Cross-Cortical Communication in Healthy Human Aging: A Mutual Information Analysis of EEG

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Background

Communication across the cortex of the brain is the basis for its processing of information. The standard measure of this cross-cortical communication in human EEG signals is coherence: the correlation of the EEG in the frequency domain over time. Despite obvious changes in EEG due to human aging, there are not clear changes in EEG coherence. This is possibly because coherence reflects only linear relations between sites, and communication patterns need not reflect such a simple relation. A potential solution is the application of Mutual Information (MI) Analysis, a nonlinear measure of cross-cortical communication in the time domain.

Mutual Information is a measurement of the statistical dependence of two time series, based on the conditional entropy of one series given knowledge of another. Because it only uses the probability distributions in the calculations it can be considered a non-linear measure.

If S is a system of n symbols $\{s_1, s_2, \ldots s_n\}$ used to send messages, and $P_s(s_i)$ the probability of the i^{th} symbol of S then the statistical entropy of a message sent using S is defined as

$$H(S) = -\sum_i P_S(s_i)\log(P_S(s_i))$$

If we have two systems S and R, then we can then define the conditional entropy of S given r_j

$$H(S \mid r_j) = -\sum_i P_S(s_i \mid r_j)\log(P_S(s_i \mid r_j))$$

And by taking a weighted average of the conditional entropy over all possible values of r_j we get

$$H(S \mid R) = -\sum_i \sum_j P_{SR}(s_i, r_j)\log(\frac{P_{SR}(s_i, r_j)}{P_R(r_j)})$$

The mutual information between two messages or time series is the amount by which the signal R reduces the entropy of the signal S. This is exactly the entropy of S subtract the conditional entropy of S given R.

$$MI(S,R) = H(S) - H(S \mid R) = \sum_i \sum_j P_{SR}(s_i, r_j)\log(\frac{P_{SR}(s_i, r_j)}{P_S(s_i)P_R(r_j)})$$

Methods

Participants: 14 young and 12 older adults

Tasks: (1) Letter stimulus discrimination flanker task
(2) source monitoring word memory task.
(3) resting (watching a "star pattern" screen saver

EEG – 3 regions with 4 sites on each side representing ventral frontal, dorsal frontal, and dorsal parietal (see Figure 1)
– 500 Hz (filtered at 1-50 Hz), ±100 μV artifact rejection
– 250 ms data segments; 100 ms lag correlations

MI calculations: Calculated for each of the 4 regional sites associated with each of the 4 sites in the paired region, and the resulting 16 MI values averaged (see Figure 3).

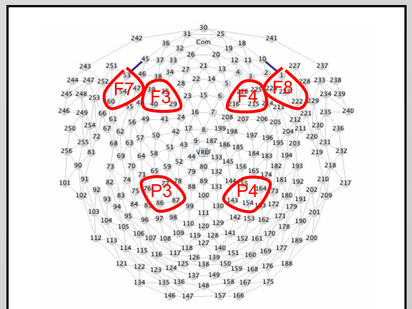


Figure 1. Electrode groupings used approximating F3/F4, F7/F8, and P3/P4 sites.

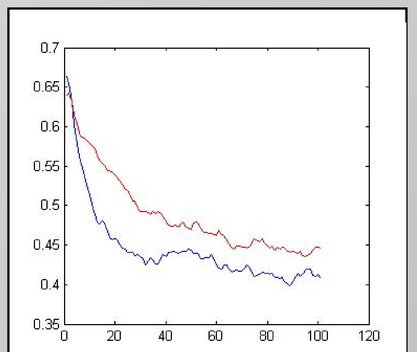
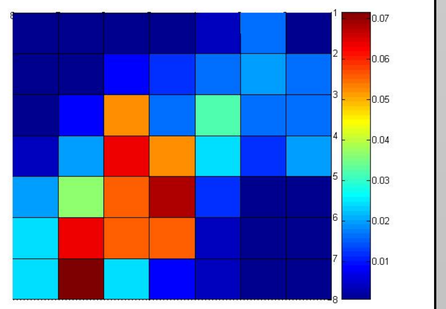


Figure 2. Example of change in MI as a function of lag for an older (red) and younger (blue) participant. The steeper slope indicates faster disengagement between sites.

MI output measures:
Information = amount of information available at the site
Maximum = maximum values over the epoch
Slope = slope of line fitted to first 100 ms (see Figure 2)
Average = mean of MI values over the epoch
Auto = slope of MI lag drop over 100 ms within a site, a reflection of the complexity of neural functioning

Figure 3. An example of a MI matrix showing regions of low (blue) vs high (red) conditional probability. Note that high conditional probability can be nonlinear.



Results

(1) EEG coherence did not differentiate groups.

(2) EEG Information (entropy): No differences between groups

(3) Maximum MI values:
– higher in younger adults (p=.003).
– greater MI in Ventral-dorsal frontal sites vs other combinations (p<.001), and more so in YNG due to greater frontal MI (p<.01).
– F7/F8 MI max greater than F4/F4 and P3/P4 regions (p<.001) especially for younger adults (p=.003).

(3) MI slope values:
– F7/F8 (interhemispheric ventral frontal) MI slope much greater than F3/F4 and P3/P4 regions (p<.001), and more so for the younger adults (p = .001)

(4) MI average values:
– Same interaction in slope MI drop over the epoch (p=.001).

(5) Autoregressive MI:
MI across the 6 sites and 3 tasks discriminates the groups 100%.

Conclusions

Mutual Information Analysis captures changes in cortical communication in the aging human brain during rest and complex task performance.

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