Autism: Mirroring, Neurofeedback, and Empathy

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Outline of Talk

1. Autism and the mirror neuron theory
2. Mu rhythms and mirror neuron activity
3. Empathy and mu rhythms
4. Mu rhythm neurofeedback as neurological rehabilitation in autism
Autism Spectrum Disorders (ASD)

Problems in:
- Social ability
- Language development
- Behavior
Common Characteristics of Social Dysfunctions

– Impairment in social play and imagination
– Difficulty interpreting actions and intentions of others
– Inability to participate in a reciprocal conversation
– Language delays
– Impaired joint/sustained attention
– Trouble imitating others
– Absence of empathy
Mirror Neurons

• A class of neurons that discharge when the monkey performs an action and when it observes a similar action done by another agent

  – **Found in:**
    • area F5 (homolog of Broca’s area)
    • inferior parietal cortex (PF/PFG/7b)

  – **Activated by:**
    • Goal directed actions (reaching, grasping, holding)
    • Observation of similar actions performed by “biological” agents

*Di Pellegrino et al., Exp. Brain Res., 1992, 91, 176-80*
Mirror Neuron Activity

Perception-to-Action Mapping Selectivity

<table>
<thead>
<tr>
<th>Perception</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congruent</td>
<td>Logically-Related</td>
</tr>
<tr>
<td>(effector dependent; Kinematics of movement)</td>
<td>(effector independent; 2X; Goal of movement)</td>
</tr>
</tbody>
</table>
The Mirror Neuron Theory of Autism

- Autism as deficits in imitation learning (Rogers and Pennington, 1991)
- MNS as the neural basis for imitation learning (Iacoboni et al., 1999)
- Dysfunctions in MNS may help explain social dysfunctions in autism (Williams et al., 2001)

“*If mirror neurons support the ability to imitate others and to understand the goal behind their actions, the disruption of this system might also impair the later development of the ability to understand the state of mind of other individuals.*”

(Iacoboni and Dapretto, 2006; Meltzoff and Decety, 2003; Oberman and Ramachandran, 2007; Rizzolatti et al., 2009)
Activation for Imitation of Facial Emotions

Dapretto et al., Nat Neurosci., 2006
Mu Rhythms and Mirror Neuron Activity

- Mu rhythms reflect activity in sensorimotor cortex that is modulated by MNS (Altschuler et al., 2000)
- Sensorimotor simulation of observed actions are reflected in mu rhythm activity (Pineda, 2005)
Characteristics of the Human Mu Rhythm

- Maximal over sensorimotor areas
- Attenuated or blocked by movement
- Not affected by opening/closing the eyes
- Not affected by auditory/visual stimulation in the absence of movement

The Mirror Neuron System

Normal Oscillations at rest

MNS Activity --> Suppression

Iacoboni and Dapretto, Nature Reviews, 2006, 7:942-951
Are Mu Rhythms Affected by Actions and the Observation of Actions?

Baseline

Move

Observe

Imagine

Do ASD Children Have A Dysfunctional MNS?

RATIONALE

• If mu rhythms reflect MNS activity then ASD individuals should show differences in mu rhythms compared to typically-developing controls

Experimental Paradigm

• Measured mu power (2 min of EEG) in children (7-17 yrs):
  – Typically developing (n=12)
  – High functioning ASD (n=10)

• Conditions
  – Self-movement of hand
  – Watching video of someone moving their hand
  – Watching a video of balls moving up and down
ASD Children Exhibit an Absence of Mu Suppression to Observation of Actions

![Graph showing data comparison between Controls and Autistic Spectrum Disorders.](image-url)
Is the Mirror Broken and Unfixable?

Oberman et al., Neuropsychologia, 2008
Do MNS Areas Modulate Mu Rhythms?

**RATIONALE**

If mirror neurons in IFG are involved in the direct modulation of sensorimotor mu rhythms, then temporary inhibition of these neurons should prevent suppression of mu rhythms and cause “autistic-like” behaviors.

*Keuken et al., Brain Research, 2011*
Method: Transcranial Magnetic Stimulation

Measured EEG in typically developing adults (n=8) before and after IFG stimulation

- Observation of movement (4 videos)
  - Simple (hand movements) and complex (social interactions)
- Baron-Cohen’s Eyes Task
  - Emotion and gender discrimination

- 1 Hz rTMS (5 min at ~ 40-50% absolute threshold) targeted at left IFG
IFG Inhibition Results in an Absence of Mu Suppression During Observation of Actions
IFG Inhibition Reduces Behavioral Performance in an Emotion Recognition Task
Empathy and Mu Rhythms

Simulation theories argue that during the processing of emotional faces observers activate sensorimotor representations involved in creating their own emotional facial expressions in order to recognize the emotions and infer the feelings and intentions of others (Adolphs, 2003; Goldman and Sripada, 2005).
Do mu rhythms reflect sensorimotor simulation of facial expressions during empathy?

- N=22 undergraduate students at UCSD (11 males/females)
- 4 blocks of faces (happy and disgusted) in two conditions (empathy/non-empathy) and 2 blocks of buildings
  - 40 unique photos for each emotion (both genders; 3 ethnicities) presented pseudorandomly
  - Empathy: “try to share the emotions felt and expressed by the photographed people”
  - Positive and Negative Affect Scale-Expanded (PANAS-X) filled out after each empathy condition
  - Non-empathy: “rate how attractive the photographed face is”
Experimental Paradigm: Timing of Individual Trials

Figure 1 –

Timing of Individual Trials. (stimuli were presented for 2000 ms)

- fixation
- face or
- blank
- fixation
- prompt &
- visual
  - cross
  - building
  - screen
  - cross
  - response
  - noise

How well did you...

Time (ms):

0  1500  3500  5500  6500  9500  13000
Methods

- 32 channels of EEG (linked mastoid)
- Bandpass: 0.05-30 Hz; 500 Hz sampling rate
- Data were FIR filtered (4-30 Hz)
- A three-stage second-order blind identification (SOBI) algorithm applied
  - Remove EOG components
  - Remove EMG components in brain activity
  - Identify mu rhythm components
Left Hemisphere Mu Component Clusters

3. A
Left Hemisphere Mu Independent Components

Mean of the left mu cluster (n=16)

3. B
Mean of 16 left mu dipole source locations

3. C
Left mu power spectra by condition

- Nonempathy Disgust
- Nonempathy Happy
- Empathy Disgust
- Empathy Happy

Frequency (Hz)
Right Hemisphere Mu Component Clusters

4. A

Mean of the right mu cluster (n=17)

4. B

Mean of 17 right mu dipole source locations

4. C

Right mu power spectra by condition

Frequency (Hz)
Spectral Analysis

- Event-related spectral perturbations computed using wavelet decomposition with Morlet tapers
- A 2 (empathy/non-empathy) x 2 (happy/disgusted) repeated measures ANOVA
ERD present at 500 ms post stimulus to both emotions regardless of empathy
ERSP Results

Main effect of Emotional Facial Expression, right hemisphere mu ERSP power

Significant Differences by Emotional Facial Expression, right hemisphere mu ERSP
Neurofeedback as Neurological Rehabilitation

- Based on operant conditioning (learning)
- Noninvasive
- Positive treatment outcomes obtained rapidly
- Few known adverse side effects
- Outcomes maintained long after treatment ends
- Principled reason or theoretical underpinning to why it would work
Application of EEG Neurofeedback

- ADHD
- Substance abuse
- Anxiety
- Depression
- Epilepsy
- OCD
- Learning disabilities
- Migraines
- Pain
- Cognitive impairments
- Sleep dysregulation
Neurofeedback and Autism

Frontal - parietal areas may be underconnected

If we change the dynamics of the sensorimotor *mu* oscillations,

And these oscillations are functionally linked to the MNS network (IFG, IPL, STS),

Then we may affect functional connectivity via neuroplastic changes and recover MNS engagement

This can lead to positive changes.
BCI System

Multichannel Data Acquisition

Feature Extraction

Pattern Recognition

Mapping to Keyboard Commands

Interface Technology

User

Application
Mu Rhythm-based Neurological Rehabilitation

- Amplitude Training at C4
  - 30 min x 3/week x 10/20 weeks
  - HF ASD: 7-17 yr olds, n=27

- Experimental/Control groups
  - Mu activity above threshold (E)
  - EMG activity below threshold (E/C)

Pineda et al., Research in ASD, 2008
Pre/Post Assessments

• Verification of diagnosis (IQ, ADI, ADOS)
• Quantitative EEG
• Test of Variable Attention (TOVA)
• Imitation ability (Apraxia imitation)
• Mu suppression index (MSI)
• Autism Treatment Evaluation Checklist
• Neuroimaging (fMRI, fcMRI, DTI, MRS)
TD and ASD Groups Learn to Control Mu Rhythms

$R^2 = 0.76725$

$R^2 = 0.7068$
Global Changes in Amplitude and Coherence

**Experimental Group**

**Placebo Group**

**Experimental Group**

**Placebo Group**
ASD Group Shows Recovery of Mu Suppression following Training
ASD Group Shows Positive Changes in Sustained Attention
ASD Groups Shows Positive Changes in Parental Assessment

Changes in ATEC scores

Autism Treatment Evaluation Checklist

% CHANGE

Speech/Lang Communication
Sociability
Health/Physical Behavior
Total Score

Experimental
Placebo
Conclusions

1. Findings support the mirror neuron theory of autism
2. EEG mu rhythms reflect mirror neuron activity
3. Aspects of empathy can be measured by changes in mu rhythms
4. Neurofeedback centered on mu rhythms has positive effects on symptoms of autism
Collaborators

- Vilayanur Ramachandran
- Lindsay Oberman
- Eric Altschuler
- Andrey Vankov
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