

Reorganization of functional networks after training with motor imagery in healthy subjects and a single case of lower limb amputation

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Introduction

Motor imagery (MI) is a cognitive task which refers to the internal reproduction of a specific movement without any overt motor output [1]. A growing body of evidence has demonstrated the influence of MI on motor practice and the improvements in the motor performances associated with mental training with MI in healthy subjects (HS) [e.g. 2]. Training with motor imagery (MIT) has already been used to improve motor performance in sports, as well as to improve motor recovery in neurorehabilitation [e.g. 3]. The benefits of MIT are linked to the activation of cerebral networks that are comparable to those activated during physical execution [4]. Previous TMS and fMRI studies have consistently shown that MIT is able to induce changes in corticomotor excitability as well as rearrangement of sensorimotor cortical maps. Within this framework, the main goal of the present study was to explore, using fMRI, the effects of a 2-week foot MIT in driving cortical reorganization in a group of HS. This experimental protocol is part of a larger study on the effects of foot MIT in reducing "phantom limb" (PL) syndrome and "phantom pain" (PP) in lower limb amputees. It has been shown that some rearrangement of the sensorimotor functional cortex can occur after limb amputation, and that this modification may represent a potential substrate for both, PL and PP. It has been recently demonstrated that a MIT is able to reduce PL and PP in upper limb amputees [5], and this project aims at extending the investigation to lower limb amputees.

Methods

Subjects: Ten right-handed HS (F/M= 6/4; mean age: 27.3 ± 4.4 years) have been recruited so far for this study. A single left lower limb amputee (car accident, M, 43 years old) has also been recruited. **MI training:** All subjects underwent a fMRI scan before foot MIT, followed by 2 weeks of foot MIT, and a fMRI post foot MIT. Foot MIT consisted in 3 different imagined motor tasks (~8 minutes duration each), separated by ~2 minutes of rest: a) a right ankle dorsi-flexion, b) a right ankle plantar-flexion; c) a goal-directed action (i.e. kicking a ball). Before starting the foot MIT, subjects had to physically practice each movement until they felt confident with the required tasks. Subjects were then instructed to imagine the same movement in a first person perspective by recalling the feelings and sensations they experienced when they had performed the movement, using the same force, speed and repetition rate (about 0.2 c/sec). **fMRI:** MRI scans were acquired using a head-only 3T (Siemens Magnetom Allegra). The same protocol was collected twice before and after the MIT. The second scan was recorded within 24 hours after the last training session. fMRI data were collected by a series of T2*-weighted EPI (TR=2080 ms, TE=30 ms, 32 axial slices parallel to AC-PC line, matrix=64x64, pixel size =3x3 mm 2, slice thickness=2.5 mm, flip angle=70°) sequence sensitised to BOLD (blood-oxygenation-level-dependent) contrast. The fMRI paradigm consisted of 3 block-design sessions with a duration of ~6 minutes each. Subjects were instructed to follow the instructions presented on a screen. Three tasks were employed: 1) execution of right or left hand movement: subjects had to squeeze a sponge ball when prompted to do so. Left/right blocks were presented in a randomized order; 2) execution of right/left ankle plantarflexion: subjects had to repeatedly push a purpose-built pedal with their right/left foot; 3) imagined right or left ankle plantarflexion, with right and left imagined movement blocks presented in a randomized order. Executed and imaged movements frequency was guided by a flashing dot (0.5 Hz). **fMRI analysis:** fMRI data were processed (including realignment, slice timing correction, and normalization) using MATLAB 7.0 (MathWork, Natick, MA) and SPM8 (<http://www.fil.ion.ucl.ac.uk/spm/>). Data from HS were analyzed using a random-effect analysis. At first level, the main effect of executed and imagined movements at either time-point were estimated. At second level, a flexible factorial model was used to include all conditions and all subjects. Contrasts were used to compare pre/post training activation. Data from the patient were analyzed to compare directly the activations associated with each task between pre and post foot MIT scans.

Results

Main effect of MI: Fig 1 shows the main effect of motor imagery in HS (top) and main effect of foot plantarflexion, confirming that MI activates the primary motor cortex (foot area) contralateral to the imagined movement, and the ipsilateral cerebellum.

Main effect of MI training: When comparing all pre- and post-training conditions (irrespective of task) in HS, significantly increased activations after training were found in: posterior cingulate cortex (PCC), bilaterally, and extending into the right precuneus; right intracalcarine cortex; left occipital and temporo-occipital fusiform cortices; left cerebellum. When comparing right (dominant) hand movement pre- and post training conditions significant increased activations were found after training in: left parahippocampal cortex, left fusiform and lingual cortex. When comparing MI tasks, pre and post training, significant increased activations were found after training in: left inferior temporal cortex, left lateral occipital cortex, right PCC.

Effect of MI training on executed vs imagined R ankle plantarflexion: Fig 2 shows the difference in activation between executed and imagined right foot motor task before and after training, mainly located in the cerebellum. The plot in the same figures confirms that this effect is driven by the difference between executed and imagined movement at baseline, which is minimized after MIT.

No significant change in activation was found in the primary motor areas, nor any significant decrease in activation when comparing pre- and after training.

fMRI results in the amputee: In contrast with findings in HC, we observed some functional reorganization of the motor cortex in the left limb amputee. Fig 3 shows the decrease in functional activation (pre > post foot-MIT) during ball-squeezing with left hand in red, and the increase in functional activation (pre < post foot-MIT) during left foot MI in yellow.

Discussion

Our results suggest that mental practice with motor imagery is able to induce changes in the pattern of fMRI activations during motor tasks, mainly due to recruitment of association cortex. Moreover, MIT reduced the engagement of the cerebellum and pontine nuclei in the lower limb executed task as compared to the imagined task. A 2 week MI training in HS does not appear to induce detectable changes in fMRI activations of the primary motor cortex. The preliminary results obtained in a single amputee suggest that mental practice with motor imagery is able to modify the functional activation of the primary motor cortex in these subjects. These data confirm that mental practice with motor imagery is able to induce persistent changes in corticomotor excitability, and support earlier findings showing that there is an inhibitory relationship between foot and hand motor cortices [6]. An evaluation with clinical scales of the effects of foot MIT on reducing PL and PP is ongoing.

References

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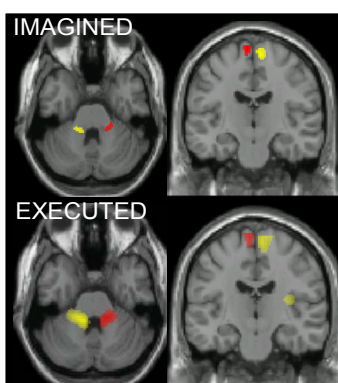


Fig 1. fMRI activations during MI task (top) and during executed planar flexion task (bottom), with left (yellow) and right foot (red).

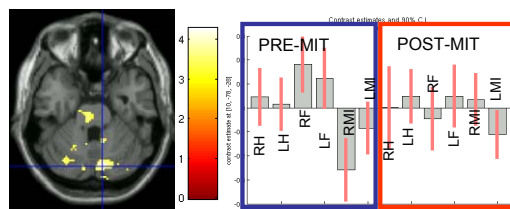


Fig 2. Effect of MIT in HS: (RF>RMI)_{pre-MIT} > (RF>RMI)_{post-MIT}. RH=right hand, LH=left hand, RF=right foot executed, LF=left foot executed, RMI=right MI, LMI=left MI.

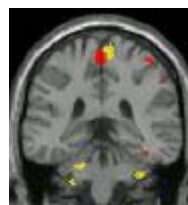


Fig 3. Effect of MIT in amputee: decrease in BOLD activation during ball squeezing with left hand (red) and increase in BOLD activation during left foot MI (yellow).