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Full Length Research Paper

Differences in brain activation during motor imagery and action observation of golf putting

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The purpose of this research is to investigate the differences in brain activation between motor imagery and action observation by analyzing suppression of mu rhythm during motor imagery and action observation of golf performance. Eighteen male university students participated in the study and were randomly assigned to one of three groups: action observation, motor imagery with eyes open or motor imagery with eyes closed. During the experiment, the action observation group observed the putting performance of a model, whereas the other groups imagined golf putting with their eyes either open or closed. Electroencephalographic (EEG) activities were measured in 3 brain areas (C3, Cz and C4) while the participants performed experimental tasks and mu rhythm suppression was calculated based on the measured data. The calculated variable was analyzed by three-way ANOVA (3 groups × 3 distances × 3 brain areas) based on repeated measurement of the last 2 factors. Mu rhythm was suppressed more significantly in the action observation group compared to the two motor imagery groups. This result suggests that action observation can activate the brain areas involved in the performance of an actual task more effectively than motor imagery.

Key words: Motor imagery, action observation, cognitive intervention, electroencephalogram, modeling, mu rhythm.

INTRODUCTION

Motor learning refers to a relatively perpetual change in the ability to perform a motor skill caused by physical practice or experience. Learning a motor skill can be achieved through systematic and repeated physical practice. However, the fact that most motor skills have both physical and cognitive factors suggests that not only physical practice but also cognitive intervention methods, such as motor imagery and action observation, can facilitate motor skill learning (Magill, 2003). Motor imagery, which has been used as a representative cognitive intervention method, was found to facilitate motor learning by activating the neural and muscular systems involved in actual performance of the imagined task (Bonnet et al., 1997; Decety, 1996; Guillot and Collect, 2005; Guillot et al., 2007; Hale et al., 2003; Jeannerod and Frak, 1999). However, motor imagery has some limitations in application such as personal differences in imagery ability (De Beni et al., 2007; Mulder et al., 2007; Gregg et al., 2007), the learner's skill level (Mulder et al., 2004), and the learner's cooperation and concentration (Papadelis et al., 2007; Rebecca and Rogers, 2006). These factors can affect the efficacy of motor imagery. The question that remains is which cognitive intervention method can complement such motor imagery limitations to facilitate motor skill learning. The present research was conducted with the intention of examining the applicability of action observation as an alternative approach for motor imagery by comparing the different mechanisms between motor imagery and action observation.

Motor imagery refers to an internal stimulus that induces indirect experience of kinesthetic sense through mental representation of task performance (Gentili et al., 2006; Mulder et al., 2004). Properly performed motor imagery can induce a reaction pattern of neural and muscular systems that are similar to the performance of an actual task. According to research conducted by

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Filimon et al. (2007), the following areas of the cerebral cortex were activated both by the imagery of moving the hand to a specific point and by actual movement of the hand according to imagery using fMRI (functional Magnetic Resonance Imaging) to measure cerebral cortex activation: the dorsal premotor cortex, superior parietal lobe, and intraparietal sulcus. Furthermore, according to research involving imagery of abduction movement of the thumb using transcranial magnetic stimulation (TMS), the motor evoked potential of the abductor pollicis brevis increased during the task performing period compared to the resting period (Stinear and Byblow, 2003). In addition, the magnitude of the potential was modulated as time progressed, showing similarity to the pattern appearing during the performance of the actual task. On the contrary, the motor evoked potential of the abductor digiti minimi, which is not involved in task performance, showed no change during the task performance compared to the resting period. Such results suggest that motor imagery induces neural and muscular responses in the same way as performance of the actual task, and that such a mechanism can facilitate motor skill learning.

However, motor imagery has some limitations in application that can act as factors that suppress the motor learning promoting effect of motor imagery. The motor learning effect of motor imagery is maximized when a learner has the ability to carry out vivid and concrete imagery of performance and can control imagery according to his intention (Weinberg and Gould, 2007). There are personal differences in imagery ability (Gregg et al., 2007) and the age of the learner can also affect imagery ability (De Beni et al., 2007; Mulder et al., 2007). In addition, the learner's skill level can affect the efficacy of motor imagery, for example, the learning promoting effect cannot be expected from a learner lacking task experience because vivid motor representation of performance has not been developed in such a person (Mulder et al., 2004). Another common problem faced during the course of applying motor imagery is that there is no proper objective index for judging how much the learner is concentrating on the imagery of task performance and the level to which the imagery is concrete and vivid is unknown (Papadelis et al., 2007). Such limitations raise questions regarding the applicability of motor imagery as a cognitive intervention for facilitating motor skill learning, suggesting that a complementary alternative approach is necessary.

Previous research analyzed the activation pattern of the brain areas and muscles involved in the actual performance of the motions observed during the task performance of a model, and suggested that action observation can be used as an alternative intervention method for motor imagery (Baldissera et al., 2001; Buccino et al., 2001; Cochin et al., 1999; Gangitano et al., 2001). Action observation refers to observing the performance of other people, or a model in a video. According to recent neurophysiological and brain image studies regarding action observation, the areas of the brain and spinal cord involved in the performance of the actual task were activated during action observation with an increase of the motor evoked potential in the pertinent muscles (Cheng et al., 2005; Clark et al., 2003; Fadiga et al., 2005; Muthukumaraswamy et al., 2004).

For example, Muthukumaraswamy et al. (2004) found that while observing the action of holding an object with a thumb and a forefinger, participants showed a significantly lower mu rhythm of the sensory motor cortex compared to during the resting period based on the measurement of their electroencephalographic (EEG) activities in the cerebral cortex. In addition, Gangitano et al. (2001) measured the motor evoked potential in the muscles involved in actual task performance using TMS while subjects observed the motion of stretching the hand to hold an object. This revealed increased amplitude of the motor evoked potential during the observation of the hand motion and this pattern of increase varied depending on the changes in the observed motion. Such a result suggests that, like motor imagery, action observation can also be used as a cognitive intervention method to facilitate the learning of an observed task by inducing the activation of the neural and muscular systems involved in the actual task performance.

Action observation has been shown to actually facilitate the learning of diverse motor skills (Breslin et al., 2005; Hayes et al., 2007; Horn et al., 2002; Weeks and Anderson, 2000). For example, according to Hayes et al. (2007), the group that observed 3-ball cascade juggling performed more juggling cycles during the practice period and during the retention test compared to the control group, and showed a coordination pattern of the arms and a ball flight orbit pattern that were similar to those shown by the model. In addition, research conducted by Horn et al. (2002) involving elementary female soccer players and soccer ball kicking task showed that observation of visual modeling using a video improved the learner's movement pattern so that it became similar to that of the model.

These data showed that action observation can facilitate motor skill learning and suggests that action observation can be an alternative cognitive intervention method that can complement the limitations of motor imagery. Action observation provides a concrete and vivid stimulus regarding task performance, thereby contributing more effectively to the development of motor representation than motor imagery (Kim and Park, 2007). However, despite the anticipated positive effects, the effect of action observation as a cognitive intervention method for improving motor skill learning has not attracted as much interest as motor imagery. In order to judge the applicability of action observation, there must be an analysis of the differences in mechanism between motor imagery and action observation. The results of the present research provide information necessary for embodying a cognitive intervention method to improve the efficiency of skill learning in actual exercise training.

The purpose of this research is to investigate the differences in brain activation between motor imagery and action observation by analyzing suppression of mu rhythm during motor imagery and action observation of golf performance. Accordingly, the following hypothesis was set up for this research: if action observation for facilitating motor skill learning provides more vivid and concrete information than motor imagery during the course of cognitive intervention, and thereby results in greater activation of the brain areas involved, then the EEG rate of mu rhythm suppression would be higher during action observation than during motor imagery.

MATERIALS AND METHODS

Participants

This research involved 18 male university students of Keimyung University, Daegu, South Korea, aged 20 to 26 (average age: 24.2 years). Participants had normal or corrected-to-normal vision, and were all right-handed based on the evaluation of the handedness of Koreans (Kang, 1994). Prior to the experiment, all participants prepared a self-report about their task experience and disease history. All participants were confirmed to be beginners with no past experience in golf putting and with no history of neurological diseases. Each participant read and signed a written consent form. The experiment was conducted from March, 2010 to July, 2010 and followed all procedures in compliance with the Declaration of Helsinki for human subjects.

Experimental apparatus

The experimental apparatus used in the present experiment included video data for action observation, a motor imagery tool, and a measuring tool for EEG activities.

Video data for action observation

The video data for action observation used in this experiment were composed of golf putting performances and verbal directions. The purpose of using the videos was to activate the observer's brain areas related to the performance in the provided video, and to additionally develop cognitive representations regarding the performance. The video data was prepared by recording golf putting movement by a certified professional golfer using a high resolution digital camcorder (Sony HDR-SR7, Japan) followed by verbal directions. The video was edited according to the purpose of the experiment.

Motor imagery tool

An audio system was used in this experiment as a motor imagery tool to provide verbal direction regarding the procedure of golf putting performance. Using the audio system, a guided imagery experiment was conducted. As in the case of the action observation, the purpose of providing the audio information was to activate the participant's brain areas related to the performance of the actual task, and to additionally develop cognitive representation regarding the task performance. The audio information for motor imagery was composed of simple verbal directions about the procedure of putting performance, edited according to the purpose of the experiment. The content of the provided verbal direction about the procedure of putting performance was the same as the video data for action observation.

Measuring tool for EEG activities

EEG activities were measured in order to analyze the activation patterns of the brain areas during the imagery or observation of the task performance. Measurement of EEG activities was carried out using a cap (CAP100, BIOPAC System Inc.) manufactured according to the International 10 to 20% electrode system. Measurements were made at C3 (left central fissure), Cz (central fissure), and C4 (right central fissure). C3 and C4 correspond to primary sensory motor areas, whereas Cz corresponds to the supplementary motor area (Neuper and Pfurtscheller, 2001). These 3 areas of the brain are directly involved in the planning of motor command and output during the actual performance of a motor skill (Ulloa and Pineda, 2007). A reference electrode was attached to the right earlobe and gel for the Ag/AgCl electrode was injected into each electrode using a needle. The resistance of all the electrodes was reduced to below 5 kΩ using a glass resistance measurer (EZM 5AB). The electrical signal of the brain was amplified 50,000 times using an EEG amplifier (EEG100B, BIOPAC System Inc.) and the frequency of the EEG signal sampling was set at 250Hz. The measured data were stored in a computer. The raw data were filtered using Telescan 2.8 (Laxtha Inc.) bio-signal analysis software to obtain the 4–50Hz band, and these data were subsequently analyzed.

Experimental procedure

Group assignment

Eighteen participants were randomly assigned to the action observation group, the motor imagery group with eyes open, and the motor imagery group with eyes closed. Six participants were assigned to each group.

Examination of EEG activities

EEG activities from the cerebral cortex were measured during the resting period as well as during observation and imagery of the task performance.

Measurement of EEG activities during observation of task performance

Participants were comfortably seated on the chair prepared for the experiment with attached electrodes to measure EEG activities. Electrodes were checked for accurate attachment. The participant was directed to observe the audio-visual video presentation on the screen and measurement began from the time the video of the task performance was presented. The participant observed the model's golf putting performance video randomly. Each video was presented a total of 18 times: 6 times for each of the 3 distances (1, 3 and 5 m), each lasting for 20 s. The observation took 2 min for each distance resulting in a total of 6 minutes. The EEG activities during the resting period were measured while the participant was in a resting stage with their eyes closed and additionally while the participant looked at a blank screen. Measurements were made for 2 min in each resting stage. The measured EEG activity data were

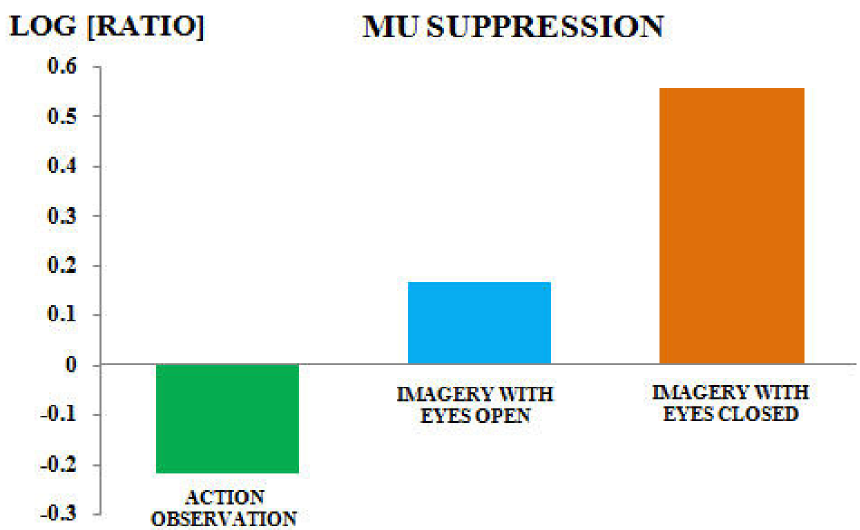

Figure 1. Mu rhythm suppression by groups with eyes open. A log ratio of less than zero signifies greater suppression of mu rhythm,indicating a higher activation of brain areas.

stored in a computer to be analyzed after the experiment.

Measurement of EEG activities during imagery of task performance

Participants were comfortably seated on the chair prepared for the experiment with electrodes attached to measure EEG activities. The same procedures were followed as during the observation task except that the participant was directed to carry out imagery of task performance according to the audio verbal direction.

Data analysis

Mu rhythm suppression was calculated based on the EEG activity data obtained from the experiment.

Mu rhythm

An EEG rhythm with a frequency range of 8~13Hz occurring in C3 (left central fissure), Cz (central fissure), and C4 (right central fissure), which is suppressed during the execution of goal-oriented exercise, or during internal observation or imagery of task performance without such definite motor output (Ulloa and Pineda, 2007). The Mu rhythm suppression was calculated using the values measured during the resting period with eyes open:

$$\frac{\text{Absolute power of mu rhythm during experimental treatment } (uV^2)}{\text{Absolute power of mu rhythm during the resting period with eyes open } (uV^2)} \rightarrow \text{Power Ratio} \rightarrow \text{Log Transform}$$

Mu rhythm suppression was calculated using the values measured during the resting period with eyes closed:

$$\frac{\text{Absolute power of mu rhythm during experimental treatment } (uV^2)}{\text{Absolute power of mu rhythm during the resting period with eyes open } (uV^2)} \rightarrow \text{Power Ratio} \rightarrow \text{Log Transform}$$

A small log transformed value (below 0) signifies greater the suppression of mu rhythm, therefore indicating a higher activation level of the corresponding brain areas. On the contrary, a larger log transformed value (above 0) indicates greater enhancement of mu rhythm, which means a higher conscious concentration of attention. If the transformed value is 0, it means there is neither suppression nor enhancement of mu rhythm.

The calculated variable was analyzed by three-way ANOVA: 3 groups (the action observation group, the motor imagery group with eyes open, and the motor imagery group with closed eyes) × 3 distances (1, 3 and 5 m) × 3 brain areas (C3, Cz, and C4), based on repeated measurement of the last 2 factors. The significance level of all the data analysis was set at 5%.

RESULTS

Analysis of mu rhythm suppression using the values measured during the resting period with eyes open

According to the analysis of mu rhythm suppression using the values measured during the resting period with eyes open, only the main effect of the groups appeared to be significant: $F(2,15) = 19.84$, $P < 0.001$, (Figure 1). Post-hoc test results showed that the mu rhythm of the action observation group was more significantly suppressed compared to the two imagery groups ($P < 0.05$). However, the mu rhythm of the motor imagery group with eyes closed was more significantly enhanced

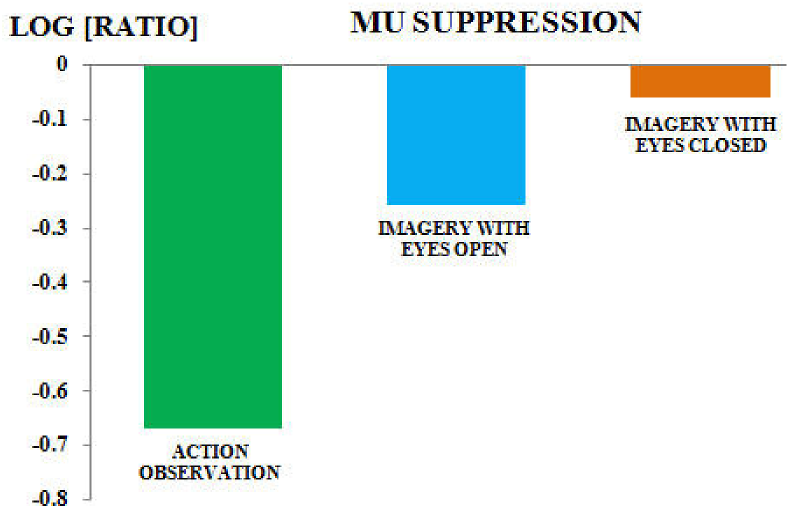

Figure 2. Mu rhythm suppression by groups with eyes closed. A log ratio of less than zero signifies greater suppression of mu rhythm, indicating a higher activation of brain areas.

compared to the motor imagery group with eyes open ($P < 0.05$).

Analysis of mu rhythm suppression using the values measured during the resting period with eyes closed

According to the analysis of mu rhythm suppression using the values measured during the resting period with eyes closed, only the main effect of the groups appeared to be significant: $F(2,15) = 10.46$, $P < 0.01$ (Figure 2). The results of the post-hoc test showed that the mu rhythm of the action observation group was more significantly suppressed compared to the motor imagery group with eyes open and the motor imagery group with eyes closed ($P < 0.05$). There was no difference between the two imagery groups.

DISCUSSION

The objective of this research was to analyze the differences in brain activation between motor imagery and action observation by analyzing suppression of mu rhythm during motor imagery and action observation of golf performance. We hypothesized that by providing more vivid and concrete information, action observation would more strongly activate the involved brain areas than motor imagery. Our experimental results appear to support this hypothesis.

Mu rhythm, which is α frequency (8 to 13Hz) occurring in the supplementary motor area and primary sensory motor area, was found to be suppressed (that is, activated) during the execution of goal-oriented movement and during observation and imagery of task performance without any actual movement (Cochin et al., 1999; Pineda et al., 2000). Such a mechanism suggests that action observation or motor imagery can be used as an effective cognitive intervention method. However, certain factors can limit the applicability of motor imagery such as age (De Beni et al., 2007) and the skill level of the learner (Lacourse et al., 2005; Mulder et al., 2004). Such limitations can diminish the learning promoting effect of motor imagery. In contrast, action observation can contribute to the development of the observer's motor representation by providing concrete and vivid information about task performance, such as the coordination pattern required for the achievement of the goal (Breslin et al., 2005). When these results are taken into consideration, our study showed that action observation induced stronger activation of brain areas than motor imagery. It suggests that action observation can facilitate motor learning more efficiently by inducing relatively more active cognitive information processing activity compared to motor imagery.

In contrast, the mu rhythm of the two imagery groups was enhanced. The motor imagery group with eyes closed showed more significant enhancement of mu rhythm than the motor imagery group with eyes open. This result can be explained in relation to concentration and subconscious visual information processing activity. In general, α frequency (8 to13 Hz) increases when proper conscious attention is given, not during the resting stage or during active cognitive information processing activity (Salenius et al., 1995). Therefore, increased α frequency has been used as an index to reflect increased concentration (Kim and Park, 2007). Taking this into consideration, the increase of α frequency (enhancement of mu rhythm) in the two imagery groups suggests that although internal stimulus through imagery promoted concentration, it failed to induce active cognitive information processing activity to such a degree that mu rhythm would be suppressed. The significant enhancement of mu rhythm in the motor imagery group with eyes closed compared to the motor imagery group with eyes open may be due to the subconscious visual information processing that occurs while eyes are opened. While eyes are open, information about the surrounding environment is processed without conscious intention (Egeth and Yantis, 1997). Thus, there is a possibility that such a process induced relatively more reduction in the enhancement of mu rhythm compared to the motor imagery group with eyes closed because it prevented more conscious concentration of attention.

Analysis of mu rhythm suppression using the values measured during the resting period with eyes closed also showed that mu rhythm was more significantly suppressed in the action observation group than in the two imagery groups. Similar to the analysis using the values measured during the resting period with eyes open, this result suggests that action observation induced stronger cognitive information processing activity than motor imagery. However, unlike the resting condition with eyes open, which caused enhancement of mu rhythm in the two imagery groups, the resting condition with eyes closed suppressed mu rhythm in the two imagery groups. This suggests that the internal stimulus through motor imagery can not only enhance concentration but also induce enough cognitive information processing activity to suppress mu rhythm. Thus, it is more desirable to use the values measured during the resting period with eyes closed in order to accurately analyze the cognitive information processing activity of the brain during imagery of task performance. Information from the surrounding environment is processed without conscious intention while the eyes are open (Egeth and Yantis, 1997) and can prevent the development of motor representation by distracting conscious attention. In contrast, it is possible that while eyes are closed the environment allows the concentration of conscious attention for the development of motor representation about the task performance, thereby inducing relatively strong cognitive information processing activity.

In conclusion, the results of the present study support previous research findings on brain activation during motor imagery and action observation. Additionally, our findings suggest that action observation more strongly activates the brain areas involved in the performance of an actual task than does motor imagery because action observation provides the learner with vivid and concrete motion information, such as the spatial positions of the arms and legs and the spatio-temporal relationship among them. The results of the analysis of EEG activities in the present study suggest that although motor imagery can also induce cognitive information processing activity regarding performance of a task, action observation can induce it more strongly. However, further studies are needed to investigate the differences in brain activation between motor imagery and action observation.

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