Semi-automated brain responses in communication: A magnetoencephalographic hyperscanning study

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Abstract—**Face to face communication is interactive, and involves continuous feedforward and feedback of information, thoughts, and feelings to the opposite party. To accurately assess the neural processing underlying these interactions, synchronous and simultaneous recording of the brain activity from both parties is needed, a method known as hyperscanning. Here, we investigated the neural processing underlying non-verbal face-to-face communication using a magnetoencephalographic (MEG) hyperscanning system, comprising two fiber optically connected MEGs. Eight pairs of subjects participated. Each individual in each pair viewed a combined 80 randomized 20 s trials of 40 real-time and 40 recorded (hereafter, real and simulated, respectively) videos of the opposite party's face. Non-verbal communication through actions such as gaze, eye blinks, and facial expression was intrinsically only possible during real videos. After each trial, subjects individually subjectively discriminated whether the viewed video was real or simulated. Overall subjective discrimination accuracies were slightly but significantly above chance level. Statistical analysis of brain activity revealed a significant three way interaction between theta-band rhythm amplitude, video type, and subjective discrimination response in the right frontal cortex. Additionally, when subjects responded that videos were simulated, theta activity was significantly lower for real videos compared with simulated videos (p = 0.01). This result not only demonstrates the importance of right frontal theta activity during non-verbal communication, but also indicates the existence of unconscious, semi-automated neural processing during non-verbal communication that underlies one's ability to subjectively discriminate whether or not the opposite party is real.**

I. INTRODUCTION

During communication between two people, each person perceives the other's words, tone, and facial expressions. Each person then cognizes the others' emotion or intention, in accordance with experience, and predicts the next step of communication [1], ultimately producing some action or output. Thereby, there is a continuous mutual-feedback of output and input between both people during communication [2-3]. These mutual feedback processes, in addition to higher-order processes, are thought to involve dynamic, semi-automatic processing such as coordination of movement [4] and blink synchronization [5] that subserve conscious predictions and decision making. Thus, to truly capture the behaviors and neurophysiological correlates of communication between two people requires simultaneous and synchronous recording of the behavioral and/or neurophysiological states of both parties. However, previous research [6-7] has largely focused on simulated communication tasks using static facial stimulation and pre-recorded video with single subject, despite the fact that there is no continuous and mutual feedback in these types of tasks. Consequently, the neurocorrelates underlying two-way communication remains unclarified.

Hyperscanning is a neuroimaging method used to simultaneously and synchronously monitor the brain 4activities of at least two communicating individuals. It has been used to investigate communication with functional magnetic resonance imaging (fMRI) [8], near infrared spectroscopy (NIRS) [9], and electroencephalography (EEG) [10]. The high spatial resolution of fMRI has made it possible to estimate brain areas involved in communication, while the flexibilities of NIRS and EEG have made it possible to record brain signals during natural communication. Magnetoencephalographic (MEG) hyperscanning studies regarding communication would be extremely desirable due to the combined high temporal and spatial resolution of MEG. However, due to the rarity of MEGs compared to other neuroimaging devices, hyperscanning studies using MEG have remained elusive. Indeed, there are only a limited number of facilities in the world capable of MEG hyperscanning [11-13].

In the present study, we used a newly developed MEG hyperscanning system at our institution comprising two fiber optically connected MEGs to investigate neurocorrelates of non-verbal communication. Our analyses focused on theta-band activity as it has shown to reflect aspects of communication which would be relevant even in non-verbal contexts such as attention, interest, and memory of others [14-16].

II. EXPERIMENT

The experimental protocol involving human subjects described in this report was approved by the Ethics Committees of School of Medicine, Hokkaido University (Sapporo, Japan). Written informed consent was obtained from each subject before the experiment.

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A. *Subjects and Equipment*

MEG signals were recorded using a dual MEG system consisting of 101- (customized; Elekta-Neuromag, Stockholm Sweden) and 306- (VectorView, Elekta-Neuromag) channel devices housed at Hokkaido University (Fig. 1). The two MEG devices, each with an identical audiovisual interface, were directly connected using fiber optic cables which thereby permitted both hyperscanning and natural communication with direct eye contact. The passband frequency of each device ranged from 0.1 to 200 Hz, and signals were sampled at 600 Hz. Eight pairs (i.e. 16 subjects) of healthy male subjects participated; as a pilot study, only male participants were recruited. MEG data from two subjects were excluded due to excessive noise in the MEG recording. Data from the remaining 14 subjects (mean age ± SD, 23.3 ± 3.9 years) were analyzed.

B. *Protocol*

A representative time sequence of the experimental session is shown in Figure 2. Subjects were instructed to gaze at one another in silence. Excessive movement was explicitly prohibited. Experimental trials were 20 s long, separated by 10 s inter-trial intervals. Each trial comprised either real-time (hereafter, real) or pre-recorded (hereafter, simulated) video stimuli of the counterpart's face projected on a back-projection screen located in within each MEG's magnetically shielded room. Non-verbal communication through actions such as gaze, eye blinks, and facial expression was intrinsically only possible during real videos. After each trial, subjects individually subjectively discriminated whether the viewed video was real or simulated by pressing one of two corresponding buttons on a controller within 5 s. Subsequently, a 5 s countdown was presented, followed by the next trial video. One experiment comprised four sessions with short breaks between sessions. Each session comprised 10 real and 10 simulated trials, presented in random order. Thus, one experiment comprised a total of 40 real and 40 simulated trials.

C. *Data processing*

MEG data for each subject were processed using Brainstorm [17] as follows. Bad channels were excluded via visual inspection, and artifacts and noise were removed via independent component analysis and signal space projection. The cleaned data was then band-pass filtered from 1–40 Hz, and source brain activity was estimated based on cortical currents at 15,002 vertices on a template brain calculated via minimum-norm estimates. The amplitude of theta-band (5–7 Hz) activity was calculated at each vertex using a band-pass filter and Hilbert transformation. Mean theta amplitude over 3–17 s was calculated at each vertex for each subject for each video type and response combination (1: video real, response real; 2: video real, response simulated; 3: video simulated,

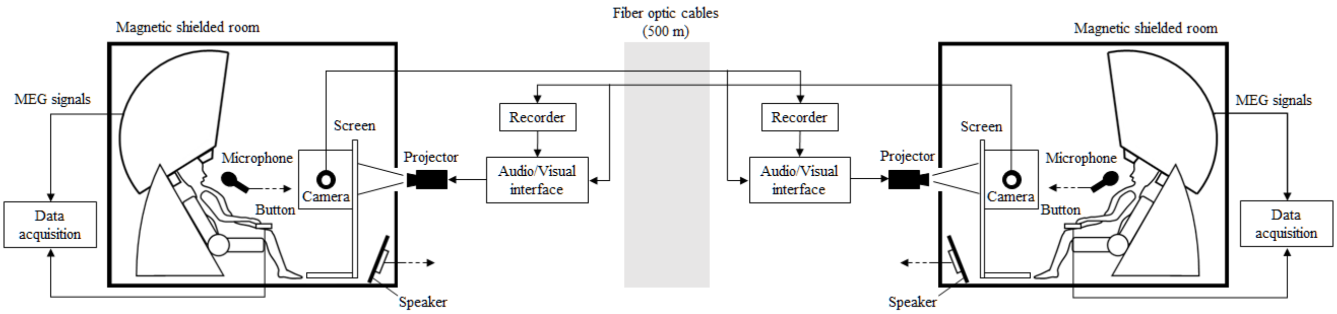

Fig. 1. Schematic diagram of the dual magnetoencephalography (MEG) system. Two MEG devices were directly connected by fiber optic cables. Two subjects can communicate naturally with direct eye contact via audiovisual interfaces.

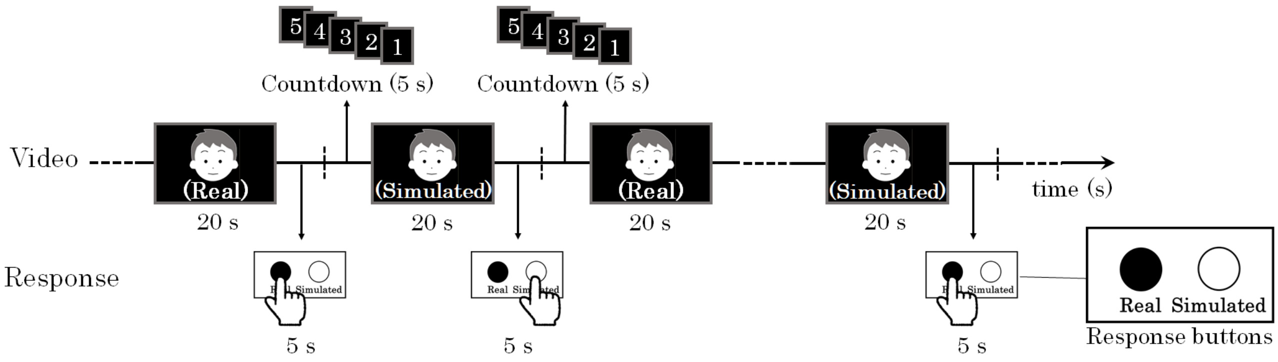

Fig. 2. A representative time sequence of one experimental trial. Video stimuli (real/simulated) are presented for 20 s. Within five seconds after video presentation, subjects discriminate whether the video was real or simulated by pressing one of two corresponding buttons on a controller. Subsequently, a 5 s countdown is presented, followed by the next video stimulus.

response real; 4: video simulated, response simulated). These theta amplitudes were then normalized by the mean amplitude over -0.5–0 s for each corresponding video type and response combination. Here, 0 s denotes the onset of the video presentation. Meanwhile, the cortical vertices were divided into four bilaterally homologous brain region pairs (Fig. 3): frontal, temporal, parietal, and occipital based on the Mindboggle cortical atlas [18]. Normalized mean theta amplitudes were averaged over all vertices in each of these brain regions, resulting in a single normalized theta-band deviation value for each brain region, for each video type and response combination, for each subject.

D. Statistical analysis

Three-way repeated measures of analysis of variance (3-way RM ANOVA) was performed with response (real/simulated), video type (real/simulated), and brain region (eight regions) as factors, and normalized theta-band deviation as the dependent variable. In the case of a significant three-way interaction, two-way RM ANOVAs were performed separately for each brain area. Simple-main effects testing was performed for significant main effects and interactions of two-way ANOVAs. The significance threshold was set at 10% for interactions and main and simple-main effects. We expected that theta activity would differ in accordance with each of the video type and response combinations, and therefore we especially focused on these interactions in the present report.

III. RESULTS

A. Behavior

The mean accuracy was 61.3 ± 10.8% for real videos and 48.6 ± 9.1% for simulated videos, with an overall mean of 54.9 ± 7.0%. Binominal testing revealed that overall accuracies were significantly above chance level (50%) ($p < 0.001$).

B. Statistical analysis

Results of the three-way RM ANOVA revealed a significant interaction ($F_{(7, 91)} = 1.895$; $p = 0.079$). Hence, Two-way RM ANOVA of response (real/simulated) and video type (real/simulated) were performed separately for each brain region. As a result, significant interaction between video type and response was observed only in the right frontal region ($F_{(1, 13)} = 6.744$; $p = 0.022$; Fig. 3). Here, simple-main effects revealed that theta activity was significantly lower for real videos when subjects responded that they were simulated compared to real ($p = 0.022$). Additionally, when subjects responded that videos were simulated, theta activity was significantly lower for real videos compared with simulated videos ($p = 0.010$) (Fig. 4).

IV. DISCUSSION

Accuracies slightly above chance level demonstrated that real and simulated videos were extremely similar to one another, and were actually a challenge to discriminate. Nevertheless, as a result, sample sizes of the video type and response combinations were virtually the same.

A significant interaction between response and video type was observed only in the right frontal region. Collectively, simple main effect results demonstrated that even when subjects judged that the videos were simulated, the theta-band rhythm in the right frontal region was suppressed when the subjects viewed real videos (Fig. 4). This result suggests that at least a part of the right frontal region can be activated in response to real-time interpersonal interactions. This activity may cause semi-automatic responses during interactive communication that subjects are not consciously aware of. Similarly, it was also demonstrated that even the video was real, the theta-band rhythm in the right frontal region was suppressed before the subjects judged that the video was simulated (Fig. 4).

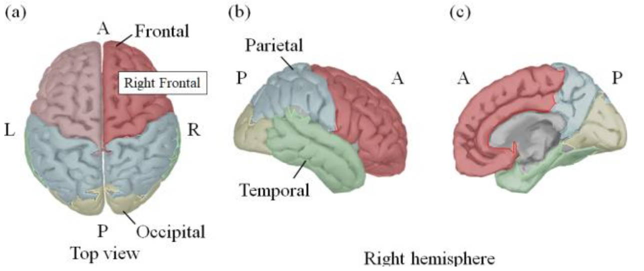

Fig. 3. Theta activity from four bilaterally homologous brain region pairs was targeted in our analysis; top view (a), right lateral view (b), and right medial view (c).

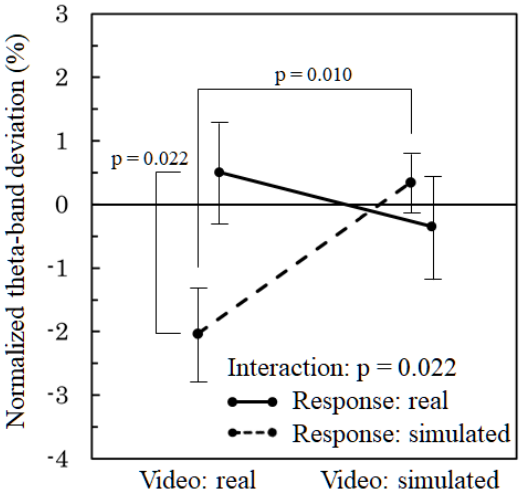

Fig. 4. The results of two-way repeated measures analysis of variance on theta-band deviation. In the right frontal region, a significant interaction was observed ($F_{(1, 13)} = 6.744$; $p = 0.022$) between response (real/simulated) and video type (real/simulated).

Several previous studies have demonstrated roles of the right frontal region in communication, although these were not conducted using hyperscanning. EEG studies have demonstrated that theta-band rhythm is involved in recognizing facial expression(s) [19-22]. In particular, González-Roldan et al. [23] argued that theta-band rhythm in the right frontal region is associated with motivation to recognize and encode facial expressions. Meanwhile, fMRI studies estimated specific brain areas involved in communication. For example, the right ventrolateral prefrontal cortex (vLPFC) was proposed to be involved when considering the state of mind of others [24, 25]. Several studies revealed that the right lateral prefrontal cortex (rLPFC) regulates expression of particular attitudes [26, 27]. An association between the rLPFC and the amygdala has also been observed [28]. Furthermore, it was reported that the dorsal anterior cingulate cortex (dACC), which is known to be a generator of frontal-midline theta, is correlated with motivation and orientation in communication [29].

The right frontal region comprises several brain areas, and the MEG cortical currents estimated in the right frontal region in the present study could be allocated to these smaller areas. By repeating statistical analyses, we may be able to identify specific brain areas in detail. However, such a step-wise approach lends itself to poor statistical power. Future experiments should use a larger number of subjects to increase statistical power, which may permit more precise identification of specific brain areas.

In this work, subjects judged whether the videos were real or simulated after video presentation ceased. However, subjects had undoubtedly made their decision while viewing the video. Therefore, brain activities should differ between the beginning and end of video presentation. Although defining the time points of the discrimination is difficult, time-domain analysis may also be useful in revealing brain activities in detail.

V. CONCLUSION

The brain activity we identified may be the generator of semi-automated responses in interactive communication. This response is likely unconscious, and hence, may have been obscure in conventional behavioral studies. Future research using hyperscanning methods may further illuminate this unknown mechanism of communication.

REFERENCES

[1] K. Fristion, and C. Frith, "A duet for one," *Consc. Cogn.*, vol. 35, pp. 390-405, 2015.

[2] R. Hari, and A. Puce, "MEG-EEG primer," *Oxford University Press*, pp. 277-293, 2017.

[3] R. Hari, and M. V. Kujala, "Brain basis of human social interaction: from concepts to brain imaging," *Physiol. Rev.*, vol. 89, pp. 453-479, 2009.

[4] F. Bernieri, J. S. Reznick, and R. Rosenthal, "Synchrony, pseudosynchrony, and dissynchrony: Measuring the entrainment process in mother-infant interactions," *J. Pers. Soc. Psychol.*, vol. 54, pp. 243-253, 1988.

[5] A. Mandel, S. Helokunnas, E. Pihko, and R. Hari, "Neuromagnetic brain responses to other person's eye blinks seen on video," *Eur. J. Neurosci.*, vol. 40, pp. 2576-2580, 2014.

[6] A. Mandel, S. Helokunnas, E. Pihko, and R. Hari, "Brain responds to another person's eye blinks in a natural setting-the more empathetic the viewer the stronger the renponses," *Eur. J. Neurosci.,* vol. 42, pp. 2508-2514, 2015.

[7] E. Blanco-Elorrieta, and L. Pylkkänen, "Bilingual language switching in the laboratory versus in the wild: the spatiotemporal dynamics of adaptive language control," *J. Neurosci.,* vol. 37, pp. 9022-9036, 2017.

[8] P. R. Montague, G. S. Berns, J. D. Cohen, S. M. McClure, G. Pagnoni, M. Dhamala, M. C. Wiest, I. Karpov, R. D. King, N. Apple, and R. E. Fisher, "Hyperscanning: simultaneous fMRI during linked social interactions," *NeuroImage*, vol. 16, pp. 1159-1164, 2002.

[9] N. Liu, C. Mok, E. E. Witt, A. H. Pradhan, J. E. Chen, and A. L. Reiss, "NIRS-based hyperscanning teveals inter-brain neural synchronization during cooperative jenga game with face-to-face communication," *Front. Hum. Neurosci.*, vol. 10, pp. 21-28, 2016.

[10] F. Babiloni, F. Cincotti, D. Mattia, M. Mattiocco, F. D. V. Fallani, A. Tocci, L. Bianchi, M. G. Marciani, and L. Astolfi, "Hypermethods for EEG hyperscanning," *Conf. Proc. IEEE. Eng. Med. Biol. Soc.*, vol. 1, pp. 3666-3669, 2006.

[11] P. Baess, A. Zhdanov, A. Mandel, L. Parkkonen, L. Hirvenkari, J. P. Mäkelä, V. Jousmäki, and R. Hari, "MEG dual scanning: a procedure to study real-time auditory interaction between two person," *Front. Hum. Neurosci.*, vol. 6, pp. 1-7. 2012.

[12] S. Ahn, H. Cho, M. Kwon, K. Kim, H. Kwon, B. S. Kim, W. S. Chang, J. W. Chang, and S. C. Jun. "Interbrain phase synchronization during turn-taking verbal interaction-a hyperscanning study using simultaneous EEG/MEG," *Hum. Brain. Mapp*, vol. 39, pp. 171-188, 2018.

[13] M. Hirata, T. Ikeda, M. Kikuchi, T. Kimura, H. Hiraishi, Y. Yoshimura, and M. Asada, "Hyperscanning MEG for understanding mother–child cerebral interactions," *Front. Hum. Neurosci*. vol. 8, pp. 1-6, 2014.

[14] P. Fries, "Rhythms for cognition: communication through coherence," Neuron, vol. 88, pp. 220-235, 2015.

[15] M. S. Clayton, N. Yeung, L. K. R. Cohen, "The roles of cortical oscillations in sustained attention," *Trends. Cogn. Sci*., vol. 19, pp. 188-195, 2015.

[16] Y. Wang, and H. Luo, "Behavioral oscillation in face priming: prediction about face identity is updated at a theta-band rhythm," *Prog. Brain. Res*., vol. 236, pp. 211-224, 2017.

[17] F. Tadel, S. Baillet, J. C. Mosher, D. Pantazis, and R. M. Leahy, "Brainstorm: a user-friendly application for MEG/EEG analysis," *Comput. Intell. Neurosci*., vol. 2011, ID 879716, 2011.

[18] A. Klein, S. S. Ghosh, F. S. Bao, J. Giard, Y. Hame, E. Stavsky, N. Lee, B. Rossa, M. Reuter, E. C. Neto, and A. Keshavan, "Mindboggling morphometry of human brains," *PLoS Comput.* Biol., vol. 13, e1005350, 2017.

[19] M. Balconi, and C. Lucchiari, "EEG correlates (event-related desynchronization) of emotional face elaboration: a temporal analysis," *Neurosci. Lett.* vol. 392, pp. 118–123, 2006.

[20] M. Balconi, and U. Pozzoli, "Arousal effect on emotional face comprehension. Frequency band changes in different time intervals," *Physiol. Behav.* vol. 97, pp. 455–462, 2009.

[21] G. G. Knyazev, J. Y. Slobodskoj-Plusnin, and A, V. Bocharov, "Event-related delta and theta synchronization during explicit and implicit emotion processing," *Neuroscience*, vol. 164, pp. 1588–1600, 2009.

[22] G. G. Knyazev, J. Y. Slobodskoj-Plusnin, and A. V. Bocharov, "Gender differences in implicit and explicit processing of emotional facial expressions as revealed by event-related theta synchronization," *Emotion,* vol.10, pp.678–687, 2010.

[23] A. M. González-Roldan, M. Martínez-Jauand, M. A. Muñoz-García, C. Sitges, I. Cifre, and P. Montoya, "Temporal dissociation in the brain processing of pain and anger faces with different intensities of emotional expression," *Pain*, vol. 152, pp. 853–859, 2011.

[24] D. Samson, I. A. Apperly, U. Kathirgamanathan, and G. W. Humphreys, "Seeing it my way: a case of selective deficit in inhibiting self-perspective," *Brain*, vol. 128, pp. 1102-1111, 2005.

[25] K. Vogeley, P. Bussfeld, A. Newen, S. Herrmann, F. Happé, P. Falkai, W. Maier, N. J. Shah, G. R. Fink, and K. Zilles, "Mind reading: neural mechanisms of theory of mind and self-perspective," *Neuroimage*, vol. 14, pp. 170-181, 2001.

[26] W. A. Cunningham, S. D. Espinet, C. G. DeYoung, and P. D. Zelazo, "Attitudes to the right- and left: frontal ERP asymmetries associated with stimulus valence and processing goals," *Neuroimage*, vol. 28, pp. 827-834, 2005.

[27] J. A. Richeson, A. A. Baird, H. L. Gordon, T. F. Heatherton, C. L. Wyland, S. Trawalter, and J. N. Shelton, "An fMRI investigation of the impact of interracial contact on executive function," *Nat. Neurosci*., vol. 6, pp. 1323-1328, 2003.

[28] W. A. Cunningham, M. K. Johnson, C. L. Raye, J. Gatenby, J. C. Gore, and M. R. Banaji, "Separable neural components in the processing of black and white faces," *Psychol. Sci.*, vol.15, pp.806-813, 2004.

[29] N. I. Eisenberger, M. D. Lieberman, and K. D. Williams, "Does rejection hurt? An fMRI study of social exclusion," *Science*, vol. 302, pp. 290-292, 2003.