ORIGINAL ARTICLE

Mirror-Induced Visual Illusion of Hand Movements: A Functional Magnetic Resonance Imaging Study

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ABSTRACT. Matthys K, Smits M, Van der Geest JN, Van der Lugt A, Seurinck R, Stam HJ, Selles RW. Mirror-induced visual illusion of hand movements: a functional magnetic resonance imaging study. Arch Phys Med Rehabil 2009;90: 675-81.

Objective: To identify neural networks associated with the use of a mirror to superimpose movement of 1 hand on top of a nonmoving contralateral hand (often referred to as *mirror therapy* or *mirror-induced visual illusion*).

Design: A functional magnetic resonance imaging (fMRI) study of mirror-induced visual illusion of hand movements using a blocked design in a 1.5T magnetic resonance imaging scanner. Neural activation was compared in a no-mirror experiment and a mirror experiment. Both experiments consisted of blocks of finger tapping of the right hand versus rest. In the mirror experiment, movement of the left hand was simulated by mirror reflection of right hand movement.

Setting: University medical center.

Participants: Eighteen healthy subjects.

Interventions: Not applicable.

Main Outcome Measures: Differences in fMRI activation between the 2 experiments.

Results: In the mirror experiment, we found supplementary activation compared with the no-mirror experiment in 2 visual areas: the right superior temporal gyrus (STG) and the right superior occipital gyrus.

Conclusions: In this study, we found 2 areas uniquely associated with the mirror-induced visual illusion of hand movements: the right STG and the right superior occipital gyrus. The STG is a higher-order visual region involved in the analysis of biological stimuli and is activated by observation of biological motion. The right superior occipital gyrus is located in the secondary visual cortex within the dorsal visual stream. In the literature, the STG has been linked with the mirror neuron system. However, we did not find activation within the frontoparietal mirror neuron system to support further a link with the mirror neuron system. Future studies are needed to explore the mechanism of mirror induced visual illusions in patient populations in more detail.

Key Words: Brain mapping; Motor activity; Neurology; Neurosciences; Rehabilitation; Visual perception.

THE VIRTUAL REALITY BOX for the treatment of phantom limb pain was first introduced by Ramachandran and Rogers-Ramachandran.[1] When a mirror is placed in a sagittal plane between the intact arm and the phantom limb, the mirror reflection of the intact arm is superimposed on the phantom limb, creating the illusion the amputated extremity is still present. This mirror reflection caused the sensation in patients with phantom limb pain that they could move and relax the often cramped phantom limb and experienced pain relief.[2] Since then, the successful use of mirror reflections has been reported in patients with other pain syndromes, such as complex regional pain syndrome[3-6] and phantom sensations in brachial plexus avulsion,[7] as well as for upper extremity rehabilitation after stroke[8-11] or peripheral nerve injury.[12] The idea of using mirror reflection of the uninjured hand superimposed on the injured hand was later referred to as *mirror therapy*,[4] *mirror visual feedback*, and *mirror-induced visual illusions*.[13] In this article, we consistently use the terms *mirror therapy* and *mirror-induced visual illusions*.

At present, little is known about the influence of the mirror reflections that are used during mirror therapy on brain activation. A study using transcranial magnetic stimulation during hand movements showed a significantly increased excitability of the M1 contralateral to the nonmoving hand behind the mirror compared with a control condition in healthy subjects.[13] In 3 patients with brachial plexus avulsion, Giraux and Sirigu[7] used a virtual reality system—very similar to the concept of mirror therapy—displaying prerecorded movements of a hand to create the illusion of normative hand movement. After an 8-week training program, an increased activation in M1 corresponding with the affected limb was found using fMRI.

Insight in brain activation during mirror-induced visual illusion of hand movements may provide better understanding of the working mechanism of mirror therapy. Several underlying

List of Abbreviations

EPI	echo-planar imaging
fMRI	functional magnetic resonance imaging
M1	primary motor cortex
MNS	mirror neuron system
MRI	magnetic resonance imaging
PMC	premotor cortex
PPC	posterior parietal cortex
SMA	supplementary motor area
SPM	statistical parametric mapping
STG	superior temporal gyrus
STS	superior temporal sulcus
TMS	transcranial magnetic stimulation
V2	secondary visual cortex

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No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit on the authors or on any organization with which the authors are associated.

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0003-9993/09/9004-00501$36.00/0
doi:10.1016/j.apmr.2008.09.571

mechanisms for mirror therapy have been proposed. For motor rehabilitation, it has been hypothesized that the alternative input obtained from the mirror reflection might facilitate recruitment of the PMC to assist recovery after stroke through an intimate connection between visual input and premotor areas.[8] Others describe mirror therapy as a form of motor imagery in which the mirror creates visual feedback of successful performance of the imagined action with the impaired limb.[10] Motor imagery itself, the mental performance of a movement without overt execution of this movement, has proven to be beneficial in the rehabilitation of hemiparesis,[14,15] and the visual feedback of the imagined movement using a mirror reflection of hand movement may further facilitate this. Finally, some authors suggested that the MNS may be the underlying neural mechanism of mirror therapy.[11,12] The MNS is a frontoparietal motor network of mirror neurons. Mirror neurons are bimodal visuomotor neurons discharging both when performing a particular action and when observing a similar action performed by another person. The MNS is proven to be activated during several action representations—for example, action observation, mental preparation of movement, and motor execution.[16] Electrophysiologic research on action observation showed a corticospinal facilitation of the M1 based on frontoparietal MNS activation. It has been shown that this facilitation of M1 is effector-specific, lateralized, and significantly greater in a first-person perspective compared with a third-person perspective.[17-19] Therefore, it could be hypothesized that increased M1 excitability during mirror-induced visual illusions is caused by mirror neuron activation because the mirror reflection of the moving hand may provide the ideal image presentation for action observation.

To evaluate brain activation during mirror-induced visual illusion of hand movements as used during mirror therapy, we used fMRI to identify the neural networks associated with the visual perception of a moving hand in healthy subjects superimposed on the nonmoving hand.

METHODS

Subjects

Ten male and 8 healthy female volunteers with an average age of 28.5 years (range, 22–48y) were recruited from staff and students of the Erasmus Medical Center and were included in the study. All subjects were right-handed, had good visual acuity, and had no known neurologic history. Subjects were not informed about the purpose of the experiment. The procedures were approved by the institutional review board, and written informed consent was obtained from all subjects.

Experimental Procedure

In this study, subjects participated in 2 experiments, a no-mirror experiment and a mirror experiment (figs 1A and B). Each experiment (no-mirror and mirror) was performed twice

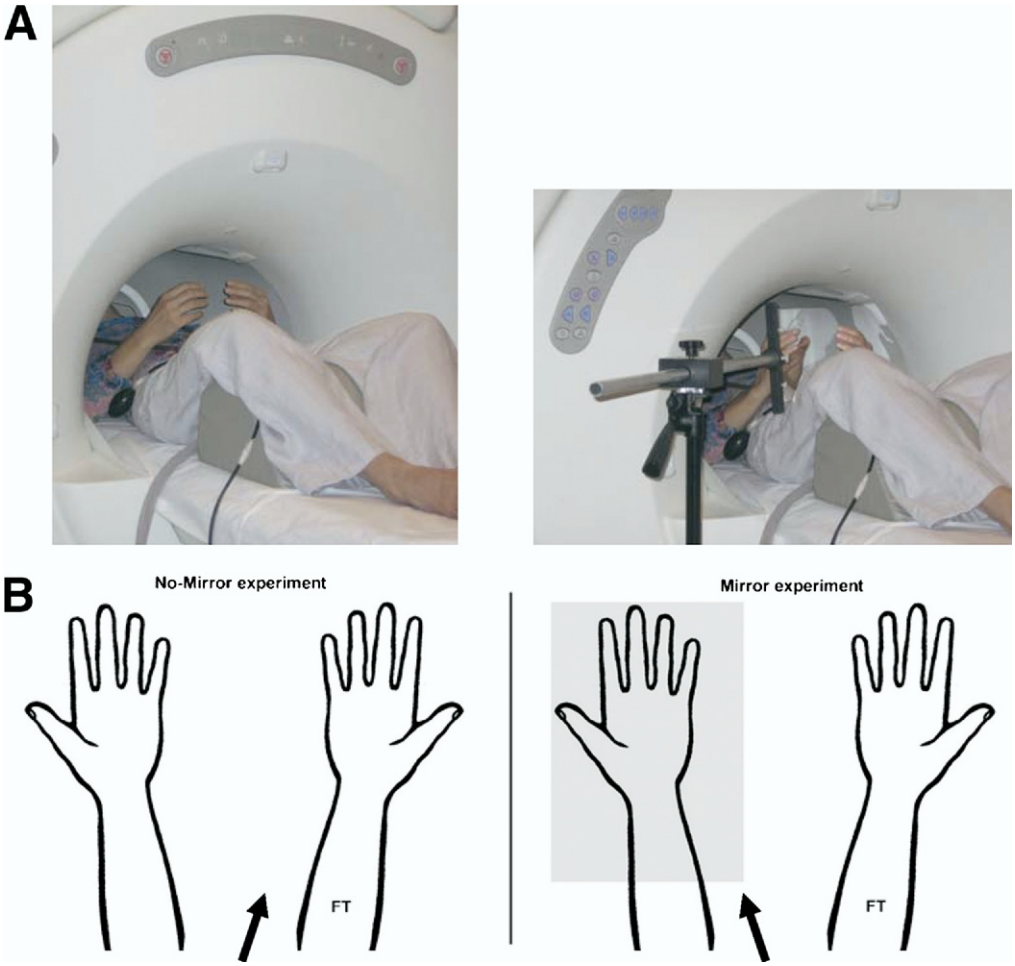

Fig 1. Illustration of the 2 measurement conditions: the no-mirror experiment (left) and the mirror experiment (right). (A) In the fMRI scanner, subjects were able to look toward the outside of the scanner in the direction of their feet to see both hands by using a little mirror that was attached to the top of the head coil and was present in all experiments. In the mirror condition, a mirror was placed between both hands in such a way that the finger tapping of the right was hand was projected on the left nonmoving hand. (B) Schematic representation of the 2 measurement conditions. FT indicates which hand is performing the finger tapping, and the arrow is used to indicate where subjects were asked to look. In the mirror experiment, a mirror was positioned in such a way that the reflection of the moving right hand was projected on the position of the nonmoving left hand.