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Research Report

Effects of motor imagery on intermanual transfer: A near-infrared spectroscopy and behavioural study

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ABSTRACT

Intermanual transfer is the ability that previous studies by one limb promote the later learning by the other limb. This ability has been demonstrated in various effectors and types of training. Motor imagery, the mental simulation of motor execution, is believed to be strongly associated with the cognitive aspects of motor execution, and the pattern of brain activity during motor imagery is similar to that of motor execution, although the activation pattern is smaller, and the level is lower. If the cognitive component of motor execution strongly contributes to transfer, the training effect of motor imagery would be expected to transfer to the contralateral limb. In the present study, we used the tapping sequence paradigm to evaluate the occurrence of intermanual transfer through motor imagery and to compare differences of transfer effects to motor execution learning. We divided participants into three groups: an execution group, a motor imagery group and a no-training control group. Before and after a nondominant left hand training session, ipsilateral hand tests were conducted. After the post-test, a contralateral right-hand test was also conducted. In order to investigate the relationship between transfer effect and neural activation during the learning phase, we measured motor-related brain area activity using near-infrared spectroscopy (NIRS). Execution was effective especially for trained movement, imagery was effective for both trained movement and intermanual transfer. Brain activity suggesting predictive transfer differed between two groups, suggesting that motor execution and motor imagery training have different behavioural effects and neural contributions.

1. Introduction

1.1. *Imagery training*

Motor imagery is the phenomenon of imagining a movement without actually carrying out the movement. This phenomenon has been the subject of numerous experiments, which have revealed that motor imagery has the same specificity as motor execution. Motor imagery and motor execution are similar in various aspects; for example, both follow Fitts' law (Decety et al., 1989; Decety and Jeannerod, 1995), and motor imagery practice improves motor performance, as does physical practice (e.g. Feltz and Landers, 1983). In addition, both motor imagery and motor execution generate similar

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autonomic responses. Heart rate and respiratory rate, for example, are believed to reach comparable levels (Oishi et al., 2000; Papadelis et al., 2007). These similarities between motor imagery and motor execution might be attributable to the similitude in their underlying neuronal substrate; i.e. the brain activation pattern during motor imagery is similar to that of motor execution (Grezes and Decety, 2001; Jeannerod, 1994, 2001; Kimberley et al., 2006; Lotze et al., 1999; Stephan et al., 1995).

Although neural activation and performance improvement associated with motor imagery and motor execution are similar, it has been commonly suggested that the area and level of activation during motor imagery are smaller and lower, respectively, than those during motor execution and that the effects of motor imagery training are not comparable to those of execution training. However, recent neuroimaging studies have suggested that despite a large overlap between the two networks, the neural network involved in motor imagery slightly differs from that involved in motor execution (Nyberg et al., 2006; Solodkin et al., 2004). Furthermore, although the training effects of motor imagery were considered weaker than those of execution training, several other studies have suggested that the efficacious training effect of motor imagery could be comparable to that of motor execution in some components (Gentili et al., 2006; Ryan and Simons, 1981; Wrisberg and Ragsdale, 1979). For example, Minas (1978), who compared motor execution and motor imagery using a complex motor-sequence task, showed that motor imagery training was superior in acquiring the complex sequence itself, while motor execution training was superior for improving task execution. The sequence acquisition feature of motor imagery has also been seen in studies on transfer (Kohl et al., 1992; Kohl and Roenker, 1983). A series of experiments by Kohl et al. revealed that the level of retention and transfer effects using motor imagery was the same as that using motor execution. Furthermore, the authors suggested that motor imagery had effects of sequence retention and the ability to transfer, although the effect of training by motor imagery was significantly lower than that by motor execution. These behavioural studies imply that motor imagery may indeed have less effect on improving the training of a motor skill but that it might be suitable for gaining abstract knowledge about the skill sequence, which is included in the motor component even though motor imagery and motor execution might have different training effects.

1.2. *Transfer*

Intermanual transfer of actual motor control has been investigated using many different tasks and effectors and such ability has been demonstrated by many experiments using motor-execution training, although some experiments have shown that transfer did not occur for certain aspects of movement. Many neural imaging experiments have also been conducted to elucidate the intermanual transfer of motor control learning, and thus far, the following brain areas have been implicated in intermanual transfer (for a review, see Halsband and Lange, 2006): the middle temporal gyrus and right middle frontal areas (Anguera et al., 2007), the frontoparietal area (Obayashi et al., 2003 [conducted on nonhuman primates]; Obayashi, 2004) and the cerebral cortex and basal ganglia (Obayashi et al. 2003; Obayashi, 2004). The involvement of the corpus callosum has also been suggested in brain pathological and lesional studies (Gazzaniga and LeDoux, 1979; Hunter et al., 1975 [conducted on nonhuman primates]; Lange et al. 2006; Thut et al., 1997). Although it has been demonstrated that different areas are activated while subjects engage in intermanual transfer tests, the brain areas that relate the acquisition of original learning to the subsequent transfer effect remain unknown.

Previous research has indicated that the correlation areas between activation during the learning phase and future behavioural intermanual transfer level are different from the areas of activation during an intermanual transfer test (Perez et al., 2007, 2008). That study showed that while a higher motor-related area–the supplementary motor area (SMA: SMA-proper)–is important in both the learning stage and transfer stage (especially interval period between movements), the SMA cannot be identified as a predictive factor of successful transfer. On the other hand, the thalamus–the area important for actual motor information–was suggested to be a factor in the prediction of transfer level. These results imply that actual physical feedback might be important for subsequent transfer.

The SMA, which must be activated during the learning phase as well as when movement strategy has to be changed (transfer), is known to be involved not only in sequence learning and the learning process, but also in motor imagery, particularly for imagery of a tapping sequence (Roland, 1993). The SMA and the areas described above, which are thought to be involved in intermanual transfer, are also believed to be involved in motor imagery. In other words, it might be concluded that intermanual transfer would also be possible in the case of motor imagery due to the similarity of cognitive components and brain activation to motor execution.

However, intermanual transfer of motor imagery training has seldom been considered as a subject of investigation, and its neural correlation has not been delineated. Thus, it remains to be determined whether intermanual transfer of motor imagery training is possible in the case of the fine tapping sequence paradigm, and the locations of the most important neural areas for intermanual transfer have yet to be revealed. Based on the results of previous cognitive studies, we sought to evaluate the transfer effect by comparing the effects of motor execution training and motor imagery training in terms of improvement in the execution of a tapping sequence and the resulting intermanual transfer.

Subjects who were right-hand dominant were randomly divided into three groups; namely, the motor-execution, motor-imagery and control groups. The subjects were required to undergo training for a left-hand tapping sequence that differed between the groups: motor execution training for the execution group, motor imagery training for the motor imagery group and counting for the control group. The subjects also took three tests before and after training: a pretest before training for the ipsilateral left hand, a post-test after training and lastly, a contralateral right-hand test (the transfer test). In addition, we measured neural activation during the training phase using near-infrared spectroscopy (NIRS) and explored the correlation between the neural data