Detection of Brain-to-Brain Synchrony for Improved Psychotherapy

Michael Dib, Akash Gami, Idrisa Rahman, and Leah Ross

Faculty & Capstone Advisor: Professor Yang Tao, Fischell Department of Bioengineering, University of Maryland

Clinical Mentor: Dr. Zhi-De Deng, National Institute of Mental Health, NIH

Clinical Mentor: Dr. Marc Lener, Psychiatrist, Chief Executive Officer, Singula Institute

Motivation

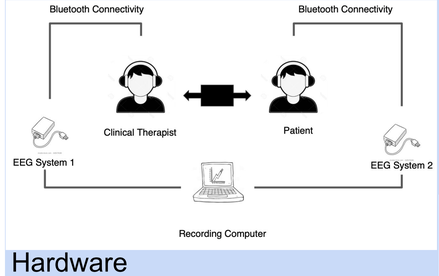
Current methods to treat mental disorders involve cognitive behavioral therapy (CBT). However, CBT provides no method to determine or measure the therapeutic alliance between the clinician and patient. The therapeutic alliance develops as a result of interpersonal synchrony, which is defined as inter-brain coupling.

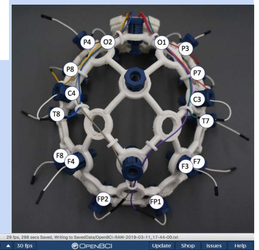
Currently, the most advanced technology for standard protocol during clinician-patient interaction is simply a voice recorder. Devices and methods involving EEG are used almost exclusively for scientific research. The implementation of EEG into psychiatry and other mental health-related fields has limitless potential in improving the efficacy of clinician-patient interactions. Using and analyzing EEG data from therapy sessions would provide the therapist more insight as to the best treatment method for the patient.

Objective

- The device will detect EEG signals between a patient and clinician and utilize hyperscanning to determine signal coherence of neural activity to detect spatial and temporal brain-to-brain synchrony.
- The device will display signal coherence results on a recording computer to allow the clinician to adjust their therapy.
- The device will archive the recorded data to serve as a reference to measure the effectiveness of therapy sessions.

Design Concept



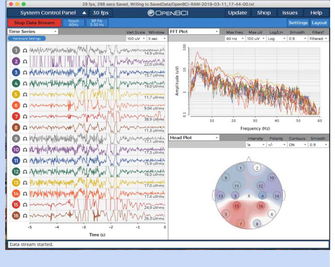


Hardware

- OpenBCI Ultracortex “Mark IV” EEG Headset
- 3D Printed Parts
  - Frame
  - Board Mount
  - Board Cover
  - Mechanical Inserts
  - Wire clips
- 16 EEG-sensing electrodes
- 16-channel biosensing boards
  - Cyton Board (8-channel)
  - Daisy Board (8-channel)

Software

- Data Collection: OpenBCI GUI
  - 16-channel EEG data text file
- Filtering Data
  - MATLAB → EEGLAB toolbox
- Data Analysis:
  - MATLAB



Testing and Results

$$\mathrm{PLV}_{j,k,t} = N^{-1}\left|\sum_{N} e^{i[\Phi j(f,t)-\Phi k(f,t)]}\right|$$

Phase Locking Value

- At a given time and frequency, calculates the absolute value of the sum of the phase difference (φ) differences of two electrodes (j, k) from two individuals of a dyad across N epochs

Synchrony Task:
Two persons keep each of their index fingers pointed outwards at the index fingers of the other in a face-to-face setting. There is a leader (Subject 1) and a follower (Subject 2).
Minute 1: Subject 1 moves his or her index finger within a 20cm by 20cm square. Subject 2 watches and keeps his or her eyes fixed on the movements of the leader.
Minute 2: Subject 1 continues to move his or her index finger within a 20cm by 20cm square. Subject 2 mirrors the movements of Subject 1.
Minutes 3 and 5 are performed as Minute 1. Minute 4 is performed as Minute 2.

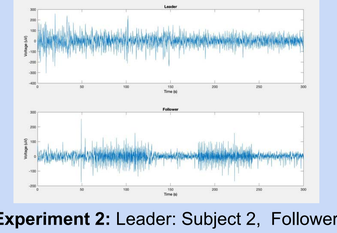
Data Analysis:
EEGLAB:

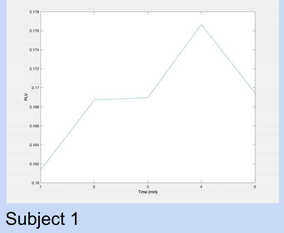
1. Select Data to be Sampled
   a. Define time frame and/or remove time
2. Reduce Noise and Artifacts of EEG Signal
   a. 0.5 to 60 Hz
3. Define channel brain locations
4. Run Independent Component Analysis (ICA)
5. Verify real EEG data, reject fake EEG data/noise
6. Perform PLV calculation on MATLAB
   a. 5 frequency bands
      i. Delta: 1-4 Hz
      ii. Theta: 4-8 Hz
      iii. Alpha: 8-12 Hz
      iv. Beta: 12-30 Hz
      v. Gamma: 30-40 Hz
   b. 2 second windows
   c. Average interbrain PLV each frequency band

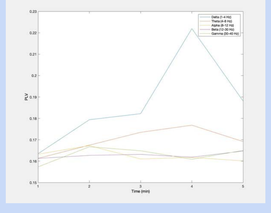
Testing Environment:
Location:

- Experiment data was collected in an isolated classroom that presented minimal outside distractions
  - Walls of the room were completely white
  - Windows and all transparent surfaces were covered
  - Test were performed at a time of low activity to simulate a soundproof domain
- Observer and time keeper were not in the main or peripheral line of vision of the two subjects
- The two subjects were facing one another over the durations of the synchtonky task

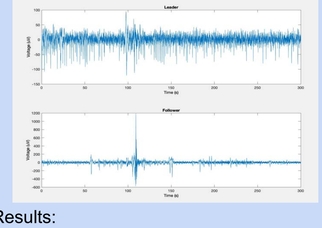
Experiment 1: Leader: Subject 1, Follower: Subject 2

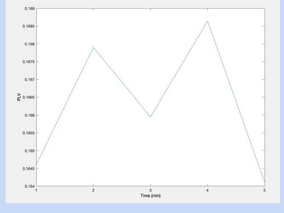


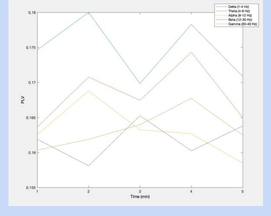




Experiment 2: Leader: Subject 2, Follower: Subject 1







Results:

- Highest PLV when Subject 2 is mirroring Subject 1.
  - PLV for Minutes 2 and 4 are higher than Minutes 1, 3, and 5
- PLV tends to increase over time as both subjects become in sync
  - Trend upward from Minute 1 to Minute 3 to Minute 5

Conclusions and Implications

- Phase locking value increases after interaction, showing that over many psychotherapy sessions, synchrony between patient and clinician should increase
- Increased synchrony helps to develop and improve therapeutic alliance, thus improving efficacy of psychotherapy treatments over time
- Potential for further use to understand underlying neural networks involved in cognition, emotion processing, and human interaction
- Potential for this device to be used as a tool for standard of care for psychotherapy patients
- Allows clinicians to deeply understand emotional and behavioral triggers to develop more effective treatment methods
- Potential for debunking stereotypes surrounding mental illness by providing quantitative data supporting CBT
- Moves beyond single brain analysis to study collective brain processes between two individuals

Potential for use in other applications:

- Relationship counseling
- Speed dating
- Group decision making

Ethical Implications:

- Expectation gap: BCI devices are expected to be more effective
- BCI technology is still limited by noise, movement, etc., lots of potential for growth

Future Works

- Emotional Video
  - Extend the research into evaluating brain synchrony between two subjects watching an emotional video.
- Automatic Data Analysis
  - Develop a Matlab program which will allow for automatic data analysis.
  - “Two Click” Approach - Therapist selects 2 data files and PLV value is displayed
- Real time feedback analysis
  - Immediate adjustment of psychotherapeutic procedure with the guide of a qualitative display for clinical progress.
  - Current limitations
    - Available technology
    - Processing/Computational speeds (MATLAB ICA)
- Multimodal Signal Analysis
  - Incorporate other phenotypic and physiological analysis modes to collect data such as EMG, EKG, voice analysis or facial learning to give more information on other dynamic detections of coherence.
- EEG headset remodeling
  - Improve comfort level of EEG headset to reflect a more natural conversation.

References

1. Gaudiano, B. A. (2005). Cognitive-behavioral therapies: Achievements and Challenges. *Evidence-Based Mental Health, 11(1),* 5.
2. Hari, R., Himberg, T., Nummenmaa, L., Hämäläinen, M., & Parkkonen, L. (2013). Synchrony of brains and bodies during implicit interpersonal interaction. *Trends in Cognitive Sciences,17*(3), 105-106. doi:10.1016/j.tics.2013.01.003
3. Hasson, U., Ghanzafar, A. A., Galantucci, B., Garrod, S., and Keysers, C. (2012). Brain-to-brain coupling: a mechanism for creating and sharing a social world. *Trends in cognitive sciences, 16*(2), 114-121.
4. Lachaux, J.P., Rodriguez, E., Martinerie, J., Varela, F.J. (1999). Measuring phase synchrony in brain signals. Human Brain Mapping, 8, 194–208.
5. Mu, Y., Han, S., & Gelfand, M. J. (2017). The role of gamma interbrain synchrony in social coordination when humans face territorial threats. *Social cognitive and affective neuroscience*, *12*(10), 1614-1623.
6. Pietrzak, T., Lohr, C., Jahn, B., & Hauke, G. (2018). Embodied Cognition and the Direct Induction of Affect as a Compliment to Cognitive Behavioural Therapy. *Behavioral Sciences*, *8*(3), 29.