35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Induced Gamma-band Brain Responses to Direct Eye Contact in the Frontal and Parietal Cortices

Sunao Iwaki, *Member, IEEE*

***Abstract*— We used simultaneous recordings of the neuromagnetic (MEG) and electrooculogram (EOG) recordings on a pair of directly facing subjects, i.e., the sender and the observer of the eye gaze, to measure changes in the spontaneous brain activities while the observer perceives changes in eye gaze direction of the sender. The MEG signals were analyzed in the time-frequency domain to evaluate event-related changes in the spontaneous brain activities induced by the onset of eye movements. Significant increase in the gamma-band power was observed in the eye-contact condition compared to the averting condition in the right superior parietal, bilateral posterior superior-temporal, and the frontal areas of the observer. Together with the preliminary results from the frequency-domain Granger-Geweke causality analysis, the current results indicate that the connectivity between (a) the bilateral frontal areas, and (b) the right frontal and parietal areas might be crucial for the perception of eye gaze of the directly facing person. The increase in gamma-band activities in these regions might reflect the integration of information processed individually in these regions for eye gaze perception.**

I. Introduction

Perception of facial expression and eye gaze direction of others is a key ability in typical social interaction which requires not only recognition of the local pattern around eyes but the global processing such as evaluating relationship between the outline of the face, and other parts of the face[1]. Among others, mutual gaze in face-to-face interactions constitutes the first social interaction in human development [2]. Many behavioral studies pointed out that the perception of eye gaze direction is impaired in developmental disorders such as autism [3,4]. Recent neuroimaging studies on the perception of facial expression have elucidated that the changes in eye gaze directed to the observer evoke specific neural responses in the middle frontal, the inferior temporal, superior parietal and the posterior superior-temporal regions [5-8]. However, it is still unclear how the changes in the eye gaze direction between the directly facing subjects changes the spontaneous brain activities in the both subjects.

Here we used neuromagnetic (MEG) and electro-oculogram (EOG) recordings on both subjects, i.e., the sender and the observer of the eye gaze, to measure changes in the spontaneous brain activities while the observer perceives changes in eye gaze direction of the sender.

*Resrach supported in part by Grants-in-aid for Scientific Research (KAKENHI) and the National Institute of Advanced Industrial Science and Technology (AIST).

S. Iwaki is with the National Institute of Advanced Industrial Science and Technology (AIST), AIST Tsukuba Central 6, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8566, Japan (phone: +81-72-751-8764; fax: +81-29-861-6790; e-mail: s.iwaki@aist.go.jp).

II. Methods

A. Eye Gaze Perception Between Directly Facing Subjects

Six pairs of subjects sat face to face, at the distance of two meters, in the MEG magnetically shielded room. One of the subject (OBSERVER) sat under the MEG scanner and observed eye gaze of another subject (SENDER). The SENDER was instructed to change the gaze direction alternately between (a) contact with (CONTACT) and (b) avert from (AVERT) the observer approximately every 2 s (Fig. 1).

B. MEG/EOG Data Acquisition

Horizontal electrooculogram (hEOG) from the SENDER, and magnetoencephalographic (MEG) signals from the OBSERVER using 122-channel whole-cortex MEG system (Neuromag122^{TM}, Elekta-Neuromag, Finland) [9] were recorded simultaneously with a sampling rate of 600 Hz while the sender changed eye gaze direction. Epochs with large MEG artifacts mainly due to the eye movements were discarded by visual inspection and 100 stimulus-related epochs were analyzed further for each pair of subjects.

C. Time-Frequency Analysis

MEG signals recorded on the OBSERVER were epoched into 2.5 s windows in reference to the hEOG onset recorded in the SENDER including 0.5 s pre-epoch baseline periods, and were analyzed in the time-frequency domain using Wavelet decomposition [10] to evaluate event-related changes in the spontaneous brain activities induced by the onset of eye movements (Fig. 2).

Connectivity analysis based on frequency-domain Granger method (Granger-Geweke causality) [11,12] was also applied to elucidate the causal relationship between the regions where significant changes in spontaneous brain activities were observed during eye contact in the MEG signals measured on OBSERVER. MEG single trial data were extracted from 2 s post-epoch periods and average waveforms were subtracted from the single trial data before applying the Granger-Geweke causality tests. Permutation tests with 200 times of resampling were used to assess the statistical significance of the estimated model parameters, where the single trial MEG data matrices were subdivided into a number of windows and then surrogate data matrices were selected by rearranging the windows for each variable separately to calculate the distribution of model parameters under a null-hypothesis assumption.

III. Results

The results of group statistics (paired t-tests) to detect significant event-related increase in the spontaneous brain activity in the CONTACT condition compared to the AVERT

978-1-4577-0216-7/13/$26.00 ©2013 IEEE

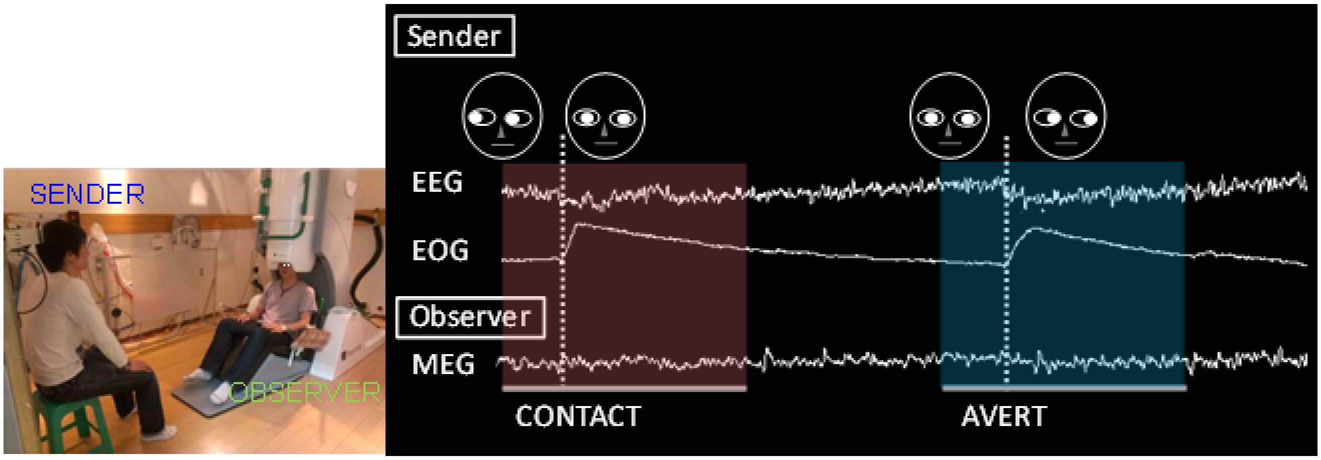

Fig. 1 Schematic diagram of the eye gaze perception task performed by a pair of directly face subjects, where hEOG signals from the sender of the gaze and MEG signals from the observer of the gaze were simultaneously recorded.

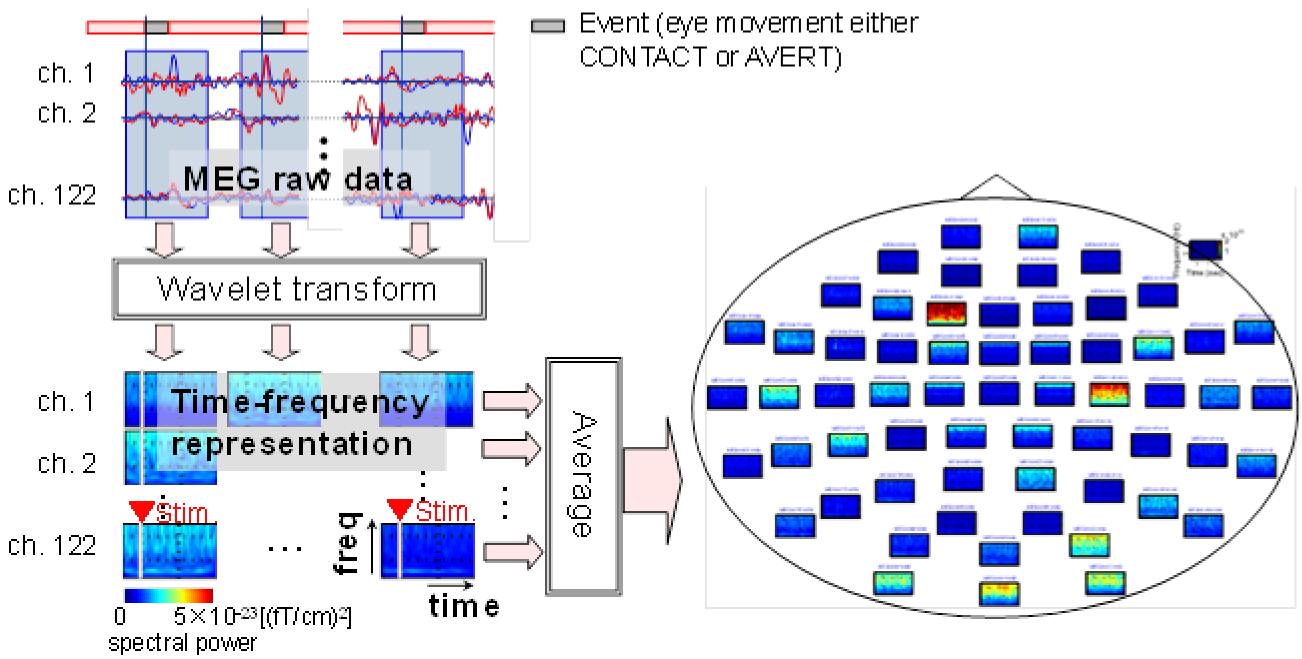

Fig. 2 Schematic diagram of the time-frequency analysis using Wavelet decomposition used in this study.

condition in the frequency range between 5 and 60 Hz are shown in Fig. 3.

Significant increase in the gamma-band power was observed in the CONTACT condition compared to the AVERT condition at the MEG sensors covering bilateral posterior superior-temporal, parietal, and bilateral frontal areas of the OBSERVER.

Results of the connectivity analysis in individual subjects inferred by using frequency-domain Granger-Geweke causality modeling were shown in Fig. 4. Red arrows show pairs of regions where significant b-directional causal relationships were observed ($p < 0.001$ with permutation test). Blue arrows show pairs and directions of significant uni-directional causality. Connectivity between the right frontal and parietal areas was significant in the CONTACT condition.

Bi-directional causal relationship between the right frontal and parietal areas was marked in the CONTACT condition. The connectivity between bilateral frontal areas was significant in all of the subjects in AVERT condition; most of them were uni-directional (from the right to the left). The left figure depicts the major differences between the conditions. The causality between these regions was bi-directional in most of the subjects (5 out of 6).

IV. DISCUSSION

Significant event-related increase in the 40 Hz gamma-band activities were observed in (a) the bilateral

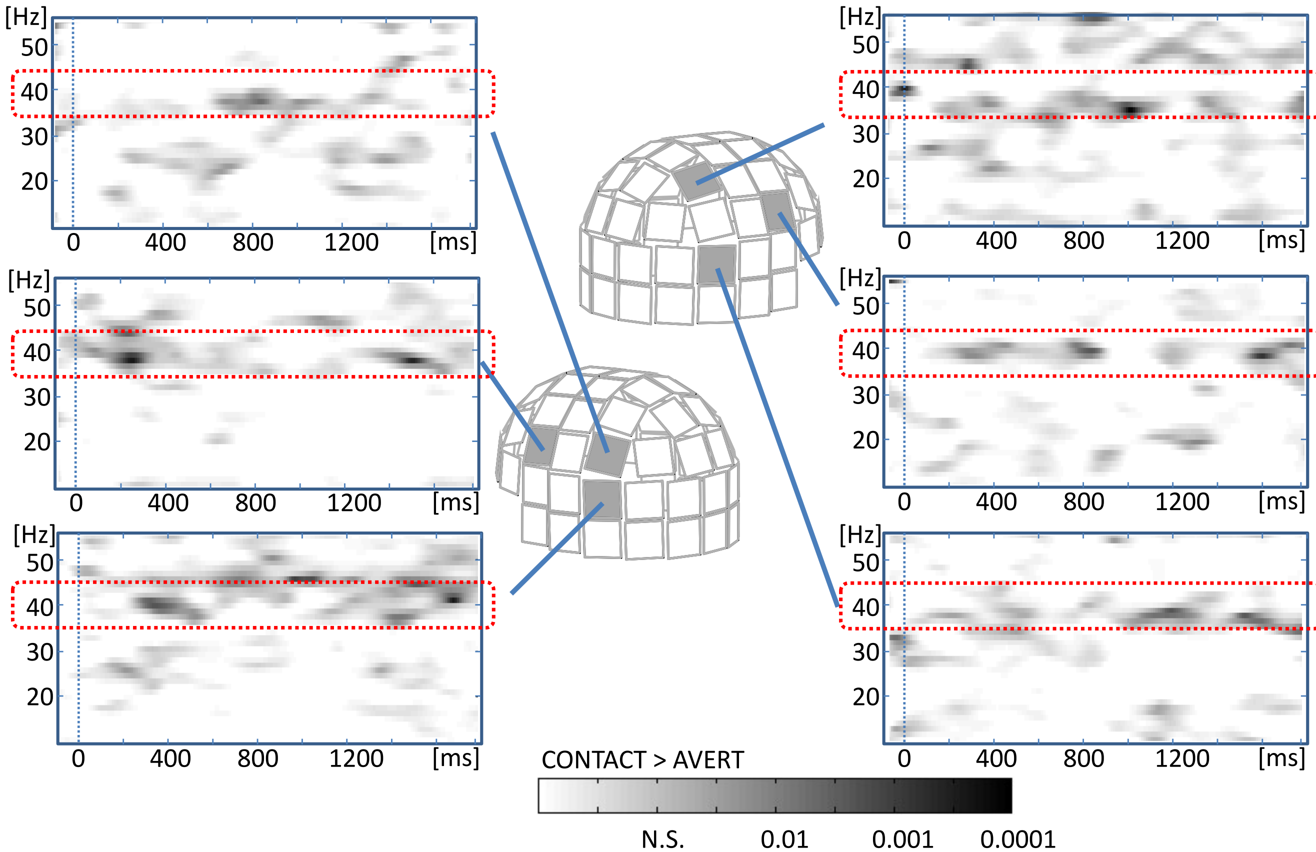

Fig. 3 Results of the group statistics on the time-frequency analysis to detect event-related changes in spontaneous brain activities during eye gaze perception task measured in the OBSERVER. Gamma-band (35 - 45 Hz) activities were significantly increased in the CONTACT condition compared to the AVERT condition.

MFG, (b) the IPS, (c) the bilateral STS, and (d) the occipito-temporal visual areas during the eye contact condition compared to the averting condition. These locations are in agreement with the previous fMRI and MEG studies reporting specific brain responses during eye gaze perception. [5-8] reporting brain responses in these areas during eye gaze perception.

The current preliminary results from the connectivity analysis indicate that the causal relationship in 40 Hz gamma-band activities between (a) the bilateral frontal areas, and (b) the right frontal and parietal areas might be crucial for the perception of eye gaze of the directly facing person.

These areas are previously reported as the sites responsible for the human mirror neuron system. It might be possible that eye contacts facilitates the involvement of the mirror neuron system as a part of the neural mechanisms underlying non-verbal social communication integrating the information required for the gaze direction perception.

V. Conclusion

Simultaneous EOG and MEG recordings were carried out on a pair of directly facing subjects who were repeating eye contact. Time-frequency analysis of the MEG signals showed significant increase in the gamma-band power in the eye contact condition compared to the averting condition in the right superior parietal, the bilateral posterior superior temporal and the bilateral middle frontal areas.

Acknowledgment

The author is grateful to Dr. Kouichi Sutani for his assistance in preparing experimental setup.

References

[1] W.H. Wollaston, “On the apparent direction of eye in a portrait,” *Phil. Trans. Royal Soc. London, B*, vol. 114, pp. 247-256, 1884.

[2] T. Gliga, G. Csibra, “Seeing the face through the eyes: A developmental perspective on face expertise,” *Progress in Brain Res.*, vol. 164, pp. 323–339, 2007.

[3] K.M. Dalton, B.M. Nacewicz, T. Johnstone, H.S. Shaefer, M.A. Gernsbacher,H.H. Goldsmith, A.L. Alexander, R.J. Davidson, “Gaze-fixation and the neural circuitry of face processing in autism,”, *Nat. Neurosci.*, vol. 8, pp. 519-526, 2005.

[4] J. Osterling, G. Dawson, “Early recognition of children with autism: a study of first birthday home videotapes,”, *J. Autism Dev. Disord.*, vol. 24, pp. 247-257, 1994.

[5] S. Watanabe, R. Kakigi, K. Miki, A. Puce, “Human MT/V5 activity on viewing eye gaze changes in others: A magnetoencephalographic study,” *Brain Res.*, vol. 1092, pp. 152-160, 2006.

[6] L. Nummenmaa, L. Passamonti, J. Rowe, A.D. Engell, A.J. Calder, “Connectivity analysis reveals a cortical network for eye gaze perception,” *Cereb. Cortex*, vol. 20, pp. 1780-1787, 2010.

[7] T. Ethofer, M. Gschwind, P. Vuilleumier, “Processing social aspects of human gaze: a combined fMRI-DTI study,” *Neuroimage*, vol. 55, pp. 411-419, 2011.

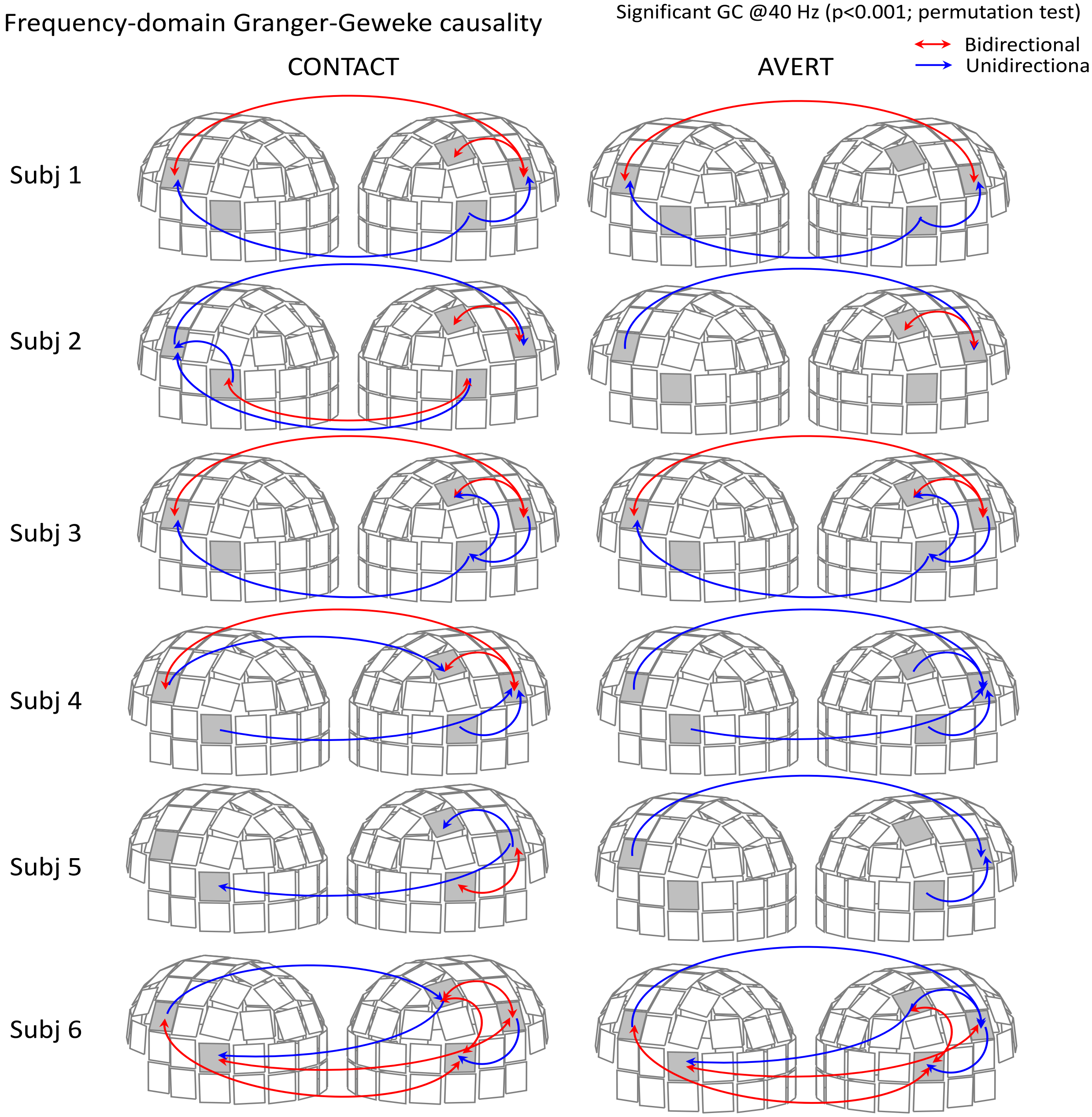

Fig. 4 Results of the connectivity analysis in individual subjects inferred by using frequency-domain Granger-Geweke causality tests with permutation resampling. Red arrows show pairs of regions where significant b-directional causal relationships were observed ($p<0.001$ with permutation test). Blue arrows show pairs and directions of significant uni-directional causality.

[8] R. Ramsey, E.S. Cross, A.F. de C. Hamilton, "Eye can see what you want: Posterior intraparietal sulcus encodes the object of an actor's gaze," *J. Cogn. Neurosci.*, vol. 23, pp. 2300-2309, 2011.

[9] C. Tallon-Baudry, O. Bertrand, C. Delpuech, J. Pernier, "Stimulus specificity of phase-locked and non-phase-locked 40 Hz visual responses in human," *J. Neurosci.*, vol. 16, pp. 4240-4249, 1996.

[10] M. Hämäläinen, R. Hari, R.J. Ilmoniem, J. Knuutila , O.V. Lounasmaa , "Magnetoencephalography--theory, instrumentation, and applications to noninvasive studies of the working human brain," *Rev Mod Phys*, vol. 65, pp. 413-497, 1993.

[11] C.W.J. Granger, "Investigating causal relations by econometric models and cross-spectral methods," *Econometrica*, vol. 37, pp. 424-438, 1969.

[12] J. Geweke, "Measure of conditional linear dependence and feedback between time series," *J. Amer. Statist. Assoc.*, vol. 79, pp. 907-915, 1984.