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# Comparison of Brain Connectivity in Mental Practice and Physical Performance of Bilateral Upper Extremity Function in a Healthy Adult: A Case Study

Jeong, Eun-Hwa[*], M. S., O.T., Kim, Hee[**], Ph.D., O.T.

[*]Dept. of Occupational Therapy, College of Health Science, Far East University

[**]Dept. of Occupational Therapy, College of Medical Science, Konyang University

## Abstract

**Objective**: The purpose of this study was to investigate whether there is a difference in the brain connectivity in mental practice and physical performance of training bilateral upper extremity function.

**Method**: The subject performed activities involving mental tasks and physical exercise for bilateral upper extremity functioning during each phase of EEG measurements. The subject performed a symmetrical task(lifting a box and placing it back) that involved moving both arms at the same time and an asymmetrical task(opening and closing a bottle cap) in order to perform functional tasks. EEG electrodes were attached to Fp1, Fp2, F3, F4, T3, T4, P3, and P4. Data analysis was performed using Cross-Line Mapping for correlational analyses between EEG electrode pairs.

**Conclusion**: This study found that the brain connectivity patterns of symmetrical and asymmetric upper extremity tasks have similar patterns for the motor and sensory area, and that the correlation of the physical practice is generally higher than that of the mental practice.

**Key words**: Bilateral upper limb function, Electroencephalogram, EEG, Functional connectivity

교신저자 : 정은화(jeunh1223@gmail.com)
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# I. Introduction

Mental practice is the acquisition of physical motor skills by imagining scenes of tasks using cognitive elements in the absence of body motions(Braun, Kleynen, van Heel, Kruithof, Wade, & Beurskens, 2013; Malouin & Richards, 2010). Mental practice is the mental representation of the performance using various senses such as visual, auditory, tactile, and kinetic stimulus which induces indirect experience(Jackson, Lafleur, Malouin, Richards, & Doyon, 2001). This method is a neurological rehabilitation approach to recover motor functions in patients with brain damage, including stroke and traumatic brain injury(Braun, Beurskens, Borm, Schack, & Wade, 2006). Based on the neuroplasticity theory, the process could stimulate the actual motion function. Previous studies reported evidence of mental practice improving the upper limb functions of stroke patients and balance ability(Braun et al., 2006).

According to brain imaging studies on imaginative training, the various neural circuits necessary for the task performance correspond to the areas activated during task performance observation or imagination(Decety & Grezes, 1999). These activated regions were premotor cortex, supplementary motor area, inferior parietal lobule, cingulate gyrus, and cerebellum(Decety & Grezes, 1999). Also, a previous study has reported that activation was observed in peripheral regions related to motor functions such as parietal lobe and basal ganglia(Guillot, Collet, Nguyen, Malouin, Richards, & Doyon, 2009)

Bilateral upper extremity activities are generally difficult to perform using only one upper extremity and refer to activities that can be performed using both upper extremities(Skold, 2010). Bilateral upper extremity activities are essential for independent activities such as self-management, occupation, leisure, and social activities(Skold, 2010). Therefore, it is generally applied intervention for patients who occupational therapy subjects such as stroke.

Previous studies have been conducted in patients with stroke, and mental practice has been used in clinical practice as a method for improving motor skills and acquiring motor skills in stroke patients(Ang et al., 2015; da Silva, Paz, de S, & Tierra-Criollo, 2019; Wu, Srinivasan, Burke Quinlan, Solodkin, Small, & Cramer, 2016). However, before studying recovery pattern after brain injury, it is necessary to confirm mental practice, physical performance and brain connectivity in bilateral upper extremity for normal pattern.

Recently, the rapid development of electrophysiologic research techniques such as electroencephalogram (EEG) and transthoracic stimulation have been very helpful in studying the causal relationship and various actions of this phenomenon. However, it has been reported that complex or simple movement of mental practice, change of excitement to the cerebrospinal fluid due to physical performance, and activation area have been reported, but studies on brain connectivity are limited(Choi, Yoo, Jung, Park, Nam, & Jun, 2008; Hanakawa, Dimyan, & Hallett, 2008; Saito, Yamaguchi, Yoshida, Tanabe, Kondo, & Sugawara, 2013).

The purpose of this study is to investigate whether there is a difference in mental practice and physical performance in the brain connectivity through the training of bilateral upper extremity function.

# II. Method

## 1. Participants

The subject was one healthy adult(females). The age of the subjects was 21 years. The subject fully understood the purpose and methods of the study and obtaining written consent in accordance with the ethical principles of the Helsinki Declaration.

## 2. Procedure

The study design was case study. A health adult without cerebral diseases performed bilateral upper extremity tasks of mental practice and physical practice during each section of EEG measurements. Bilateral upper extremity tasks were common activity in everyday life, The subject performed a symmetrical task of moving both arms at the same time or asymmetry task to perform functional tasks. 1) Symmetric task – Put the box up down. In a proper sitting position, the participant lifted a box of 33 * 37 * 11.5 cm on the table and laid out placed on a shelf with a height of 10 and p lace the box back in place. 2)Asymmetric task – opening and closing bottle cap. In a proper sitting position, the participant held a plastic bottle of 5cm in diameter and 15cm in height with one hand and open the bottle cap with the other. Then, close the bottle cap and put it on the table. Each task was repeated for two minutes after one practice. Mental practice consisted of closing the eyes in a sitting position on the chair and imagining the movement of the symmetric task and the asymmetric task for 2 minutes each.

Mental practice and physical performance were performed randomly according to the subject and the order of the tasks was randomized according to the subject.

## 3. Electroencephalogram(EEG)

EEG was used to measure functional connectivity in the cerebral cortex, and the equipment used was a 32-channel EEG device from Laxtha. The electrodes were attached according to the 10/20 International Standard Electrode Method.

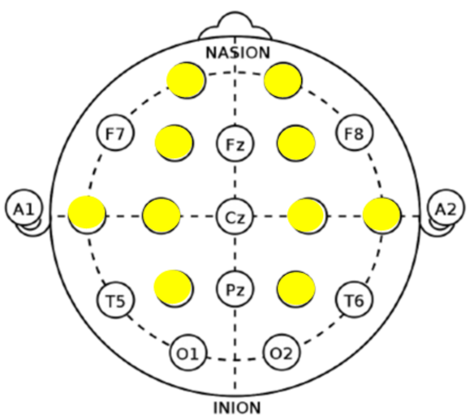


Figure 1. Electrode Region

Based on the previous studies, the electrodes were attached to the frontal region including the primary motor cortex, SMA, and the sensorimotor region, and the electrodes were attached to the prefrontal, parietal, and temporal regions to examine the interconnection between the different regions ch1(Fp1), ch2(Fp2), ch3(F3), ch4(F4), ch5(T3), ch6(T4), ch7(P3), and ch8(P4)(Figure 1).

### 4. Data analysis

Data analysis was performed using Cross-Line Mapping for correlation analysis between EEG electrode pairs using software Telescan version 3.2.8.0. Cross-Line Mapping is a method of expressing cross-correlation between lines on the surface of the skull. This analysis method is advantageous in that the correlation of each channel is represented by the color of the line connected between the channels and can be confirmed at a glance. The interpretation of the results shows that the highest value is 1, the lowest value is 0, the red is the highest correlated link, and the blue has a relatively low correlation.

## III. Results

In this study, Cross-Line Mapping analysis showed that the nerve activity in the cerebral cortex was complex interconnected during the task. It is possible to classify the connection having the strongest connectivity and the relatively low connectivity.

The functional connectivity of the cerebral cortex between all channels was 0.000 at the resting status(Figure 2a).

In the symmetry of bilateral upper extremity tasks, the brain connectivity of physical practice between ch1 and ch2 was 1.000. The connectivity of between ch1 and ch3, and between ch1 and ch4, between ch2 and ch4, and between ch3 and ch4 were 0.898. Also, between ch2 and ch3 and between ch7 and ch8 was approximately 0.85. The connectivity between ch3 and ch7, between ch3 and ch8, and between ch4 and ch8 was 0.795. The connectivity between ch8 and ch1 and ch2 is 0.693 and the other connectivity was less than 0.6(Figure 2b).

In the symmetrical task of bilateral upper extremity tasks, the functional connectivity of the cerebral cortex of mental practice was 1.000 for ch1 and ch2, and the connectivity between ch3 and ch4 and between ch7 and ch8 was 0.874. The connectivity between ch1 and ch3, between ch2 and ch4, and between ch3 and ch5 is approximately 0.8. Also, the connectivity between ch3 and ch7, ch8, the connectivity between ch4 and ch7, ch8, the connectivity between ch5 and ch7 And the connectivity between ch6 and ch8 was found to be 0.748. In addition, the connectivity between ch5 and ch1, ch2, ch3 and ch8 was 0.622, and the other connectivity was less than 0.5(Figure 2c).

In the asymmetric task of bilateral upper extremity tasks, the brain connectivity of physical practice between ch1 and ch2 was 1.000. The connectivity between ch1 and ch3 and between ch2 and ch4 was 0.866. The connectivity between ch1 and ch4, ch2 and ch3, and between ch3 and ch4 was approximately 0.8, and the connectivity between ch3 and ch5, ch7, ch8 and between ch4 and ch8 was 0.733. The other connectivity was found to be less than 0.6(Figure 2d).

In the asymmetrical task of bilateral upper extremity tasks, the functional connectivity of the cerebral cortex in the mental practice showed that the connectivity between ch1 and ch2 was 1.000, and the connectivity between ch1 and ch3, ch2, ch4 was 0.866. The connectivity between ch1 and ch4, between ch2 and ch3, between ch3 and ch4, and the connectivity between ch3 and ch5, ch7 and between ch7 and ch8 were found to be 0.733. The other connectivity was found to be less than 0.6 (Figure 2e).

This is consistent with the assertion that the mental practice of physical performance activates in-

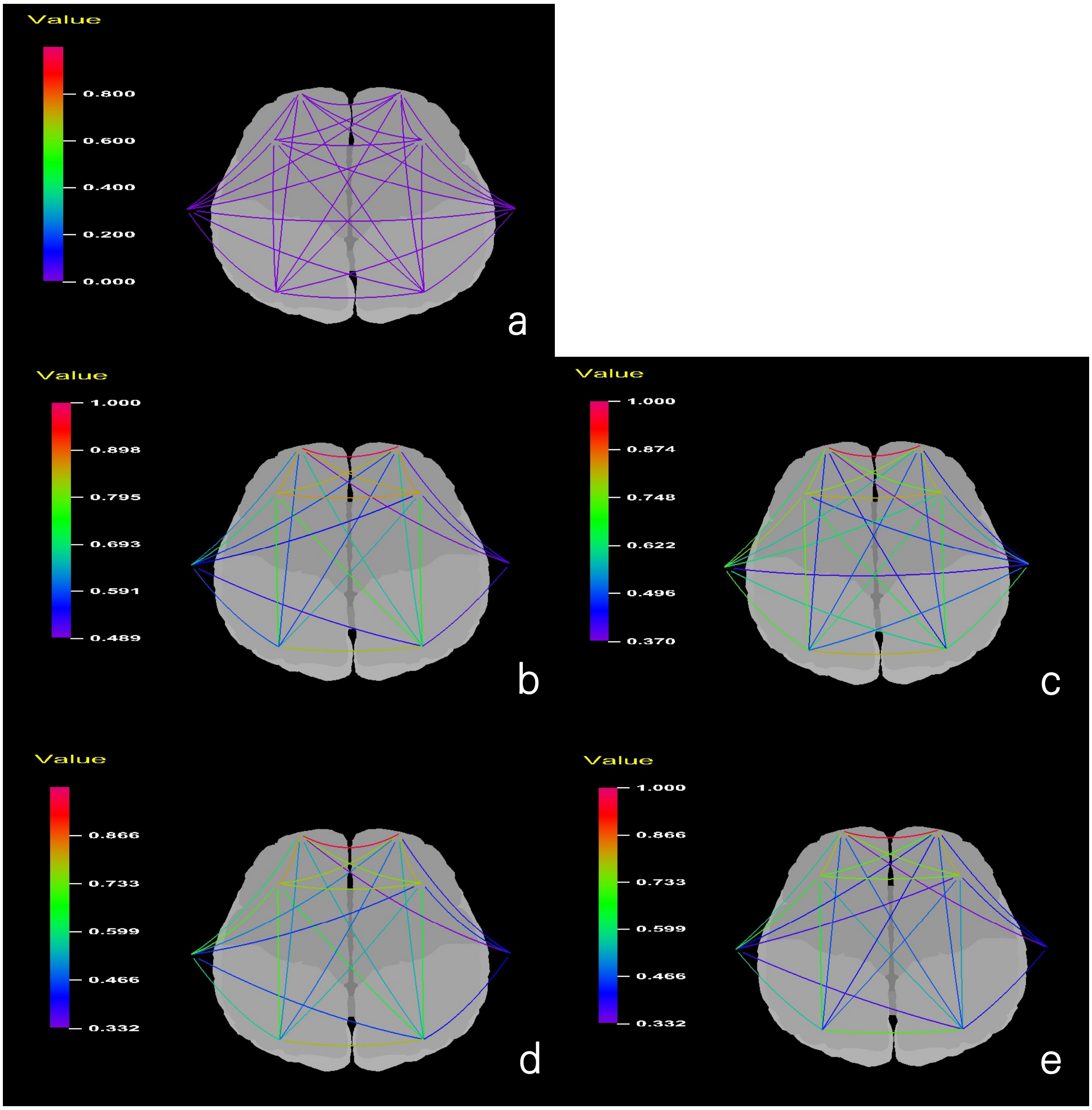


**Figure 2. Brain Connectivity Using EEG Cross-Line Mapping Analysis.**
a) resting status, b) symmetry task-physical practice, c) symmetry task-mental practice, d) asymmetry task-physical practice, e) asymmetry task-mental practice

ternal feedback and therefore has the same effect as changing in the muscles resulting from performing actual movements(Decety & Ingvar, 1990).

# Ⅳ. Discussion

The purpose of this study was to identify any differences in cerebral cortex connectivity between mental and physical practices during the bilateral upper extremity tasks through EEG analysis. The study found that the connectivity between the prefrontal regions of both hemispheres showed high correlations in the physical practice of the symmetrical upper extremity task of lifting boxes with both hands on the shelves, and that the connectivity between the prefrontal and frontal areas of both hemispheric hemispheres also showed high correlations. It was also found that the relationship between the frontal and parietal area in the intrahemisphere has a moderate correlation. In other words, the connectivity of the bilateral prefrontal, frontal, parietal, and frontoparital regions within each hemisphere have high correlations in symmetrical bilateral upper tasks, with high correlation in the frontoparital regions in the interhemisphere. These results indicate that the connection between the motor and sensory area within the inter and intra hemispheres is activated in bilateral upper extremity tasks, and the prefrontal area is related to cognitive functions such as attention(Braun et al., 2006; Jackson et al., 2001; Guillot et al., 2009).

In performing the mental practices of symmetrical upper extremity tasks, the interhemisphere connectivity patterns of the bilateral prefrontal, frontal, parietal, and frontoparital areas within each hemisphere have similar patterns to physical practice. However, the connectivity between the frontal and temporal regions in the interhemisphere was shown to have high correlation compared to physical practice, and the connectivity between the parietal and temporal regions was also highly correlated. It was also found low correlation in  interhemisphere of temporal area. Therefore, in the mental practice of symmetrical upper extremity tasks, the moderate correlation between the frontotemporal and parietotemporal areas was thought to reflect the connectivity between visuokinesthetic motor engram(superior temporal gyrus and inferior parietal lobule) and motor area(Arnadottir, 1990).

The physical practice of the asymmetric bilateral upper extremity task of opening the bottle cap with both hands also showed high brain connectivity in the areas of the prefrontal, frontal, parietal, and frontoparital in each hemisphere of the cerebral cortex. In addition, the brain connectivity during the mental practices of asymmetric upper extremity tasks had a similar pattern to the physical practice, but the correlation was shown to be lower than that of the physical practice.

Therefore, this study found that the brain connectivity patterns of symmetrical and asymmetric upper extremity tasks have similar patterns of the motor area and the sensory area, and that the correlation of the physical practice is generally higher than that of the mental practice.

Previous studies of mental practices through EEG analysis also reported the activation of motor-related activated regions(Jackson et al., 2001). Green, Bialy, Sora and Thatcher(1997) reported that the premotor cortex and supplementary motor area in the mental practice were activated, and primary motor cortex was activated in the physical practice. A study of Deiber et al.(1998) using PET analysis reported that prefrontal cortex was activated in the mental practice and primary motor cortex were activated in the physical practice. Studies using fMRI have reported activation in the areas of premotor cortex, primary motor cortex, supplementary motor cortex, cingulate gyrus, sensorimotor cortex, primary sensory cortex, superior parietal cortex, basal ganglia and cerebellum(Luft, Skalej, Stefanou, Klose, & Voigt, 1998; Sabbah et al, 1995; Saito et al., 2013; Tyszka, Grafton, Chew, Woods, & Colletti, 1994).

Szameitat et al.(2012) reported increased functional connectivity in the bimanual task compared to the unimanual task, particularly between superior front gyrus, suprmarginal gyrus, and angular gyrus in the right hemisphere. Therefore, we found that the results of this study and the existing fMRI studies were consistent with the results of the functional connectivity using EEG Cross-Line Mapping Analysis.

Currently, studies are focused on brain connectivity through structural and functional networks that connect brain regions. In particular, brain connectivity analysis through EEG is possible on how cortical currents relate to brain structures and also how functional and structural connections in other frequency bands are affected(Chu, Tanaka, Diaz, Edlow, Wu, & Kramer, 2015). The Cross-Line Mapping Analysis used in this study shows the results of all-Paire-Cross Correlation analysis as brain mapping and is a correlation analysis of each channel. This analysis also shows motor functions and functional outcomes through which connections between brain areas have been increased or decreased. However, the limitations of this study cannot be generalized in that it is a case study. Also, the results would have been affected by the failure to control the noise that could occur during bilateral upper extremity tasks during the EEG measurements.

## V. Conclusion

The purpose of this study was to identify any differentiate in brain connectivity between mental and physical practices during the bilateral upper extremity tasks using EEG analysis. The study found that the correlation of physical practice was generally higher than that of the mental practice in the symmetrical and asymmetric upper extremity tasks. The brain connectivity pattern was similar between the motor area and the sensory area and the association area in both condition. In addition, we found the connectivity with the temporal region of the motor and sensory association area in the mental practice.

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## 국문초록

# 건강한 성인의 양측상지기능의 상상훈련과 신체적 수행의 대뇌 연결성 비교: 사례 연구

**정은화[*], 김희[**]**

[*]극동대학교 의료보건과학대학 작업치료학과

[**]건양대학교 의과학대학 작업치료학과

**목적**: 본 연구의 목적은 건강한 성인을 대상으로 양측상지기능 훈련을 통해서 활성화 되는 대뇌 연결성에서 상상 훈련과 신체적 수행 간에 차이가 있는지를 알아보고자 한다.

**연구방법**: 연구 대상자는 건강한 성인 1명으로 상상훈련과 신체적 수행 시 EEG 측정이 이루어졌다. 양측상지기능 훈련은 대칭 과제와 비대칭 과제로 구성되었다. 대칭 과제는 양손으로 박스를 잡고 동시에 위의 선반으로 올렸다가 다시 내려놓는 과제이고, 비대칭 과제는 한 손으로 병을 잡고 다른 한 손으로 뚜껑을 여는 과제였다. EEG 전극은 Fp1, Fp2, F3, F4, T3, T4, P3 및 P4에 부착되었다. 데이터 분석은 EEG 전극 쌍 간의 상관 분석을 위해 Cross-Line Mapping을 사용하였다.

**결론**: 본 연구 결과 대칭 및 비대칭의 양측 상지 과제에서 대뇌 연결성 패턴은 운동과 감각 영역에서 유사한 패턴을 가지는 것으로 나타났다. 또한 본 연구를 통해 양측상지기능 훈련 시 상상훈련보다 신체적 수행에서 대뇌 연결성이 더 높은 상호상관을 갖는다는 것을 확인하였다.

**주제어**: 기능적 연결성, 뇌파, 양측상지기능, EEG