Using Phase Shifting and Granger Causality to Measure Effective Connectivity in EEG Recordings

William J. Marshallǂ, Christine L. Lackner*, Paul Marriottǂ, Diane L. Santesso* & Sidney J. Segalowitz*

ǂDepartment of Statistics and Actuarial Science, University of Waterloo, Waterloo, Ontario, Canada
*Department of Psychology, Brock University, St. Catharines, Ontario, Canada

BACKGROUND

Information transmission in the cortex is carried out by neural assemblies – transient dynamic groups of functionally connected neurons. Their firing patterns are characterized by synchronous phase relationships, which form the basis for measuring functional connectivity [1] or coherence. However, EEG coherence lacks the temporal resolution required to divide the relationship into periods of synchrony (or “locking”) and desynchrony (or “shifting”), which has been shown to provide important information [2,3]. It is also unable to specify the direction of information transmission.

Phase patterns at a single site can also be characterized as “locked” or “shifting” across time. We present here a new method to capture how phase shift events at one site influence those at another, called Phase Shift Granger Causality (PSGC).

DATA

EEG Recording:
- 18 participants [9 Female, 9 Male; Age = 13.0 ± 1 year]
- Continuous EEG collected using 121 EEG channels at a rate of 500 Hz, analog filtering set at 0.1-100 Hz, referenced to vertex
- Offline 1-30 Hz band-pass filtered, re-referenced to common average and corrected for eye movements using the Gratton and Goles procedure
- Participants completed a resting period and two vigilance tasks:
  - A two-channel auditory oddball task
  - A visual Erikson Flanker task

REFERENCES


GROUP RESULTS

In the resting condition (A), most of the connections are short range (neighbouring sites) and bidirectional. In contrast, both the auditory (B) and visual (C) tasks show more long range and directed connections. The connections in the active tasks are predominantly anterior-posterior, connecting the prefrontal sites to the parietal sites, instead of lateral-medial.

PHASE SHIFT GRANGER CAUSALITY

- Instantaneous phase is calculated using the Complex Demodulation algorithm; here we have concentrated on the 8-10Hz band (middle panel)
- Although many shifts are obvious, it is often difficult to classify whether a feature is a legitimate shift or just noise. Shifts are defined as changes greater than some threshold (bottom panel).
- The choice of threshold is done visually and depends on signal properties (sampling rate and filters applied), but does not change from person to person.
- A multivariate Poisson process with conditional intensity function is used to model the phase shift events.
- Granger causality asks the question: Can the past pattern of one signal improve the prediction of another signal?
- The hypothesis of Granger causality between signals is tested using a likelihood ratio test.

INDIVIDUAL RESULTS

To examine the reliability of this pattern further, we constructed for each participant a metric reflecting the extent to which the resting condition was associated with more short connections and the active tasks more long connections. Each hemisphere of every participant followed this general classification (range = 6.5 to 23.5, with any value above zero indicating this general pattern), indicating an extremely high reliability of the pattern.

CONCLUSIONS

- By applying Granger causality, a directed measure of connectivity is produced using phase shift events.
- It takes advantage of the full temporal resolution of EEG recordings because there is no need to average over segments.
- The number of significant short connections during the resting state exceeds those during the vigilance tasks, but of more importance, the longer distance connections dramatically increase in number during the vigilance tasks.
- Increases in the number of long range connections are seen across development, and so our method of quantifying the number of short and long range connections may have unique developmental applications.