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Noninvasive EEG Based Control of a Robotic Arm for Reach and Grasp Tasks

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Introduction: It is of significance to develop brain-computer interface systems controlling external devices or prosthetic limbs [1]. Noninvasive electroencephalography (EEG) based control of a robotic arm for reaching and grasping targets by motor imagination in real world was explored in this study. Compared with BCI studies in virtual environments [2], interaction with physical device might greatly motivate the subjects to engage into the experiments [3]. We aim to test the hypothesis that human subjects using motor imagination protocol can operate a robotic arm reliably, from sensorimotor rhythms detected from noninvasive scalp EEG.

Material, Methods and Results: EEG data were recorded for six subjects by a 64 channel Neuroscan cap, among which EEG channels over left and right motor cortex were utilized to be the online control signals. Each subject performed eight to eleven sessions of instructed experiments including virtual cursor control and physical robotic arm control. Each subject first performed one to four sessions of virtual cursor experiments as training and then progressed to two sessions of reaching and grasping with four targets via the robotic arm and three sessions of reaching and grasping with five targets via the robotic arm, all while the moving cursor was displayed on the monitor (**Fig. 1a**). Finally, they performed two extra sessions of reaching and grasping via the robotic arm with four and five targets in absence of the virtual cursor movement. All of the protocols were approved by the Institutional Review Board of University of Minnesota. EEG activity from the control channels were spatially filtered and then fed into an autoregressive model to extract the power spectra features. The power activities in the upper mu frequency band over the left and right hemisphere were linearly mapped to the position of the robotic arm. The robotic arm, which is a seven degree of freedoms human-like robotic arm, was mounted on the right side of the subject (**Fig. 1a**). A two-step task was employed to assist the participants' ability to reach and grasp an object in 3D space. The robotic arm moved in a horizontal plane in the first step and moved vertically in the second step.

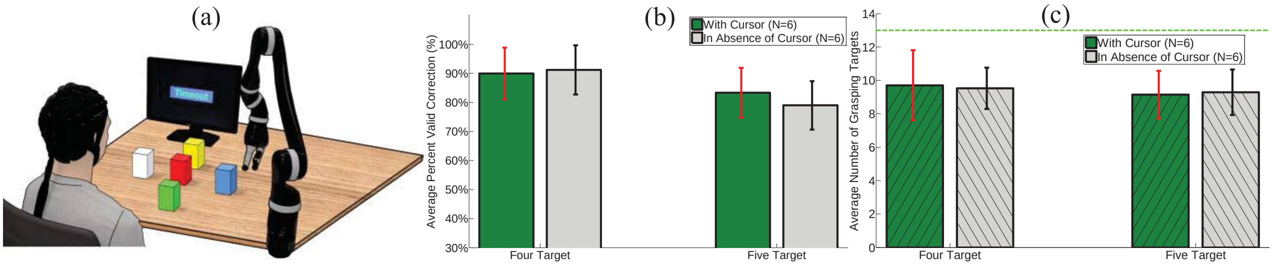

***Fig. 1** (a) Experimental paradigm for 5 targets reaching and grapsing. (b)Group average PVC of 4 and 5 targets reaching and grasping with and in absence of cursor movement. (c) Group average number of blocks grasped for the same two tasks with and in absence of cursor movement.*

Fig. 1b shows the group average percent valid correction (PVC) for the four targets and five targets reaching and grasping tasks on the left side and right side of the plot, respectively. The green bar shows the results of reaching and grasping with the cursor displayed on the monitor and the gray bar shows the same results in absence of cursor movement, in which only designated target to be grasped was shown. The group average PVC for six subjects of reaching and grasping with four targets was about 90%, which was similar to the corresponding results in absence of cursor (~91%). The group average PVC of reaching and grasping with five targets was about 83% and the corresponding results in absence of cursor was about 79%. The group average number of blocks for grasping four targets and five targets in each run are 9.7±2.1 and 9.2±1.4, respectively, where 26 trials in each run were completed in about six to nine minutes and each session consisted of four or five runs. The maximum number of blocks (targets) in each run that can be grasped was 13. The group average numbers of blocks for counterparts in absence of cursor in each run are 9.5±1.2 and 9.3±1.4, respectively.

Discussion: With the motivation of controlling a real robotic arm to accomplish a series of reaching and grasping task, the majority of subjects showed high and consistent accuracies in the relatively longitudinal sessions. The comparison of results between the controlling the robotic arm with virtual cursor and in absence of virtual cursor indicates that there is no significance difference between the two conditions. This implies that controlling a robotic arm by the input of either a remote terminal or subjects' direct visual input would show similar performance.

Significance: We demonstrate the capability for human subjects to control a robotic arm from noninvasive EEG for reaching and grasping tasks in 3D space. Our promising results indicate that noninvasive EEG based BCI is able to provide high precision and efficiency for controlling a robotic arm to finish complex reaching and grasping tasks in a real world. This promising finding indicates potential in future applications of noninvasive BCI for neuroprosthetics.

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