Multivariate Coherence Training for Developmental Trauma

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WHAT IS DEVELOPMENTAL TRAUMA?

• The Complex Trauma Taskforce of the National Child Traumatic Stress Network [Van der Kolk, B. A. (2005) Developmental Trauma Disorder, Psychiatric Annals, 35(5): 401-40] coined the term “Developmental Trauma Disorder” because most of the maltreated children did not meet the criteria for PTSD.

• PTSD also cannot capture the multiplicity of physical, emotional, and sexual abuse.

• PTSD diagnosis does not also encompass the developmental effects, such as self endangering behaviors, self-hatred, self-blame, chronic feelings of ineffectiveness, and loss of body regulation in areas of sleep, food and self-care.

- Study of linkage between epidemiologic and neurobiological evidence of the effects of childhood trauma.
- Questions pertained to respondent’s first 18 years of life.
- Assessed 8 adverse childhood experiences: abuse (emotional, physical, or sexual); witnessing domestic violence; parental marital discord; growing up with mentally ill; substance abusing; or criminal household members.
Relationship of ACE Score to the Prevalence of Mental Health Disturbances and Somatic Health Disturbances

Panic Reactions
Depressed Affect
Anxiety
Hallucinations
Sleep Disturbances
Severe Obesity
Multiple Somatic Symptoms

Prevalence %

ACE Score

Mental Health Disturbances
Somatic Disturbances

0 1 2 3 ≥4
Relationship of ACE Score to the Prevalence of Substance Abuse and Sexuality

- Smoking
- Alcoholism
- Illicit Drug Use
- Injected Drug Use
- Early Intercourse
- Promiscuity (≥30 partners)
- Sexual Dissatisfaction

ACE Score:
- 0
- 1
- 2
- 3
- ≥4
Relationship of ACE Score to the Prevalence of Memory and Stress & Anger

- Memory Impairment
- High Level of Perceived Stress
- Difficulty Controlling Anger
- Risk of Intimate Partner Violence

ACE Score: 0, 1, 2, 3, ≥4
• Verbal abuse: higher grey matter volume (GMV) in auditory cortex and lower integrity of left arcuate fasciculus. Diminished arcuate fasciculus integrity associated with lower verbal IQ and comprehension.

• Witness domestic abuse: Lower grey matter density in right lingual gyrus and reduced thickness in portions of visual cortex. Witnessing domestic violence between 11-13 years of age had considerable effect on thickness and volume.

• Sexual abuse: Lower GMV in primary visual cortex and visual association cortices directly correlate with duration of exposure before age of 12 and associated with deficit in visual memory.
Plasticity of the limbic system was found to be altered.

Structural connectivity was lower for maltreated subjects in the left anterior cingulate (emotions), as well as the temporal pole, and medial frontal gyrus (social cognition and theory of mind).

In contrast structural connectivity was higher for maltreated subjects in areas such as precuneus and anterior insula, which are linked to self-awareness.
- Re-experiencing severity correlated positively with right anterior insula activity (involved in aspects of emotional states) and negatively with rostral anterior cingulate cortex activity (which can inhibit the amygdala).

- Re-experiencing correlated negatively with activation of right inferior frontal cortex (IFC), a region implicated in inhibition of movement and of emotional experience.

- Avoidance was negatively correlated with activation in three separate anterior cingulate cortex (ACC) clusters: left rostral ACC and SC, and bilateral dorsal ACC.

- Dissociation was negatively correlated with activity in left superior temporal cortex, as well as right anterior insula and right IFC.
Impact of Developmental Trauma on Brain Function and Connectivity
Armes & Coben (2017), presented at ISNR conf Foxwoods, Connecticut

53 adult subjects with DT were compared to 23 controls using 19 channel and high density 64 channel EEG.

- Left frontal subgyral white matter
- Left middle temporal gyrus white matter
- Right frontal paracentral white matter
- Right parietal precuneus
- Right middle occipital gyrus white matter
- Midline frontal, anterior cingulate
Eyes Closed: significant difference for path length (p < 0.038) and diameter (p < 0.011).

Eyes Open: significant difference for global efficiency (p < 0.01), path length (p < 0.002), radius (p < 0.009) and diameter (p < 0.002)

Abuse groups differ from controls on diameter (p < 0.04), but not from each other.
Novel EEG Analysis pipeline

- EEG data collection
- Independent Components Analysis
- Dipole Source Localization
- Multivariate Granger Causality
- Graph Theory Metrics
ICA/EEGLAB Scientists and Journals

- Journal of Neuroscience
- Methods
- Plos One
- Computational Intelligence and Neuroscience
- NeuroImage
- Computational Intelligence and Neuroscience
- Frontiers in Neuroscience
- Frontiers in Neural Circuits
- UCSD Swartz Center for Computational Neuroscience
- University of Oxford
- UCLA Semmel Neuroscience Institute
- MGH/Harvard Medical School
- Georgetown University Medical Center
- University of Michigan Neuroscience Department
EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis

Arnaud Delorme, Scott Makeig

Independent Component Analysis

\[ x = \text{scalp EEG} \]

\[ W = \text{unmixing matrix} \]

\[ u = \text{sources} \]

\[ W^*x = u \]

ICA

\[ x = W^{-1}*u \]

\[ W^{-1} (\text{scalp projections}) \]
Example: 25 year old woman with a history of emotional abuse as a child and adult. Presents with anxiety, panic, nightmares and dissociation.
Graph Theory Metrics

<table>
<thead>
<tr>
<th>Time Range</th>
<th>Freq Range</th>
<th>Clust Coeff</th>
<th>Path Length</th>
<th>Global Eff</th>
<th>Radius</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>281-352s</td>
<td>4-23Hz</td>
<td>0.031157467</td>
<td>37.27736431</td>
<td>0.044989651</td>
<td>39.41305</td>
<td>91.9196607</td>
</tr>
</tbody>
</table>
Graph Theory: Network Dynamics

Figure 1. Basic network attributes. (A) Brain networks can be described and analyzed as graphs comprising a collection of nodes (describing neurons/brain regions) and a collection of edges (describing structural connections or functional relationships). The arrangement of nodes and edges defines the topological organization of the network. (B) A path corresponds to a sequence of unique edges that are crossed when traveling between two nodes in the network. Low-degree nodes are nodes that have a relatively low number of edges; high-degree nodes (often referred to as hubs) are nodes that have a relatively high number of edges. (C) A module includes a subset of nodes of the network that show a relatively high level of within-module connectivity and a relatively low level of intermodule connectivity. ‘Provincial hubs’ are high-degree nodes that primarily connect to nodes in the same module. ‘Connector hubs’ are high-degree nodes that show a diverse connectivity profile by connecting to several different modules within the network.
Graph Elements

- Hubs: A node with links that exceeds average.
- Low vs High Degree Hubs.
- Provincial Hubs.
- Modules.
- Connector Hubs.
the structural brain network

graph

weighted graph

d strength $S_i$

e clustering-coefficient $C_i$

path length $L_i$

betweenness centrality $B_i$

Radius Diameter
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

\[
\begin{align*}
A &= (AB + AC + AD)/3 \\
B &= (BA + BC + BD)/3 \\
C &= (CA + CB + CD)/3 \\
D &= (DA + DB + DC)/3 \\
\text{QPS Ave} &= (A + B + C + D)/4
\end{align*}
\]
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 v 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>
</tbody>
</table>
Study Methodology

◎ Subjects were assigned to one of two groups (N = 40).
◎ 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.
Hypothesis

Individuals with developmental trauma will demonstrate greater clinical improvement of statistical significance through 4-channel multivariate coherence training compared to those in psychotherapy. We also theorize that multivariate connectivity metrics will significantly improve among the experimental group.
Statistical comparisons for demographics across groups

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th>Handedness</th>
<th>Medications</th>
</tr>
</thead>
<tbody>
<tr>
<td>F = 2.32</td>
<td>X² = 0.102</td>
<td>X² = 0.229</td>
<td>F = 0.928</td>
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<tr>
<td>p = 0.136</td>
<td>p = 0.749</td>
<td>p = 0.633</td>
<td>p = 0.341</td>
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</tbody>
</table>
## ANOVA

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>202</td>
<td>1</td>
<td>202.5</td>
<td>12.1</td>
<td>0.001</td>
</tr>
<tr>
<td>Residuals</td>
<td>636</td>
<td>38</td>
<td>16.7</td>
<td></td>
<td></td>
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</tbody>
</table>

![Box plot showing client improvement by group (MVCNF and Therapy).](image1)

![Histograms showing client improvement by group (MVCNF and Therapy).](image2)
ANOVA

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
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<tbody>
<tr>
<td>Group</td>
<td>578</td>
<td>1</td>
<td>577.6</td>
<td>45.1</td>
<td>&lt;.001</td>
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<tr>
<td>Residuals</td>
<td>486</td>
<td>38</td>
<td>12.8</td>
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### Chi-squared Tests

<table>
<thead>
<tr>
<th>Value</th>
<th>df</th>
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<tr>
<td>$\chi^2$</td>
<td>0.125</td>
<td>1</td>
</tr>
<tr>
<td>N</td>
<td>40</td>
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### ANOVA

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>p</th>
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</thead>
<tbody>
<tr>
<td>Group</td>
<td>0.0</td>
<td>1</td>
<td>0.00</td>
<td>1.00</td>
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<tr>
<td>Residuals</td>
<td>25.9</td>
<td>38</td>
<td>0.682</td>
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</table>

### Contingency Tables

#### Contingency Tables

<table>
<thead>
<tr>
<th>Neg Sx Resolve</th>
<th>MVCNF</th>
<th>Therapy</th>
<th>Total</th>
</tr>
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<tbody>
<tr>
<td>no</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>yes</td>
<td>19</td>
<td>18</td>
<td>37</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>20</td>
<td>40</td>
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</table>

### Chi-squared Tests

<table>
<thead>
<tr>
<th>Value</th>
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<tbody>
<tr>
<td>$\chi^2$</td>
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</tr>
<tr>
<td>N</td>
<td>40</td>
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## Graph Theory Connectivity Findings

### Paired Samples T-Test

<table>
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<tr>
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<th></th>
<th></th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clust Coeff 2</td>
<td>Clust Coeff 1</td>
<td>Student's t</td>
<td>0.827</td>
<td>19.0</td>
</tr>
<tr>
<td>Path Length 2</td>
<td>Path Length 1</td>
<td>Student's t</td>
<td>-3.231</td>
<td>19.0</td>
</tr>
<tr>
<td>Global Eff 2</td>
<td>Global Eff 1</td>
<td>Student's t</td>
<td>2.470</td>
<td>19.0</td>
</tr>
<tr>
<td>Radius 2</td>
<td>Radius 1</td>
<td>Student's t</td>
<td>-2.472</td>
<td>19.0</td>
</tr>
<tr>
<td>Diameter 2</td>
<td>Diameter 1</td>
<td>Student's t</td>
<td>-3.618</td>
<td>19.0</td>
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</table>
### Correlation Matrix

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Meds</th>
<th>Client Improve</th>
<th>Therapy Outcome Measure</th>
<th>Neg Sx Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
<td>0.137</td>
<td>0.061</td>
<td>-0.044</td>
</tr>
<tr>
<td></td>
<td><strong>r</strong></td>
<td></td>
<td>0.061</td>
<td>0.262</td>
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<tr>
<td></td>
<td><strong>p-value</strong></td>
<td>0.400</td>
<td>0.710</td>
<td>0.102</td>
<td>0.786</td>
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<tr>
<td><strong>Meds</strong></td>
<td></td>
<td></td>
<td>-0.229</td>
<td>-0.122</td>
<td>0.569</td>
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<tr>
<td></td>
<td><strong>r</strong></td>
<td></td>
<td>-0.229</td>
<td>-0.122</td>
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<tr>
<td></td>
<td><strong>p-value</strong></td>
<td>0.156</td>
<td>0.452</td>
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<td>0.569</td>
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<tr>
<td><strong>Client Improve</strong></td>
<td></td>
<td></td>
<td>0.699</td>
<td>-0.437</td>
<td>0.005</td>
</tr>
<tr>
<td></td>
<td><strong>r</strong></td>
<td></td>
<td>0.699</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>p-value</strong></td>
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<td></td>
<td>0.699</td>
<td>0.005</td>
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<tr>
<td><strong>Therapy Outcome Measure</strong></td>
<td></td>
<td></td>
<td>-0.337</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>r</strong></td>
<td></td>
<td>-0.337</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>p-value</strong></td>
<td></td>
<td></td>
<td>-0.337</td>
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<tr>
<td><strong>Neg Sx Severity</strong></td>
<td></td>
<td></td>
<td>0.034</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>r</strong></td>
<td></td>
<td>0.034</td>
<td></td>
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</tr>
<tr>
<td></td>
<td><strong>p-value</strong></td>
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<td></td>
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<tr>
<td>Predictor</td>
<td>Estimate</td>
<td>SE</td>
<td>t</td>
<td>p</td>
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</tr>
<tr>
<td>---------------------</td>
<td>----------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td></td>
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<tr>
<td>Intercept</td>
<td>0.142</td>
<td>0.1299</td>
<td>1.097</td>
<td>0.280</td>
<td></td>
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<tr>
<td>Meds</td>
<td>0.362</td>
<td>0.0845</td>
<td>4.280</td>
<td>&lt; .001</td>
<td></td>
</tr>
<tr>
<td>Group:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Therapy – MVCNF</td>
<td>0.145</td>
<td>0.2190</td>
<td>0.661</td>
<td>0.513</td>
<td></td>
</tr>
</tbody>
</table>
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.
Thanks to our team:

Carl Armes, BS
Melchizedek Ghandour, BS
Tarik Bel-Bahar, PhD