MEG-based Brain-Geminoid Interface Using Bilateral Motor Imagery Characteristics

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Background:

A brain machine interface (BMI) provides the possibility of controlling artificial arms for patients with severe motor dysfunction by only using their thoughts. However, most of researchers have been using only unilateral hand movements for decoding motor imagery which are not enough for daily-life applications. To provide multidimensional control, we describe the first reported decoding of bilateral hand movements by using single-trial magnetoencephalography (MEG) signals as a new approach to enhance a user’s ability to interact with a complex environment through a multidimensional BMI. In addition, bilateral movement requires multitask processing whose neural correlates remains unclear. In order to study the multitasking neural process, we analyzed and decoded the brain activity for four types of bilateral hand movements using non-invasive MEG measurement. Furthermore, we have been working on controlling not only bilateral arms but also an additional third arm using brain activity.

Methods:

Ten healthy participants participated in this study. These participants were instructed to grasp or open both hands once at the time of the execution cues given visually and aurally. For experimental paradigm, four classes of bilateral movement were presented on the screen and 10 sessions of MEG recording were conducted. Each session included 20 movements for each class. To reduce motion artefacts, the participants were instructed to perform the actual or imagined movement without moving any other body part. The order of the movement type instructions was randomized. Furthermore, a 3 T structural MRI scan was performed to more clearly obtain detailed images of the head and brain structures in slices for each subject.

Results:

Regarding MEG preprocessing, we used the spatio-temporal signal space separation method for reducing magnetic noise and calculated the average of 100 trials for each class and its sensor-based time-frequency distribution. Using sensor levels analysis, we observed a clear bilateral activation around the sensorimotor area with the four movement types. For offline decoding the real and imagined bilateral movements, the Gaussian radial basis function kernel support vector machine achieved binary classification results near the real-time BMI requirement (i. e., a classification accuracy of 70%), whereas the multi-class SVM

algorithms achieved individual decoding results with a classification accuracy approximately twice the chance level using single-trial classification. None of these results fell near or below chance level.

To demonstrate the efficacy of bilateral hand movements decoding in real world applications, we controlled a Geminoid (humanlike robot) by sending commands from Osaka to Kyoto, Japan. The implementation of the control application was divided into three modules, the MEG signal acquisition, decoding module and the Geminoid control module. MEG signals were recorded every 1 s using real-time FieldTrip toolbox, the classification algorithm module was implemented in MATLAB, the Geminoid control module (control's logic) was implemented using the Java. The last two modules interfaced with each other via TCP/IP protocol. In real-time tests, two subjects were asked to perform real-time control of humanlike robot hands with two commands based on their bilateral hand movements. For calibration phase, the participants achieved an average accuracy of 72. 5% for contralateral hand movements and 77% for ipsilateral hand movements. For real-time test, the participants demonstrated reliable control of the humanlike robot hands, achieving an average accuracy of 63% for contralateral hand movements and 65,75% for ipsilateral hand movements using 80 single-trial for each class in real-time binary classification. Our results provided further proof that the slow components of neuromagnetic fields carry sufficient neural information to classify even bilateral hand movements and demonstrated the potential utility of decoding bilateral movements for engineering purposes such as multidimensional motor control.

Discussion:

All previous studies have decoded unilateral movements, such as right or left hand/finger/toe grasping, and tongue motions during real and imagined movements to achieve a practical real-time BMI control. These types of unilateral BMI tasks are not suitable for the development of multidimensional BMI systems that require higher dimensional control and more naturalistic BMI tasks such as bilateral arm/hand/finger movements. The present study investigated decoding the multi-class simultaneous bilateral hand movements of a subject in the context of a noninvasive multidimensional BMI for both voluntary control and motor imagery situations. We analyzed and decoded the sensorimotor activity associated with four types of bilateral hand movements, as determined using neuromagnetic event-related modulation, to obtain proof-of-concept evidence for multidimensional BMI applications. To our knowledge, no previous studies have investigated the analysis and classification of 4 types of bilateral hand movements by using noninvasive measurements.

As noted above, the present MEG experiments sought to provide a conceptual advancement and proof-of-concept. Notably, being able to decode bilateral hand movements is an important step toward understanding dual-task characteristics, thereby leading to enhanced multidimensional BMI control and performance. In summary, we used a single-trial SVM classification to distinguish among four types of bilateral hand movements by using MEG measurements in two scenarios: motor execution and motor imagery. Regarding brain activation, the sensorimotor cortex showed discriminative time-series signals and power frequency distributions in bilateral hemispheres according to the four tasks. In addition, our decoding results demonstrated the potential utility of bilateral hand movement decoding for engineering purposes such as multidimensional BMI control. Although further studies are required, our decoding results suggested that our BMI protocol may enhance human multitasking ability through the use of multidimensional brain-controlled prosthetic devices.

Index Terms— Bilateral movements, Brain-machine interface, Geminoid, Magnetoencephalography, Motor imagery, Voluntary motor control.