Bilateral transfer phenomenon: A functional magnetic resonance imaging pilot study of healthy subjects

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Abstract

Background: The bilateral transfer of a motor skill is a physiological phenomenon: the development of a motor skill with one hand can trigger the development of the same ability of the other hand.

Objective: The purpose of this study was to verify whether bilateral transfer is associated with a specific brain activation pattern using functional magnetic resonance imaging (fMRI).

Methods: The motor task was implemented as the execution of the Nine Hole Peg Test. Fifteen healthy subjects (10 right-handers and five left-handers) underwent two identical fMRI runs performing the motor task with the non-dominant hand. Between the first and the second run, each subject was intensively trained for five minutes to perform the same motor task with the dominant hand.

Results: Comparing the two functional scans across the pool of subjects, a change of the motor activation pattern was observed. In particular, we observed, in the second run, a change in the activation pattern both in the cerebellum and in the cerebral cortex. We found activations in cortical areas involved in somatosensory integration, areas involved in procedural memory.

Conclusions: Our study shows, in a small group of healthy subjects, the modification of the fMRI activation pathway of a motor task performed by the non-dominant hand after intensive exercise performing the same task with the dominant hand.

Keywords

Functional magnetic resonance imaging, bilateral transfer, motor skills

Introduction

When motor learning is accomplished with one limb, the ability to perform the same task with the untrained limb improves.1 The possibility of transfer of a motor skill from one hand to the other, performing repetitive movements, is called bilateral transfer (BT) or cross-limb transfer.2–4

The neural mechanism underlying this phenomenon is not fully clear. There are three main models explaining it: the first model is the ‘callosal access’ which proposes that the motor ability is generated in the dominant hemisphere and then reached by the opposite one through the corpus callosum to facilitate task execution with the untrained limb. The second one is the proficiency model: the motor programmes are created and stored in the opposite hemisphere to the hand being trained. The third is the so-called cross activation hypothesis, based on the evidence that performing a repetitive unilateral task generates cortical activity both contralateral and ipsilateral to the trained limb.5

Even though the neurological basis is not definitely known, BT evidence is supported by several studies based, for instance, on electromyogram signal recordings6 or on mirror visual feedback.3

Considering a clinical perspective, our group has already proposed an approach using BT in rehabilitation: in patients affected by stroke, we showed improvement of the paretic hand dexterity with three days of exercise of the other hand.7

To our knowledge there are only few data on fMRI activation in learning and transfer of learning from the dominant arm to the non-dominant arm.5 Our aim was to study with fMRI a group of healthy subjects, the modification of the fMRI activation pathway of a motor task performed by the non-dominant hand after intensive exercise performing the same task with the dominant hand.

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Materials and methods
The study was approved by the Ethic Committee of our Institute.

Fifteen healthy male subjects (age 35 ± 9.4 years) participated voluntarily in the study. They were divided in two groups, one formed by 10 right-handed men and the other by five left-handed men. We assessed the handedness aspect using the Edinburgh Inventory test. Functional data were acquired on a 1.5T Achieva MR scanner (Philips Healthcare, the Netherlands) equipped with an eight-channel brain coil. The functional data were acquired using a dynamic single-shot gradient-echo echo planar imaging (EPI) sequence with the following parameters: time of repetition (TR) 3000 ms, time of echo (TE) 50 ms, field of view (FOV) 240 x 240 mm², matrix size 64 x 64, 30 slices, slice thickness 4 mm, no gap. The total acquisition time was five minutes for each single functional run.

We performed the first functional run (F1) on each subject. We used a block-design scheme of stimulation with 30 s of activation alternated with 30 s of rest. During the activation periods, the subject performed the Nine Hole Peg Test with the non-dominant hand (the left hand for right-handed subjects and the right hand for left-handed subjects).

While still lying on the scanner bed, the subject was then intensively trained for five minutes to perform the same motor task with the dominant hand. Finally another functional run (F2) was done identical to F1.

The data were analysed using the SPM8 software (Statistical Parametric Mapping, www.fil.ion.ucl.ac.uk/spm). Each functional run was realigned, normalized to the standard Montréal Neurological Institute (MNI) space and filtered with a spatial smoothing filter (kernel size 12 mm isotropic). The group analysis comparing the activation patterns from F2 runs to F1 runs was performed for the right-handers group and the left-handers group separately. We used a paired t-test with a statistical significance of p < 0.001 uncorrected for multiple comparisons.

Results
We found an increase in activation signal of fMRI comparing F2 to F1 (p < 0.001, uncorrected), both for right and left-handed subjects.

Activation pattern similar for the two groups
We reported major activation of the following areas for the two groups:

Left cerebellar hemisphere for right-handed subjects or right cerebellar hemisphere for left-handed subjects: in particular lingula, culmen, pyramid and uvula.
Right cerebral cortex areas for right-handed subjects or left cerebral cortex areas for left-handed subjects: in particular Brodmann area 40 and Brodmann area 7 in the parietal lobe.

Right-handers activation pattern
We reported major activation of the following areas only in right-handers:

Brodmann area 20 in the right temporal lobe.
Brodmann area 9 in the left dorsolateral prefrontal cortex.

We show activation areas for right-handed subjects in Figure 1.

Left-handers activation pattern
We reported major activation of the following areas only in left-handers: Brodmann areas 3 and 5 in the left paracentral lobule.

Discussion
The present fMRI study demonstrated that a short training performed with the dominant hand produces modifications in the activated areas while performing task with the non-dominant hand, in particular in areas implicated in the movement control, coordination and working memory.

Brodmann area 40 and 7
The premotor and inferior parietal cortex showed significant activation in all of our 15 subjects comparing the second run F2 to the first one F1.

It is known from the literature that these areas are involved in the process of so-called early adaptation in the presence of visuomotor stimulation. These parietal areas in fact are considered to be part of a network contributing to spatial cognitive processes and to adaptation, in particular in terms of spatial working memory and spatial attention.

Cerebellum
We have also reported an important cerebellar activation in both groups.

This could be supported by a recent consensus paper. The authors proposed that the uniform structure of the cerebellum and its recurrent connections with multiple cortical areas, including not only the primary motor cortex, but also areas of premotor and prefrontal cortex, suggest that it could play a similar coordination and support role in the anticipatory control loops of motor and non-motor domains.

Considering BT as the phenomenon of transferring an ability from one hand to the other, a major
activation of areas involved in working memory, spatial attention and coordination is easily understandable after intense training.

**Other activated areas**

We reported some differences in fMRI activation comparing the right-handed and the left-handed groups which are not easy to explain. However it is interesting to notice in which cerebral functions these areas are involved. The prefrontal cortex is activated only in right-handed subjects and it is one of the most important cortical areas involved in the working memory process of action planning.12,13

Many tasks attending spatial attention require the maintenance of information that is necessary for performance of working memory; in the literature there is a wide agreement about the relevance of the dorsolateral prefrontal cortex for the maintenance and the manipulation of memory contents.13

Right Brodmann area 20, in the temporal hemisphere, is implicated in some types of visual processing and, specifically in the right hemisphere, has a role in dual working memory task processing.

In left-handed subjects we found the activation of the areas 3 and 5, which are both implicated in the ability to produce skilled movements, bimanual manipulation, praxic abilities and in the somatosensory neuron mirror system.

The difference in activation we reported could be because of the small number of our subjects. Anyway we could relate it also to the hemispheric lateralization and organization of cerebral complex functions.

**The mirror neuron system**

The significant differences of fMRI activation we reported after the training compared to that before training, cannot be explicated with the hypothesis of neuronal reorganization, due to the very short time between the first and the second functional runs.

Recent studies14,15 suggested that the mirror neuron system may participate in learning by imitation, creating a ‘motor image’ by neural interactions with anticipatory motor areas and the dorso-lateral prefrontal cortex. Our study potentially shows an involvement of the same brain areas in the mirror neurons system and in BT (as prefrontal cortex and Brodmann areas 3 and 5) suggesting the hypothesis that the mirror neuron system might be involved in BT.

Considering the very small number of our subjects with activation of these areas, more data are necessary to validate this hypothesis.

**Limits**

The most important limit of the present trial is that we considered only 15 subjects. This could be justified by the fact that our study was thought to be a pilot study with the aim to verifying if it is possible to use the BT phenomenon in patients with a motor deficit during the
rehabilitation period. Our results seem to confirm this hypothesis.

Conclusion
A significant change in fMRI activation was demonstrated before and after training. Our results suggest that BT is a phenomenon that requires early adaptation, working memory processes and a cerebellar role. The speed of change in cortical activation has not yet had an exhaustive explanation; a possible role of the mirror neuron system should be further investigated. Data that we collected support the possibility of realizing further functional study based on the BT phenomenon.

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Conflict of interest
The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References