Frontal EEG theta oscillation differences during two-person, live, eye-to-eye contact compared to picture gaze

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Introduction

Human eye-to-eye contact is a primary source of social cueing and communication. A series of face-specific regions, including the fusiform gyrus, amygdala, superior and middle temporal gyrus, and orbitofrontal cortices have been shown to be more sensitive to direct rather than indirect gaze (1-3). Using functional near-infrared spectroscopy (fNIRS), we have previously shown responses during live eye-to-eye contact were greater than eye-to-picture gaze in the subcentral area, pars opercularis (Broca's area) and pre- and supplementary motor cortex. These areas also increased functional connectivity compared to eye-picture gaze to the left superior temporal gyrus, primary somatosensory cortex, and the subcentral area (4). Cross-brain interaction during eye-to-eye contact relative to eye-to-picture gaze revealed increased coherence across subjects within left superior temporal, middle temporal, and supramarginal gyri as well as the pre- and supplementary motor cortices of both interacting brains. This work suggests the left frontal, temporal, and parietal cortices comprise a long-range network that mediates neural responses during eye-to-eye contact between dyads.

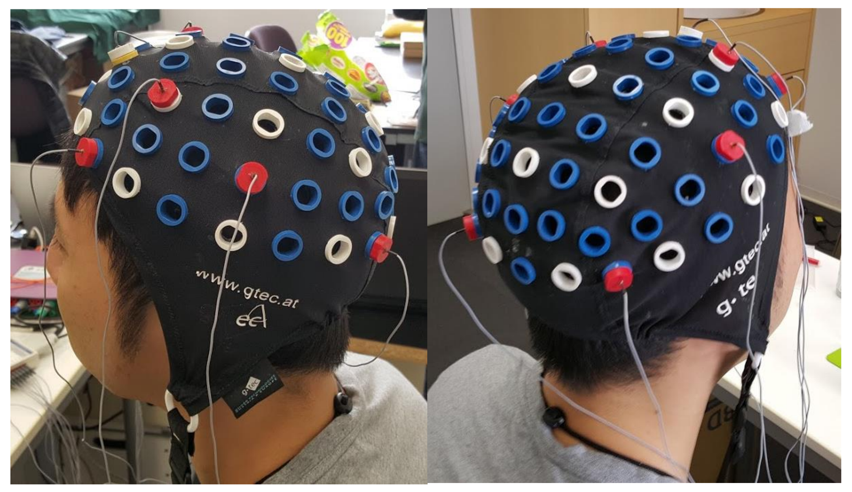
Aim: As hemodynamic signals are slow relative to direct neural responses, our goal was to test the hypothesis that early effects of eye-to-eye contact are represented in specific frequency bands of the EEG signal. We also test the hypothesis that eye-to-eye contact will show specific changes in cross-brain synchrony as measured by EEG.

Methods

Subjects: Twenty-six adults, 3 pairs, 22+/- 6 years old, 15% female, 100% right-handed (5) participated in the study. EEG data were obtained at Meiji University, Kawasaki, Japan. Participants provided written informed consent in accordance with guidelines approved by the Institutional Review Board of the Department of Science and Technology (No. 12-514) at Meiji University and Yale University. Dyads were assigned in order of recruitment, and participants were either strangers prior to the experiment or acquainted as classmates. Participants were not stratified further by affiliation. Four pairs were mixed gender and nine pairs were male-male.

EEG Acquisition: EEG recordings were obtained at a sample rate of 256/sec from electrode positions at F3, F4, F7, F8, C5, C6, PO7, and PO8 according to the 10-20 standard EEG layout. The rendering on the right below shows the position of the left hemisphere electrodes (blue dots).

A.



B.

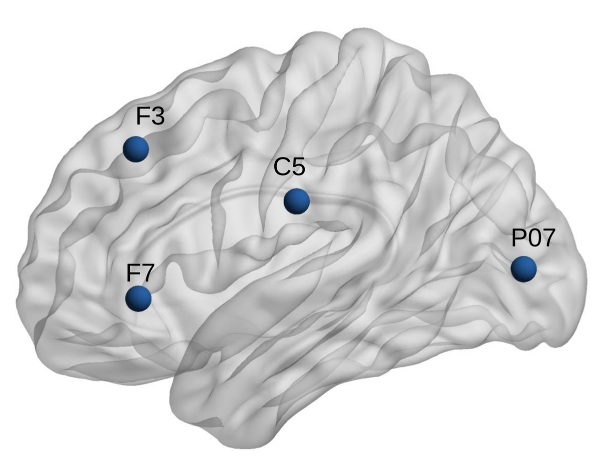


Figure 1. EEG setup and acquisition. A. EEG electrodes on subject. B. Rendering showing EEG locations.

Eye-tracking and Task: Gaze data was obtained using two SMI ETG2 eye-tracking systems. The task paradigm cued dyads of partners to look at each other or at a fixation object placed ten degrees to the side of their partner in block design in which three seconds of eye viewing was interleaved with three seconds of fixation object viewing. Subjects also participated in an identical paradigm in which both individuals concurrently looked at the eyes of a calibrated photograph instead of their partner using the same block design. No significance difference in eye-tracking behavior was found in either condition.

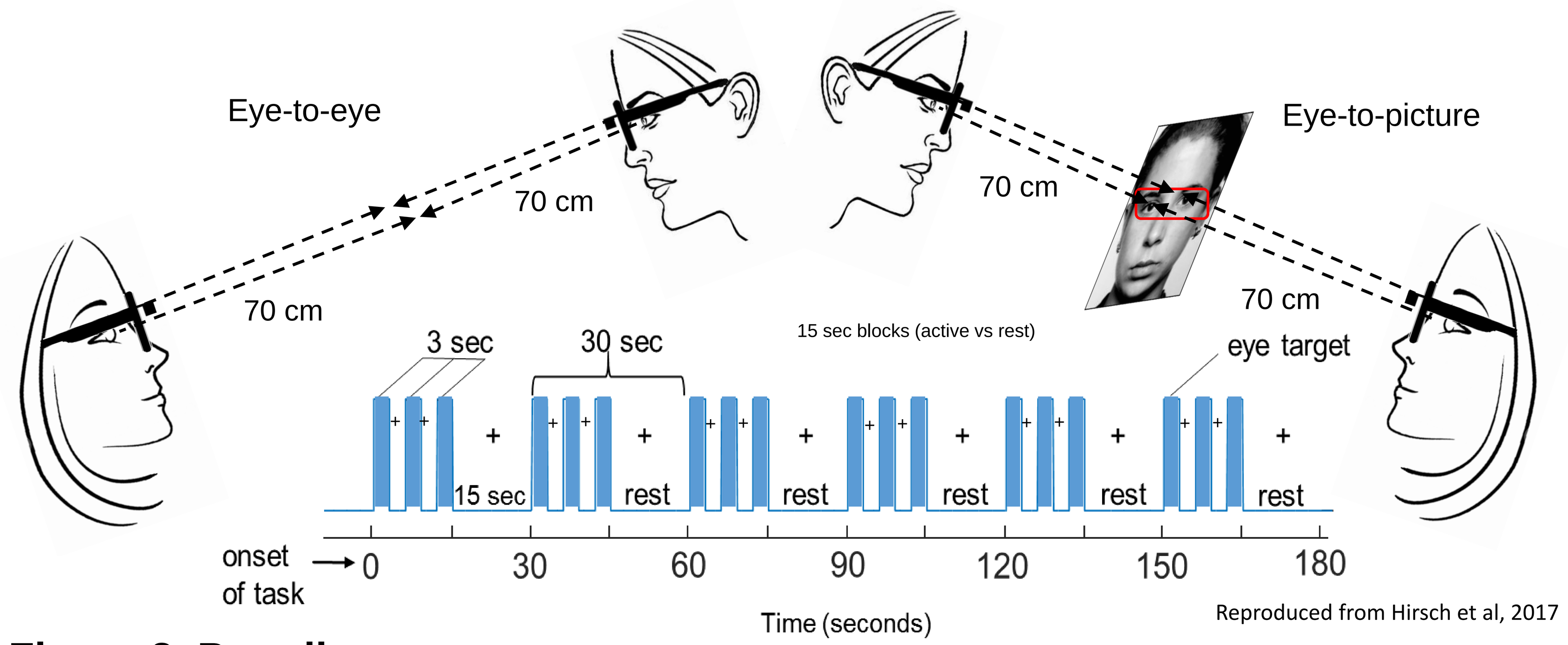


Figure 2. Paradigm.

Results

Event-triggered average: Raw EEG signals from the 4 frontal electrodes (left & right) were averaged and plotted for all subjects. A significant difference in amplitude/latency between the eye-to-eye and eye-to-picture condition was seen from 2-3 seconds (grey box Fig. 3A) during the direct eye gaze condition only. No difference in amplitude/latency were seen in other periods or tasks.

Frequency band analysis: Raw EEG signals were decomposed into component frequencies. Results of the decomposition show theta oscillations were in phase from time 0 until roughly 2 seconds. A phase reversal was seen between eye-to-eye and eye-to-picture conditions during direct eye gaze from 2-3 sec. Other frequency bands showed no significant differences.

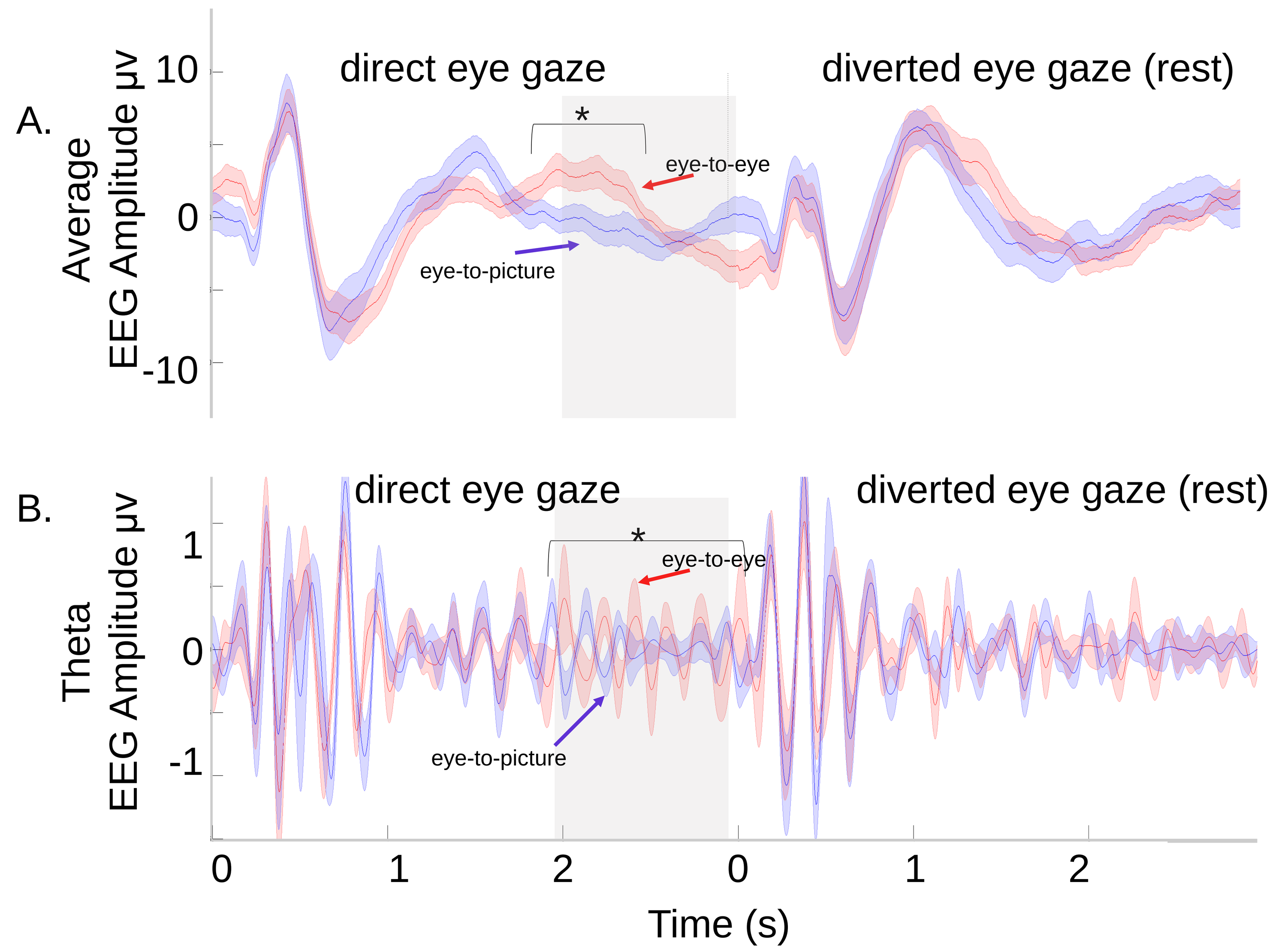


Figure 3. Single subject EEG recordings. A. Raw event-triggered data. B. decomposed theta band average.

Cross Brain Analysis: We performed a Phase Locking Value (PLV) analysis (5) on theta signals to determine cross-brain coherence between subjects during the final 2 seconds of the direct eye gaze task.. We calculated PLV of all time points of all pairs of electrodes. T-test of PLV between Real eye and Picture eye was performed for each time point. Significance level was set to p=0.05. A significant difference in theta band PLV values between electrodes F3 and C5 was found across brains.

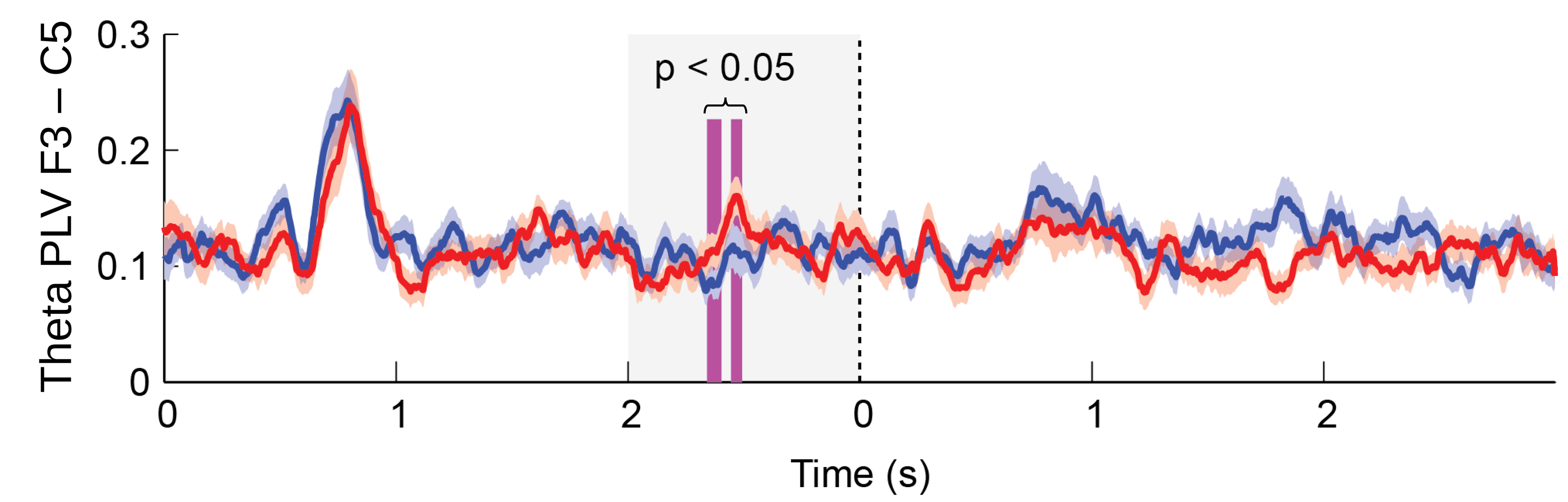


Figure 4. Cross-brain phase-locking value (PLV) analysis.

Conclusions

Point-by-point t-tests of event-triggered averaged EEG recordings indicated altered frontal activity 2s after onset of the active eye-to-eye contact relative to the eye picture gaze during direct eye gaze. In comparison, there was no difference between the two waveforms during the resting baseline (or during eye motion events). Wavelet decomposition analysis shows results are specific to theta band when comparing direct eye-to-eye contact versus eye-to-picture conditions (p = 0.01). Other frequency bands were not differentiated by this condition. Increased coherence across subjects was found between frontal and central electrodes further implicating the left frontal, temporal, and parietal network in mediating neural responses during eye-to-eye contact.

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