings only or parental ratings at the completion of training and during the process.
- Therapist ratings were performed at the completion of training and were based on objective test findings including neuropsychological, behavioral and qeeg findings that reflected change over time.
- QEEG analysis of change included measures of power at the component level, dipole sources, spectral properties, and multiple measures of graph theory connectivity.

### ANOVA

<table>
<thead>
<tr>
<th>ANOVA</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
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<td>42</td>
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### Contrasts

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<tbody>
<tr>
<td>Fx Conn (witl) - Eff Conn</td>
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ANOVA

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<tr>
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Contrasts

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Statistical Analyses of Graph Theory Metrics (Connectivity)

Analysis of Variance

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<th>Cluster Coefficient</th>
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Correlation Matrix

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<th>Clinical Improvement</th>
<th>Therapist Outcome Measure</th>
<th>Diameter</th>
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<tbody>
<tr>
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<td>Pearson's r</td>
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<td>Therapist Outcome Measure</td>
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<td>p-value</td>
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</tbody>
</table>
Conclusions

◎ Measures of effective connectivity can be gleaned from QEEG data.
◎ Effective connectivity guided multivariate coherence training led to enhanced client and therapist ratings of outcome.
◎ Therapist ratings are consistently higher than clients and show more significant differences.
◎ Both ratings show an increased likelihood of greater outcomes (> 10) in the effective connectivity group.
◎ Positive NF outcomes in this group showed greater reductions of delta/theta, alpha and beta frequencies. These were commonly seen over bilateral posterior brain regions including temporal locations and midline frontal locations as well.
◎ Positive NF outcomes were associated with greater changes in multivariate connectivity. This is especially true for long range connectivity (diameter).
◎ Use of effective connectivity leads to changes in connectivity and is more likely to prevent negative connectivity changes.

What have we learned?

◎ Coherence training is a helpful form on neurofeedback for many different types of problems.
◎ Problems with connectivity-based problems (i.e., autism, ld, depression, trauma) appear to benefit the most.
◎ Four channel multivariate coherence training appears more potent that two channel coherence training for multiple problems.
◎ This can be used to help many different disorders and has a persistent effect.
◎ The method used to calculate coherence/connectivity has a large impact on the efficacy of such interventions.
◎ Measures of effective connectivity enhance the efficacy of four channel multivariate coherence training.
◎ So much more to learn......
Thank you.