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Effect of Grasping Speed During Wearable Robotic Glove-Based Motor Imagery Training

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***Abstract*—Wearable robotic gloves have recently gained attention in the field of rehabilitation for their ability to support the movement of affected hands. One of the widely used rehabilitation methods for grasping is through action observation, where participants continuously monitor specific actions while thinking as if they were performing the bodily movements themselves. While previous studies claim that such a method, based on the mirror neuron system, may effectively induce brain activity related to corresponding movements, it is unclear how the speed of grasping movements may affect neural activity performance. In this paper, we conducted a preliminary study with healthy participants to investigate whether the speed of grasping from a wearable robotic glove may influence the motor imagery performance of users during action observation. Our results show that using a wearable robotic glove to demonstrate grasping movements improves motor imagery performance compared to when no movements are provided. Additionally, our experiment conveys that the grasping speed of the wearable glove has an impact on motor imagery performance. Our study highlights that detailed experimental designs, such as manipulating grasping speed for action observation, play an important role in rehabilitation.**

***Keywords*—electroencephalogram (EEG), wearable robotic glove, rehabilitation, motor imagery, event-related desynchronization (ERD)**

I. INTRODUCTION

Motor imagery, the imagination of specific body movements without actual execution, is often used to improve neural activity in patients during clinical trials and rehabilitation. It induces a decrease in oscillatory rhythms known as event-related desynchronization (ERD) in sensorimotor areas and specific patterns in cortical areas related to the imagined body part [1]. This advantage allows motor imagery to be used not only as a measure of neural activity performance but also as a control paradigm for brain-computer interfaces [2]–[4].

Action observation for motor imagery is a widely used method in rehabilitation to help users induce better neural activation. Its approach of providing a visualized body part movement related to the motor imagery task aligns with the theoretical background of mirror neuron theory and has been shown to improve brain activation in many previous studies [5]–[7]. Specifically, in terms of hand rehabilitation, the way the movement is visualized for action observation is considered to be a critical factor. Recent studies have investigated the effect of embodiment, which relates to the sensation that users perceive movement as if they are actually performing the action. Previous studies have employed various visualizations to highlight the significance of embodiment in enhancing motor imagery performance. These include comparisons of participants' own hand movements with those of others [8], simulations on 2D monitors versus 3D immersive virtual reality [9], and the presence or absence of anatomical compatibility for simulated hand observation [10]. Wearable robotics is another rising tool that aims to improve the sense of embodiment while preserving the functionality of other supportive devices [11], [12]. Unlike traditional devices such as robotic arms, wearable robotics overlaps the affected body parts of users and assists them in executing certain actions. Due to its advantages, wearable robotics has been utilized in many experimental trials to induce better motor imagery performance from users.

Although many studies have utilized various visualization tools and devices to provide better embodiment for hand rehabilitation, providing observatory actions also relies on other experimental factors. For instance, it is unclear whether the speed of grasping for action observation affects the performance of users with motor imagery. Other variations, such as how the presented hands are placed and the detailed movement of each finger, may also influence users' perception, affecting their motor imagery performance. As individuals have varying perceptions and adaptability even within the same scenario [13], designing experimental procedures that consider such aspects may additionally serve as a critical component for rehabilitation performance.

While previous studies have focused on the visualized representations or devices employed to present the same grasping movement, our study aims to investigate whether the speed of grasping movement may influence the motor imagery performance of users. To explore this aspect, we asked our participants to perform sequences of right-hand grasping motor imagery tasks while wearing a wearable robotic glove. Three different action observation scenarios were presented using a wearable robotic glove: no movement, slow grasping movement, and fast grasping movement. To measure the motor imagery performance from the experiment, electroencephalogram (EEG) signals were acquired from participants while they were instructed to perform the given tasks.

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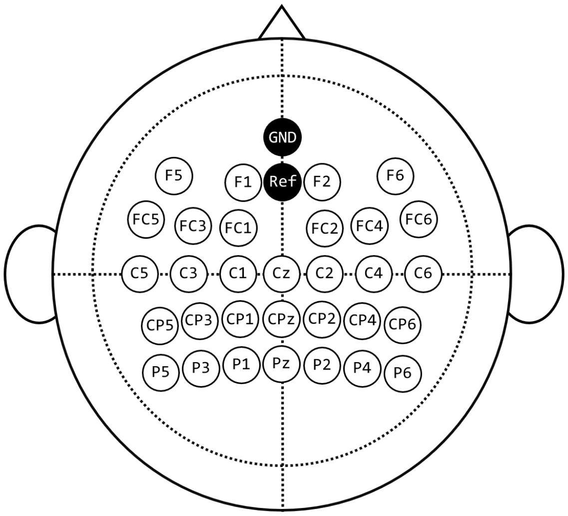

Fig. 1: The electrode positions used in our experiment. The positions in black represent the ground and reference locations.

II. METHODS

A. Participants

Six healthy participants (2 females, aged between 24 and 27) who had no neurological disorders volunteered for our experiment. All participants were given detailed instructions prior to conducting the experiment. In order to familiarize participants with our system, they were asked to experience our wearable robotic glove before EEG acquisition.

B. EEG Acquisition

The Brainvision antiCHamp system was used to collect EEG data from participants. The EEG of the participants was recorded using a total of 33 electrodes according to the 10-20 system as shown in Fig. 1, mainly located around the sensorimotor cortex with AFz and Fz as ground and reference electrodes, respectively. Brain signals were acquired at a sampling rate of 500Hz and a band-pass filter between 8 and 15 Hz was applied to the data to account for motor imagery-related EEG signals. The impedance of the electrodes were kept under 10 kΩ throughout the experiment to obtain high-quality data.

C. Experimental Procedure

Participants sat on a comfortable chair with a soundproof room in front of the monitor screen with a wearable robotic glove worn on their right hand as previously described in [14]. As shown in Fig. 2, the wearable robotic glove performs grasping movement through actuators and cables attached to the parts of the glove related to the palm, index, and middle fingers.

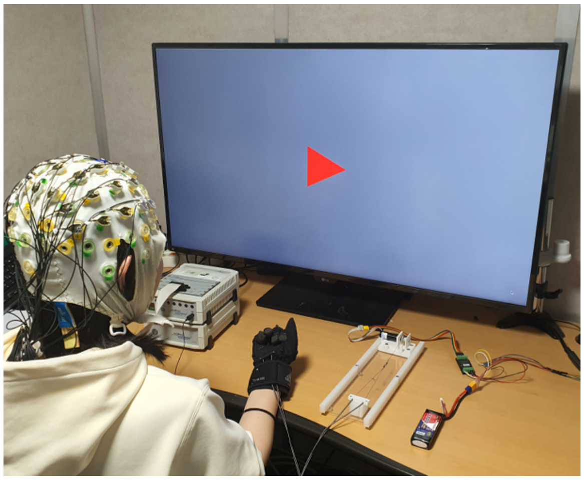

Fig. 2: Environmental setup for the experiment using a wearable robotic glove.

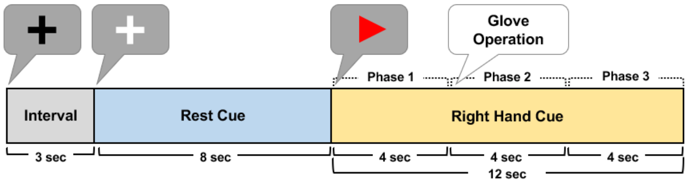

Fig. 3: The timeline of a single trial employed for our experiment.

A total of 30 trials were conducted for each participant, 10 each for the 3 wearable robot operations: no movement, slow grasping movement, and fast grasping movement. As shown in Fig. 3, the trial includes a 3-second interval period with a dark cross cue, an 8-second resting period represented by a white cross cue, and a 12-second right-hand cue indicated by a red arrow shown on the monitor screen. When the interval cue was shown, participants were instructed to adjust the wearable robotic glove by attempting to open their right hand. When the resting cue was shown, participants were asked to remain calm and not to perform any movement. When the right-hand cue was shown, participants were expected to perform right-hand grasping motor imagery for the entire 12-second period.

The right-hand period was divided into three different phases, each lasting 4 seconds. For the first phase, the wearable robotic glove remained open without any movement. In the second phase, the wearable robotic glove either remained open, performed slow grasping movement, or performed fast grasping movement depending on the trial. The wearable robotic glove stopped its execution during the last phase, maintaining its recent position for the rest of the phase. During the whole three periods, participants were instructed to continuously gaze at the wearable robotic glove while performing right-hand grasping motor imagery.

D. ERD ratio calcuation

We calculated the ERD value from the electrode C3 to quantify the motor imagery performance of participants, which is claimed to be the electrode position related to right hand

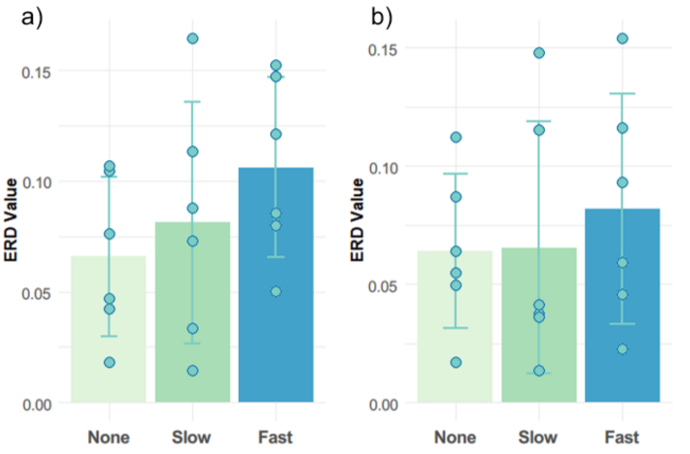

Fig. 4: (a) The average ERD value from only phase 2 on three different operations. (b) The average ERD value from three different operations considering all three phases.

movements. The ERD value of a single trial in this study was calculated using the following equation:

$$ERD_{phase} = \frac{PSD_{rest} - PSD_{phase}}{PSD_{rest}} \quad (1)$$

where PSD_{rest} indicates the power spectral density (PSD) measured from the last 4-second of the resting period of a trial and PSD_{phase} indicates the PSD measured from the whole 4-second phase of the trial.

The ERD value of each participant with respect to the three different operations was then calculated by averaging the ERD of all the corresponding trials.

III. Results and Discussion

The average ERD value results for only considering phase 2 and the average value combining all three phases are shown in Fig. 4. As shown in Fig. 4(a) where the averaged ERD values from phase 2 are shown for the three different operations, participants exhibited the least ERD (0.066) when no movement was performed by the wearable robotic glove. The average ERD value was the greatest when the robotic wearable glove executed fast grasping movement, with a value of 0.11. The ERD value during the slow grasping movement exhibited an average value of 0.081. While the ERD value for the slow grasping movement exceeded the ERD from when no grasping was performed, it was comparatively less than when fast grasping movement was performed.

The average ERD values considering all three phases were also measured for the three different operations, as can be seen in Fig. 4(b). The lowest ERD value was when no execution was performed by the wearable robotic glove, with a value of 0.064. The greatest ERD was from the fast grasping movement with a value of 0.082, while the slow grasping movement exhibited a relatively lower ERD value (0.065).

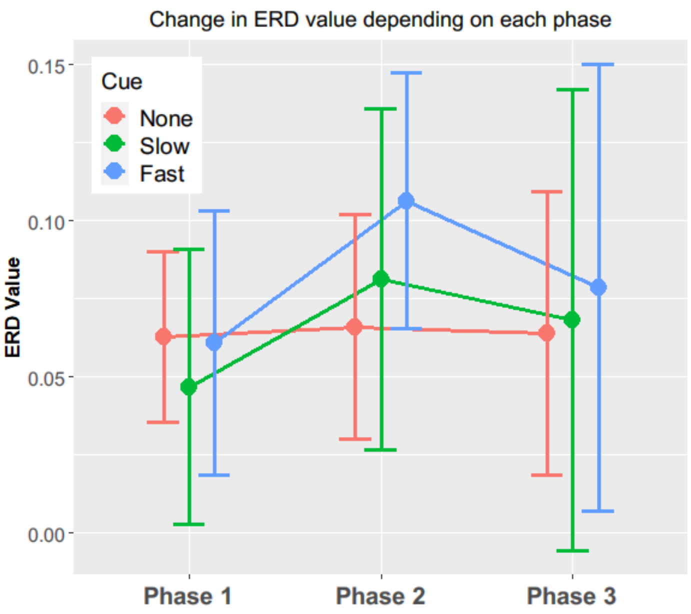

Fig. 5: The ERD values with respect to each phase while participants were performing motor imagery.

The changes in ERD values across the three phases are shown in Fig. 5. As can be seen from the figure, the ERD values increased from phase 1 to phase 2 and decreased from phase 2 to phase 3 in all three different operations. However, the degree of change differed between the operations. The increment and decrement of ERD values from when no movement was performed (increment: 0.003, decrement: 0.002) were relatively less than those of when slow grasping was performed (increment: 0.034, decrement: 0.013). Moreover, even larger incremental and decremental gaps were shown when fast grasping movement was performed (increment: 0.045, decrement: 0.028) compared to those of slow grasping. Such results indicate that the operation from the wearable robotic glove was the most effective in inducing motor imagery-based signals when fast grasping movement was performed. Furthermore, slow grasping also provided positive influences in supporting the motor imagery performance of participants. Consequently, our findings suggest that the presence of glove movement not only benefits motor imagery training, but that its grasping speed may also affect the performance of users during motor imagery training.

Although we have seen the effect of grasping speed for our wearable robotic glove during motor imagery training, there are some limitations in our study. As our experiments were performed with healthy participants, there are possibilities that other sensations besides visualizations, such as proprioception, may have also taken effect. Thus, whether the cause of neural activity enhancement lies purely on action observation needs further investigation. Furthermore, our study involves a limited number of samples. To perform statistical analysis, investigations involving more participants should be conducted as future work.

IV. CONCLUSION

In this paper, we performed a preliminary study with healthy participants to investigate whether the speed of grasping from the wearable robotic glove may influence the motor imagery performance of users during action observation. The results of our experiments indicate that a wearable robotic glove can support users' motor imagery performance. Moreover, our results indicate that grasping speed should be taken into consideration when designing experiments related to motor imagery training, as different grasping speeds may affect motor imagery performance. The results of our study suggest that not only rehabilitation tools but also a specific experimental design tailored to the target user may play an important role in rehabilitation.

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