Electroencephalogram Dynamics during Social Communication among Multiple Persons

Naoyuki Sato, Taiki Sato, Takeya Okazaki, and Mitsuru Takami

Department of Complex and Intelligent Systems, School of Systems Information Science, Future University Hakodate, 116-2 Kamedanakano-cho, Hakodate-shi, Hokkaido 041-8655, Japan
{satonao,b1009092,b1009088,b1009155}@fun.ac.jp
http://www.fun.ac.jp/~satonao/

Abstract. The brain dynamics of social behavior are important for understanding the group intelligence that occurs in humans. Coordinated behavior between two subjects has been used as an experimental model of social behavior, but the creativity occurring in a group of multiple persons has not yet been discussed. In this study, a rhythmic communication task was proposed as a model of social communication, and simultaneous electroencephalogram (EEG) of three subjects were evaluated. Results showed that the decrease of theta-band power in the EEG was correlated with the rhythm delay in the ensemble pattern, and the decreases of upper and lower alpha-band power were associated with the rhythm tempo and the rareness of ensemble pattern. This suggests that the theta- and alpha-band powers in the EEG associate with social communication and cross-frequency EEG dynamics is essential for understanding the creativity in the social behavior.

Keywords: brain oscillations, electroencephalogram, creativity, social coordination, music, synchronization.

1 Introduction

The brain dynamics of social behavior are important for understanding the group intelligence that emerges between multiple persons; as the saying goes, "two (or more) heads are better than one". Social behavior is thought to include various sub-processes, such as perception, action, emotion etc. [1]; thus, its experimental model is important for the investigation. One model is a coordinated behavior between two subjects. Tognoli et al. (2007) [2] evaluated electroencephalogram (EEG) during an alternative tapping task of two subjects and showed the association between sub-components of EEG alpha power and the social behavior. Moreover, inter-brain synchronization was also shown to increase during coordinated behavior [3]. These studies produced the important clues for understanding the intelligence in social behavior; however, the creativity that can occur in groups of multiple persons has not yet been discussed. Since the neural mechanisms of creativity have been discussed in terms of divergent thinking,

M. Lee et al. (Eds.): ICONIP 2013, Part I, LNCS 8226, pp. 145–152, 2013.

artistic performance, and insight [4], some experimental model of creativity in social communication is thought to be important for the understanding of social behavior.

In this study, a rhythmic communication task among multiple persons was proposed and simultaneous EEG signals of three subjects were evaluated. During the task, the subjects used a tapping button to sound a note and they were asked to tap voluntary with listening rhythms of others. Although they were not explicitly asked to produce synchronous or asynchronous tapping, the tap timings of subjects is expected to be intermittently entrained to the group ensemble (see, a review by Repp [5]).Then, the rareness of the ensemble pattern was used to measure the creativity in the rhythmic communication. Moreover, music emotion was shown to be correlated with EEG signals [6,7] and other physiological indices [8]. Multiple regression analysis of EEG signals with these indices was expected to be able to decompose sub-process of creativity in the social behavior.

2 Methods

Twelve subjects with mean age of 21.0 years (ranging from 20 to 22 years; 8 males, 10 right-handed) to part in the experiment after giving informed consent. All of them had no specific experience for musical instruments. The Ethics Committee in Future University approved the experiment.

A rhythmic communication task was performed by a set of three subjects with their eyes closed. Each subject used a keyboard with a single button to sound a note of different tone (528 Hz (C), 660 Hz (E) and 792 Hz (G) with a 100 ms duration). The subjects were asked to tap the button with their right finger voluntary while listening to the rhythms produced by others. Every subject participated in a session of 20 min.

During the task, EEG signals were acquired using two Neuroscan amplifiers (SymAmpI, Neuroscan, Texas, USA) with Ag/AgCl electrodes and a TEAC amplifier (Polymate AP-216, TEAC, Japan) with active electrodes. Electrodes provided 9 EEG channels (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4), an electro-oculography (EOG) channel and an electrocardiography (ECG) channel on left wrist. EEG data (0.3-100Hz band pass, 500Hz sampling rate) were referenced to a Fz electrode during measurement and re-referenced to linked-earlobes for analysis.

The following five regressors were considered in the multiple regression analysis of EEG signals. First was the tap interval (TI) of each subject. Second was the smallest shift of tap with others (TS). Preceding and following taps were given by positive and negative values, respectively. Third was the tap pattern information (PI) that was calculated by probability map of tap shifts with two others. This value was thought to associate with creativity in the rhythmic communication. Fourth was the heart beat interval (R-R interval, RRI) that was shown to correlate with the music perception [8]. Last was an index of parasympathetic nervous activity given by heart rate variability (HRV), log(LF/HF) where LF and HF denotes 0.04-0.15 Hz and 0.15-0.3 Hz component of R-R interval, respectively. This value was shown to correlate with emotion during performance and perception of music [9].

Tapping-related instantaneous frequency-energy characteristics for EEG were calculated with the Morlet wavelet transformation (width=6) from 4 to 20 Hz in 0.5 Hz step. Multiple regression analysis of the logarithmic EEG power at frequency f and time t from the k-th tap timing was performed by using the following equation [10]:

$$E(f, t, k) = \beta_0 + \beta_i(f, t) \sum_{i=1}^{5} R_i(t, k) \tag{1}$$

where R_i denotes value of the low-pass filtered(<1Hz) i-th regressor at time t with the k-th tap timing and β_i is regression slope for the i-th regressor that will be statistically evaluated. Taps with an interval less than 0.5 sec were discarded from the analysis. The comparison was made separately for each electrode, each frequency, and then averaged across all participants. Statistical value was given by $p < 0.001$ with spatial extent of 300 pixels in the frequency-energy map (time bin: 2 ms, spectral bin: 0.5 Hz) without any correction for multiple comparison.

3 Results

Fig.1a shows tap timing of three subjects. Distribution of the tap interval is shown in Fig.1b where average tap interval across all subjects was 0.64 ± 0.20 sec (ranged 0.27-0.91 sec). Tap intervals of three subjects in the same session appeared similarly distributed. Fig.1c shows a cross-correlation of tap sequences between two subjects in the same session, where the tap sequences in two sessions were found significantly synchronous at zero shift but those in the remaining two session were not (p<0.05). Fig. 1d-f show three repressors, the tap interval, the tap shift and the tap information. Tap intervals between subjects in the same session was found to be significantly correlated (with 0.5 Hz-sampling, r=0.08 (ranging from -0.04 to 0.16), t-value: 6.42, p<0.001).

Fig. 2 shows ECG signals of three subjects in the same session and their R-R interval and heart rate variability. Both of R-R interval and the heart rate variability were found to show significant inter-subject correlation (with 0.5 Hz-sampling, RRI: r=0.11 (ranging from -0.08 to 0.34), t-value:9.32, p<0.001; HRV: r=-0.07 (ranging from -0.18 to 0.23), t-value: 5.58, p<0.001).

Before applying these regressors to EEG regression analysis, collinearity of these regressors should be evaluated. Variance inflation factor among five regressors were found less than 1.3 indicating that the collinearly was not a problem in the regression analysis. However, correlation between R-R interval and the heart rate variability was found to be ranged widely in comparison to others (Fig. 3). Thus, four regressors except for the heart rate variability were applied to the following regression analysis.

Fig.4 shows EEG signals at a Cz electrode of three subjects in the same session. Fig. 4b shows a time-frequency plot of EEG wavelet power of a subject,

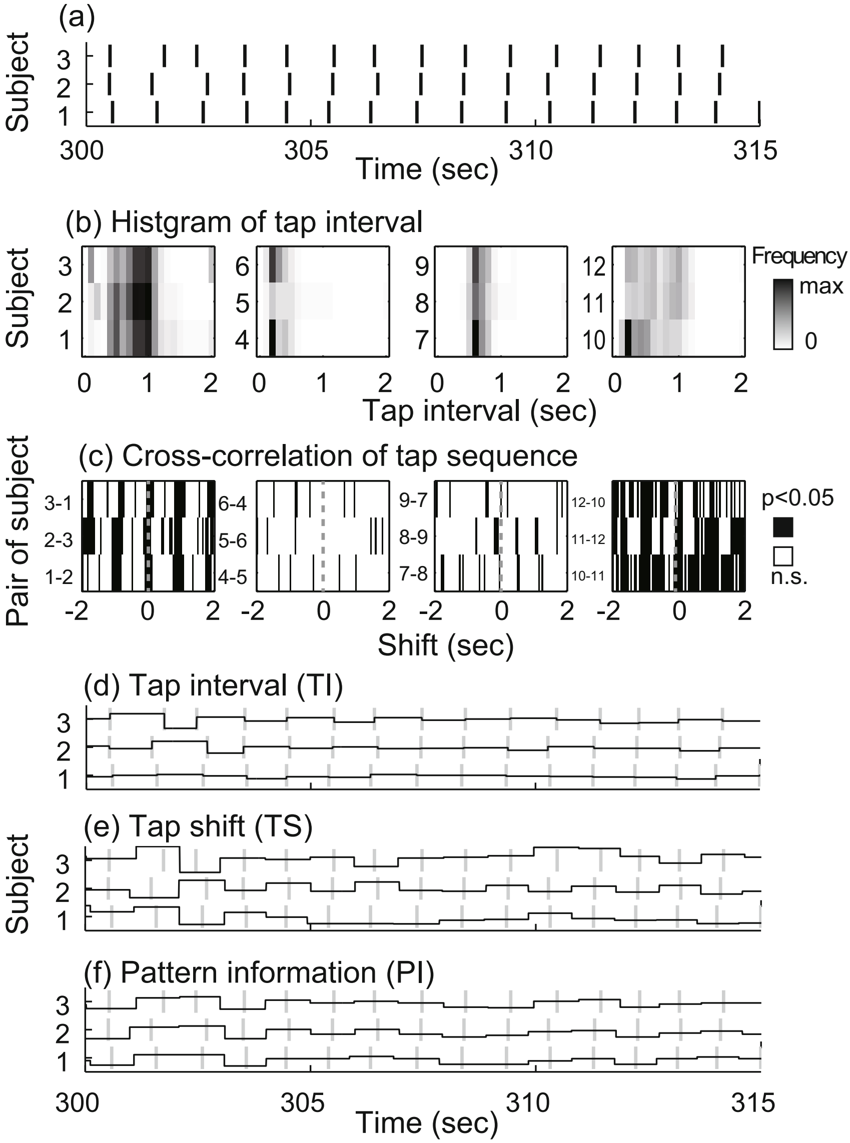

Fig. 1. Result of tap sequences. (a) Tap sequences of three subjects in a session. (b) Distributions of tap interval of each subject. Different map indicates different session. Tap frequency is shown by gray scale. (c) Cross-correlation of tap sequences between two subjects in the same session. Black represents significant correlation defined by the permutation test ($p<0.05$). (d, e, f) Temporal evolution of three kinds of repressors, tap interval (d), tap shift (e), and tap pattern information (f). Vertical lines indicate tap timing of each subject.

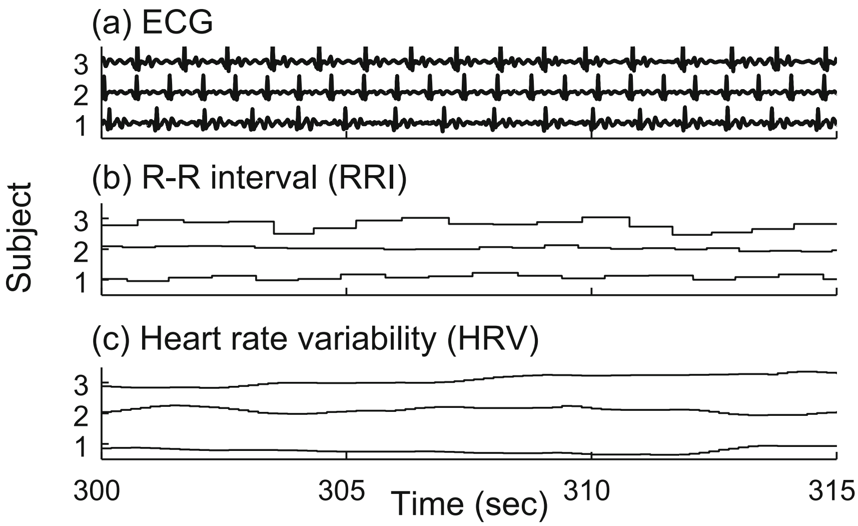

Fig. 2. Result of ECG signals. (a) Temporal evolution of ECG signals of three subjects. (b, c) Temporal evolution of two regressors, R-R interval (b) and heart rate variability (c).

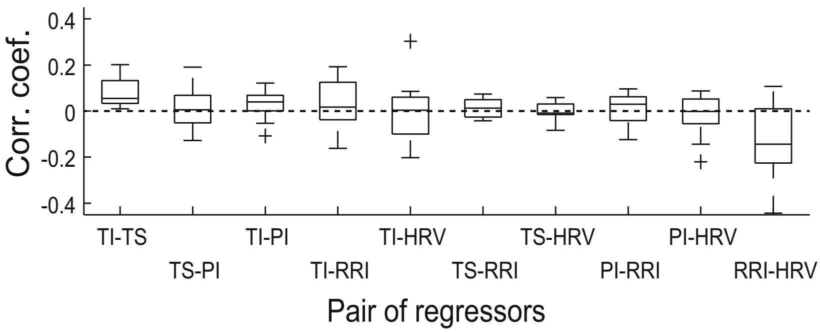

Fig. 3. Correlation coefficient between regressors

where the continuously increase of alpha-band power in EEG and no obvious tap-related change were shown. When the induced EEG power with a baseline of the averaged power from -300 to -200 ms before tapping was calculated, a significant increase of beta-band power was found at the tap timing dominantly in the left hemisphere. Since all tapping were performed with the right index finger, this effect is thought to be a motion-related activity.

Fig. 5 shows result of multiple regression analysis. Tap interval was found to correlate with EEG 12 Hz power where topographic pattern of the statistical value was shown dominantly in the frontal region. Tap shift showed a significant correlation to the EEG 6 Hz power after 250 ms of tap timing. Tap pattern information was found to correlate with EEG 10 Hz power before the tapping. R-

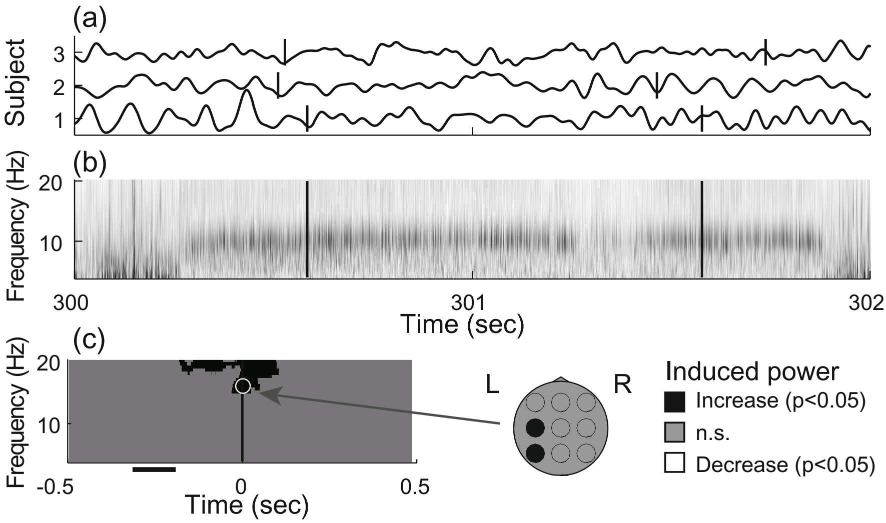

Fig. 4. Result of EEG measurement. (a) Temporal evolution of EEG at a Cz electrode. (b) Time-frequency plot of EEG wavelet power of Subject 1. (c) Induced EEG power of tapping where baseline was given by averaged EEG power from -300 to -200 ms of the tap timing. Black and white indicate significant increase and decrease of EEG power, respectively. Figure in right column shows a topographical map of the statistical value for the induced EEG power.

R interval was shown to significantly correlate with EEG 10 Hz power dominantly in the occipital region. These results indicated that the different aspect of the rhythmic interaction can be associated with different components in the EEG ranging over spectral band and locations in the topographical map.

4 Discussion

Three spectral band powers in the EEG were found to be significantly correlated to regressors that were expected to associate with rhythmic communication (Fig. 6). First, the decreases of lower alpha-band power in the occipital region were shown to associate with the rareness of ensemble pattern. This effect may be thought to associate with creativity during rhythmic communication. However, the desynchronization of occipital alpha is also known to associate with the attention during oddball tasks (see a review by Klimesch (1999) [11]) and social coordination [2]. Second, the decrease of upper alpha-band power in the frontal region was found to associate with the slower tempo of the tapping. Although the desynchronization of upper alpha is thought to be associated with semantic memory [11], the interpretation of the current result is unclear. Third, the decrease of theta-band EEG power in the frontal region was found to correlate with the preceding tap in the ensemble. In the previous reports, the decrease of frontal midline theta was shown to associate

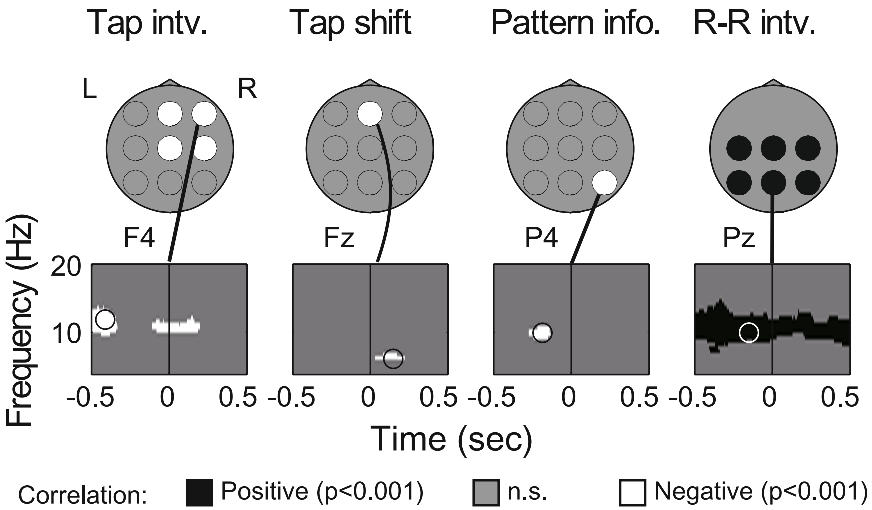

Fig. 5. Result of multiple regression analysis. Upper topographic map shows the statistical values for regression slopes of each regressor, of which time and frequency were chosen by a point in the time-frequency plots of the statistical values showing the largest statistical value over all electrodes. Circle indicates location of each electrode. Black and white indicate positive and negative correlations, respectively. Lower plot shows time-frequency map of the statistical value at an electrode having the largest statistical value.

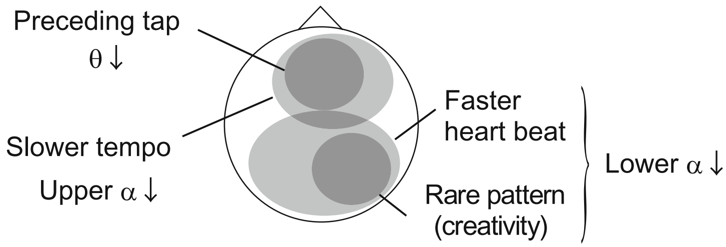

Fig. 6. Summary of the results. Decrease in the upper and lower alpha-band powers and the theta-band power in the EEG over distributed region were found to associate with the rhythmic communication.

with unpleasant music [6], episodic memory encoding [11] and smaller mental effort. The current result may be interpreted as that the preceding tap needed a lower mental effort in comparison to the following tapping.

The current task of rhythmic communication was shown to be useful as a tool for decomposing multiple brain dynamics during the communication. However, there are some concerns that should be improved. First, it may be a problem that the ensemble appeared monotonic and noteless and its tempo was mostly constant (see, Fig. 2b). To induce a more rich and musical ensemble, some explicit instructions on the individual role in the ensemble may be necessary. Second, the set of regressors was not unique and the regressor associated with creativity should be further explored. In the current study, the tap pattern information was used to measure the rareness of the ensemble pattern, but in the future it should be improved to detect 'creative' ensemble pattern.

In summary, the current results suggest that the multiple aspects of social communication associated with different spectral components in the EEG and the cross-frequency dynamics of the EEG over cortical areas are essential for understanding the creativity during social behavior. As a future study, inter-subject EEG dynamics may be also important for understanding their more detailed roles in social communication.

Acknowledgments. This work was supported by a Grant-in-Aid for Scientific Research on Innovative Areas "Neural creativity for communication (No.4103)" (24120714) of MEXT, Japan.

References

1. Adolphs, R.: Cognitive neuroscience of human social behaviour. Nat. Rev. Neurosci. 4, 165–178 (2003)
2. Tognoli, E., Lagarde, J., DeGuzman, G.C., Kelso, J.A.: The phi complex as a neuromarker of human social coordination. Proc. Natl. Acad. Sci. USA 104, 8190–8195 (2007)
3. Hasson, U., Ghazanfar, A.A., Galantucci, B., Garrod, S., Keysers, C.: Brain-to-brain coupling: a mechanism for creating and sharing a social world. Trends Cogn. Sci. 16, 114–121 (2012)
4. Dietrich, A., Kanso, R.: A review of EEG, ERP, and neuroimaging studies of creativity and insight. Psychol. Bull. 136, 822–848 (2010)
5. Repp, B.H.: Sensorimotor synchronization: a review of the tapping literature. Psychon. Bull. Rev. 12, 969–992 (2005)
6. Sammler, D., Grigutsch, M., Fritz, T., Koelsch, S.: Music and emotion: electrophysiological correlates of the processing of pleasant and unpleasant music. Psychophysiology 44, 293–304 (2007)
7. Schmidt, L.A., Trainor, L.J.: Frontal brain electrical activity (EEG) distinguishes valence and intensity of musical emotions. Cognition and Emotion 15, 487–500 (2001)
8. Krumhansl, C.L.: An exploratory study of musical emotions and psychophysiology. Can. J. Exp. Psychol. 51, 336–353 (1997)
9. Nakahara, H., Furuya, S., Obata, S., Masuko, T., Kinoshita, H.: Emotion-related changes in heart rate and its variability during performance and perception of music. Ann. New York Acad. Sci. 1169, 359–362 (2009)
10. Jacobs, J., Hwang, G., Curran, T., Kahana, M.J.: EEG oscillations and recognition memory: theta correlates of memory retrieval and decision making. NeuroImage 32, 978–987 (2006)
11. Klimesch, W.: EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res. Brain Res. Rev. 29, 169–195 (1999)