Big Dataset for 11 intuitive movement tasks from single upper Limb

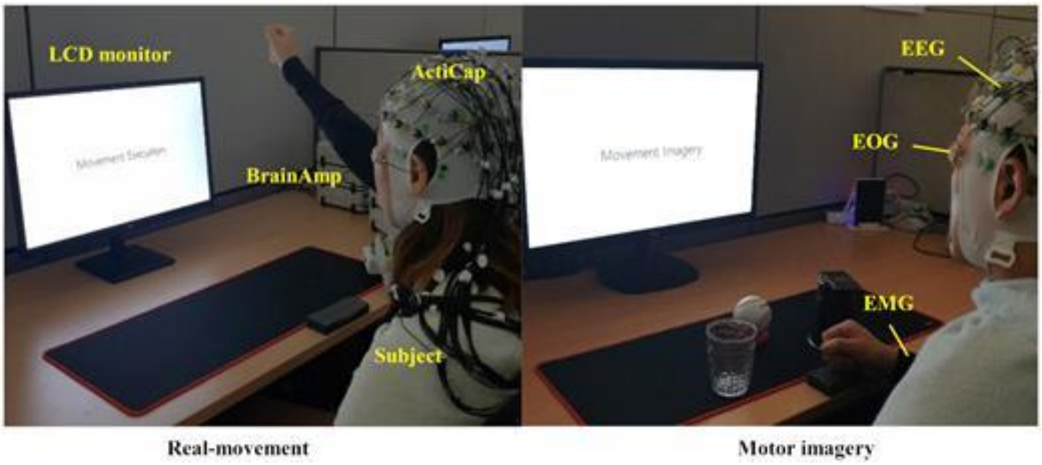
Participants

Twenty-five participants (all right-handed, aged 24–32 years, 15 men and 10 women) who were naive BCI users participated in the experiments. They were healthy individuals with no known neurophysiological anomalies or musculoskeletal disorders. Before the experiments, they were informed about the experimental protocols, paradigms, and purpose. After ensuring that they had understood the information, they provided their written consent according to the Declaration of Helsinki. The participants signed a form that agreed to the anonymous public release of their data. We checked their physical and mental states so that the influence of the BCI performance could be compared according to individual state. Additionally, each participant was required to be in normal health, get sufficient sleep (~8 h), and avoid alcohol, caffeinated drinks, and strenuous physical activity before the experiments. All the experimental protocols and environments were reviewed and approved by the Institutional Review Board (IRB) at Korea University (1040548-KU-IRB-17-181-A-2).

Environment

During the experiments, each participant was comfortably seated in a chair with armrests facing the front of an LCD monitor, ~80 ± 5 cm away from each other [30]. An EEG cap (Fig. 1) with 60 channels (actiCap, BrainProduct GmbH, Gilching, Bayern, Germany) was placed on the head of each participant. Surface EMG and EOG electrodes were attached to pre-assigned locations on the right arm and around the eyes of each participant, respectively. The participants were then asked to perform the movements with relaxed muscles and minimum eye and body movements during the data recording.

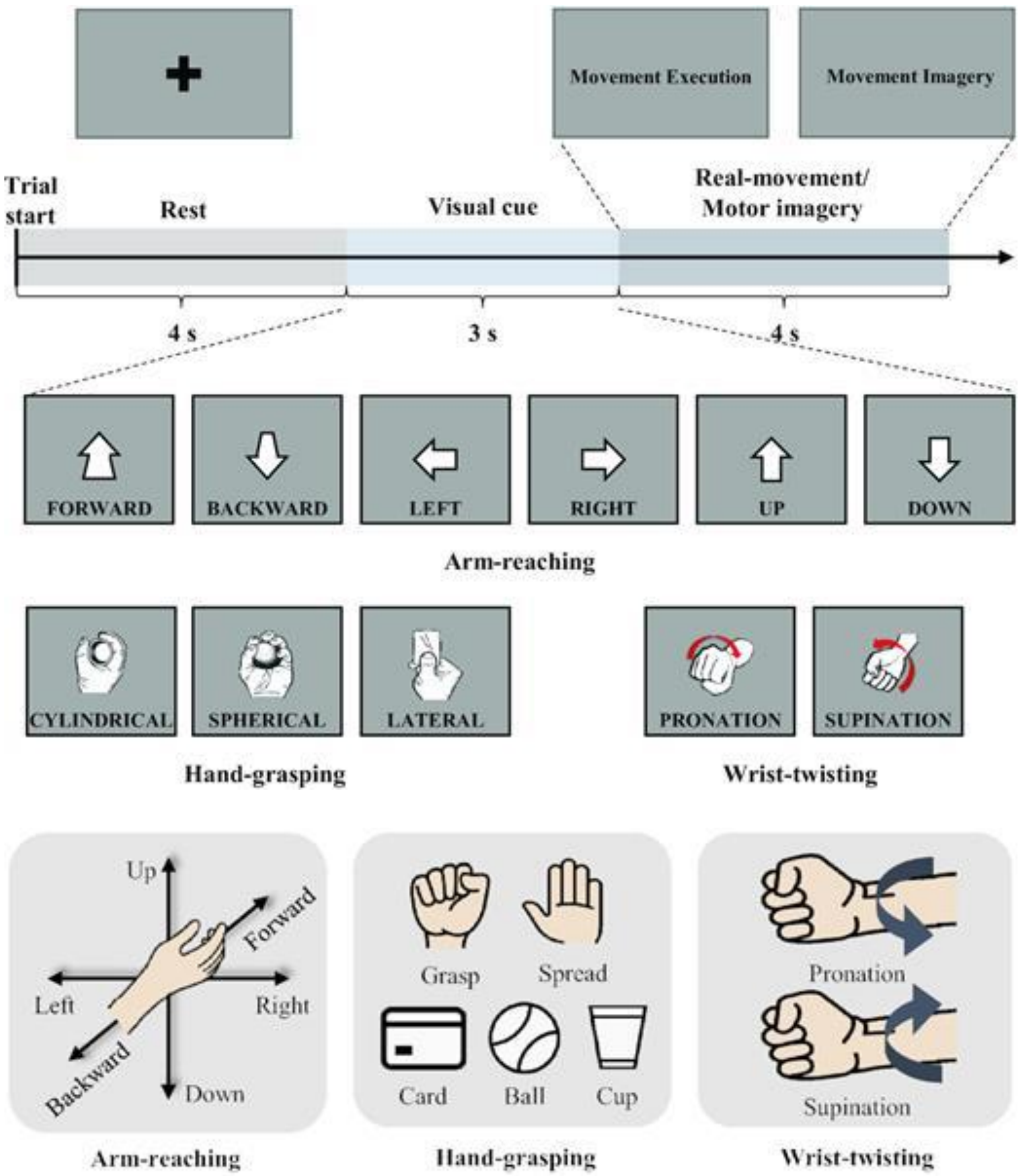
The duration of the experiment was ~6-7 h a day. Our experiment comprised multiple recording sessions (3 days) to consider inter-session and inter-participant variabilities. Compared with typical BCI experiments, our experiments required a longer recording time. To maintain the physical and mental condition of the participants and thus ensure high signal quality, the participants took sufficient breaks between each task. During the breaks, we first confirmed the physical and mental condition of the participants through self-report. If they reported any inconvenient position or unstable condition, we either adjusted the experimental environment according to their requests or halted the experiment. In the case the experiment was halted, the participants could ask to conduct the experiment next time or withdraw from the experiment altogether. However, if the conditions of the participants were good to conduct the experiment, we checked the impedances of the EEG, EMG, and EOG electrodes and injected electrolyte gel into them to maintain impedance values <15 kΩ. Thus, we attempted to obtain clear signals excluding spontaneous noise due to muscle and mental fatigue during the recording.



Experimental paradigm

The experiment was designed to quantitatively acquire data related to the 11 different upper extremity movements for both real-movement and MI tasks. The participants conducted the experimental tasks using the same limbs. Decoding different tasks related to the same limb by using EEG signals could increase the number of possibilities of controlling the BCI system compared with typical somatosensory rhythm–based BCIs, which often only detected left/right hand and foot imagery [27]. The experimental tasks comprised 3 main upper extremity motions: arm-reaching, hand-grasping, and wrist-twisting. When the experiment began, visual instructions were provided on the monitor by displaying a black cross sign on a gray background. The participants stared at the visual instructions for 4 s while resting. After resting, a visual cue was displayed on the monitor with a text sign for 3 s, following which the participants began preparing to perform the real-movement or MI tasks according to the visual cue (see Fig. 2). Upon changing the visual cue to a text sign reading “Movement Execution” and “Movement Imagery,” the participants performed the corresponding tasks during 4 s. During the real-movement tasks, the participants were asked to focus on the sensations involved with each motion and to remember those sensations for the MI tasks.

Arm-reaching along 6 directions: The participants were asked to perform multi-direction arm-reaching tasks directed from the center of their bodies outward. They performed the tasks along 6 different directions in 3D space: forward, backward, left, right, up, and down, as depicted in Fig. 3. In the real-movement tasks, the participants extended their arms along 1 of the directions. The arm-reaching paradigm required 50 trials along each direction so that data could be collected for a total of 300 trials. However, in the MI tasks, the participants only imagined performing an arm-reaching task; the number of trials in the MI paradigm was the same as in the real-movement paradigm.



Hand-grasping 3 objects: The participants were asked to grasp 3 objects of daily use via the corresponding grasping motions. They performed the 3 designated grasp motions by holding the objects, namely, card, ball, and cup, corresponding to lateral, spherical, and cylindrical grasp, respectively (see Fig. 3). In the real-movement tasks, we asked the participants to use their right hands to grasp a randomly selected object and hold it using its corresponding grasping motion. Eventually, we acquired data on 50 trials for each grasp, and hence, we collected 150 trials per participant. In the MI tasks, the participants performed only 1 of the 3 grasping motions per trial, randomly. The number of trials in the MI paradigm was the same as that in the real-movement paradigm.

Wrist-twisting with 2 different motions: For the wrist-twisting tasks, the participants rotated their wrists to the left (pronation) and right (supination), as depicted in Fig. 3. During real-movement task, each participant maintained his/her right hand in a neutral position with the elbow comfortably placed on the desk. Notably, wrist pronation and supination are complex actions used to decode user intentions from brain signals. Additionally, these movements are intuitive motions for realizing neurorehabilitation and prosthetic control [31]. We collected data for 50 trials per motion (i.e., total 100 trials) per day, and the visual cues were randomly displayed.

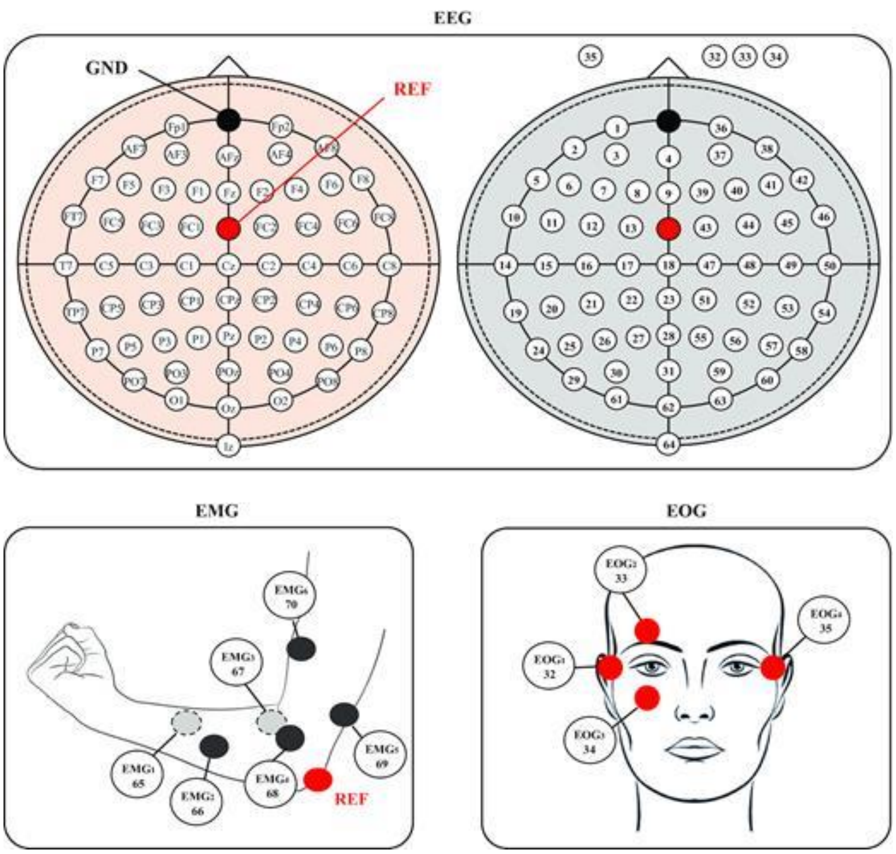
Additionally, the participants were asked to participate in 3 recording sessions with a 1-week interval between each session. The experimental environment and protocols were the same for all 3 sessions. Consequently, we collected data from 3,300 trials (1,800 trials for arm-reaching, 900 for hand-grasping, and 600 for wrist-twisting) in all classes per participant, for both real-movement and MI paradigms.

Data records

We simultaneously collected 3 different kinds of physiological signals, namely, EEG, EMG, and EOG signals for 11 different upper extremity movements (see Fig. 3). During the experiment, the signals were acquired using the same digital amplifier and types of electrodes. Therefore, the raw signals were stored together in 1 data file according to each participant. To obtain high-quality signals, the impedances of all the channels were maintained to be <15 kΩ. After applying conductive gel to the electrodes, we validated the accuracy of the EEG and EOG signals by asking the participants to blink and close their eyes. The eye-blinking task was used to identify strong spikes in the frontal EEG channels (e.g., Fp1 and Fp2) and 4 EOG channels. The eye-closing task was used to confirm the α oscillations in the occipital channels (e.g., O1, O2, and Oz). We also asked the participants to perform a simple hand-grasping motion to confirm the strong spikes in the EMG signals.

EEG signals

The EEG data were recorded in conjunction with an EEG signal amplifier (BrainAmp, BrainProduct GmbH, Germany), sampled at 2,500 Hz. Additionally, we applied a 60 Hz with a notch filter to reduce the effect of external electrical noises (e.g., DC noise due to power supply, scan rate of the monitor display, and frequency of the fluorescent lamp) in raw signals [21,32,33]. The raw data were recorded using BrainVision (BrainProduct GmbH, Germany) with MATLAB 2019a (MathWorks Inc., USA). Furthermore, a toal of 60 EEG electrodes were selected by following a 10-20 international configuration (Fp1-2, AF5-6, AF7-8, AFz, F1-8, Fz, FT7-8, FC1-6, T7-8, C1-6, Cz, TP7-8, CP1-6, CPz, P1-8, Pz, PO3-4, PO7-8, POz, O1-2, Oz, and Iz). Ground and reference channels were placed on the Fpz and FCz, respectively (see Fig. 4). The impedances of all the electrodes between the sensors and scalp skin were maintained to be <15 kΩ. During breaks, conductive gel was injected into the electrodes using a syringe with a blunt needle.



EMG signals

The EMG signals were recorded using 7 silver/silver chloride electrodes from the digital amplifier, the same equipment used to record the EEG signals. We simultaneously acquired the EMG and EEG signals using the same amplifer [34]. The signals were captured at a sampling rate of 2,500 Hz with a 60 Hz notch filter, the same as the setting used to record the EEG signals. The EMG data were recorded from 6 related muscles for right arm movement: extensor carpi ulnaris, extensor digitorum, flexor carpi radialis, flexor carpi ulnaris, biceps brachii, and triceps brachii (see Fig. 4) [35]. The ground and reference were recorded in Fpz and FCz, respectively, which are the same as the EEG and EOG signals. The last electrode was placed on the elbow of the right arm, which is a non–muscle movement area, as an alternative reference signal [36]. The purpose of recording EMG signals was to detect muscle activities when the participants performed the designated tasks. The signals could prove that the participants performed MI tasks without muscle movement. Simultaneously, the electrodes were placed so as to record a sufficient number of signals from various arm and hand movements (i.e., 6 arm-reaching, 3 hand-grasping, and 2 wrist-twisting motions).

EOG signals

The EOG signals were recorded using 4 channels while following the same protocol. Subsequently, the FT9, FT10, TP9, and TP10 electrodes were moved to the region around the eyes to function as EOG channels to eliminate artifacts due to ocular activities. One of these channels was moved to the region around the left eye and the others to the region around the right eye (see Fig. 4). The electrodes EOG_1 and EOG_4 were used to record horizontal eye movements, while EOG_2 and EOG_3 were used to record vertical movements [37]. Medical tape was used to hold the sensors around the eyes and maintain the impedances of all the electrodes to be <15 kΩ.