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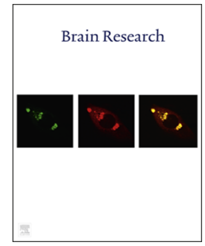

Research Report

The neuronal correlates of mirror therapy: A functional magnetic resonance imaging study on mirror-induced visual illusions of ankle movements

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ABSTRACT

Recovery in stroke is mediated by neural plasticity. Mirror therapy is an effective method in the rehabilitation of stroke patients, but the mechanism is still obscure. To identify the neural networks associated with the effect of lower-limbs mirror therapy, we investigated a functional magnetic resonance imaging (fMRI) study of mirror-induced visual illusion of ankle movements. Five healthy controls and five left hemiplegic stroke patients performed tasks related to mirror therapy in the fMRI study. Neural activation was compared in a no-mirror condition and a mirror condition. All subjects in the experiment performed the task of flexing and extending the right ankle. In a mirror condition, movement of the left ankle was simulated by mirror reflection of right ankle movement. Changes in neural activation in response to mirror therapy were assessed both in healthy controls and stroke patients. We found strong activation of the motor cortex bilaterally in healthy controls, as well as significant activation of the ipsilateral sensorimotor cortex, the occipital gyrus, and the anterior prefrontal gyrus in stroke patients with respect to the non-mirror condition. We concluded that mirror therapy of ankle movements may induce neural activation of the ipsilesional sensorimotor cortex, and that cortical reorganization may be useful for motor rehabilitation in stroke.

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1. Introduction

Stroke is an important cause of disability; it is the third leading cause of death worldwide (Herrington et al., 2015) and is now the leading cause of disability and death in the Chinese population (Yang et al., 2013). It is therefore necessary to discover techniques that enable the brain to recover more efficiently and explore potential mechanisms involved in stroke rehabilitation.

Mirror therapy, one of the new treatment modalities, has attracted interest due to its simplicity and low cost. Ramachandran et al first used mirror therapy for treating phantom limb pain after amputation (Ramachandran and Rogers-Ramachandran, 1996). In 1999, Altschuler et al. (1999) introduced the use of mirror therapy for stroke rehabilitation. Previous studies have demonstrated an effect of mirror therapy on the motor function of the upper extremities in stroke patients (Mirela et al., 2015; Kim and Shim, 2015). Functions such as grip strength, range of motion, movement speed and hand dexterity have been shown to improve more with the use of mirror therapy (Kim and Lee, 2015). Moreover, studies have reported that mirror therapy significantly improves dorsiflexion of the ankle joint (Wada et al., 2011; Hirano et al., 2008), which is important for walking ability in stroke patients.

Despite these encouraging clinical results, the mechanism behind the effectiveness of mirror therapy remains unclear. The two most common theories, proposed involve a primary motor cortex mechanism and a mirror neuron system mechanism (Lamont et al., 2011). Garry et al. (2005) reported that ipsilateral limb movement and the passive observation of movement of the contralateral limb reflected in the mirror modulate the excitability of the primary motor cortex. Ezendam et al. (2009) reported that observing the movement performed by the unaffected limb in a mirror activates the contralateral M1 (Primary Motor Cortex Area) and the actual movement of the affected limb activates the ipsilateral M1. Mirror neurons are bimodal neurons that fire when an individual performs or observes a motor action; these neurons are involved with the frontotemporal region and the superior temporal gyrus. Matthys et al. (2009) found that the superior temporal gyrus, which is associated with the mirror neuron system, was activated during hand movement with a mirror. Although several hypotheses have been proposed regarding the mechanism underlying how mirror therapy functions in motor rehabilitation, they have only focused on the upper extremities (Deconinck et al., 2015; Schuster-Amft et al., 2015). However, motor deficit resulting from sustained distal weakness in the hemiparetic leg is a common and widely recognized impairment caused by stroke, affecting approximately 80% of stroke victims to varying degrees (Brewer et al., 2013). Therefore, research on the impact of mirror therapy with a focus on lower limbs is needed.

This study was designed to further identify neural networks associated with the effect of mirror therapy on the lower extremity. We compared the neural activity of healthy subjects with stroke patients in a mirror and a no-mirror condition. This is the first report investigating the effects of lower-limb mirror therapy by functional magnetic resonance imaging (fMRI). The focus of our study has potential clinical effects and provides further support for the use of mirror therapy in promoting stroke rehabilitation.

Table 1 – Characteristics of enrolled subjects.

	Healthy controls (N=5)	Stroke patients (N=5)
Age (years)	37.70±5.07[a]	53.10±7.75[a]
Gender (Female/Male)	2/3	2/3
Duration of stroke (days)	–	42.50±6.70[a]
Type (Hemorrhage/Ischemia)	–	2/3
Paretic side (Left/Right)	–	5/0
Body mass index (Kg/m^2)	23.3±1.07[a]	22.9±0.68[a]

[a] Mean±SD.

2. Results

A summary of the demographic and clinical features of the stroke patients ($n=10$) is shown in Table 1.

In the mirror condition of the healthy subjects, the mirror-induced visual illusion of ankle movements induced activation of the motor cortex bilaterally. Different brain regions were activated in the non-mirror condition. In the mirror condition of the stroke patients, the fMRI results showed that there was significant activation of the ipsilateral sensorimotor cortex, the occipital gyrus, and the anterior prefrontal gyrus due to the mirror visual illusion of ankle movements.

An analysis of the main effect of the mirror (mirror versus no-mirror in all subjects) showed significant areas of activation in the experiment. Areas associated with the mirror-induced visual illusion of ankle movements included the superior parietal lobule, the cerebellum, and the middle and superior temporal gyri ($P<0.005$, voxel size>30). The number of clusters activated in healthy ($P<0.001$, voxel size>30) and stroke subjects are shown in Table 2 and Fig. 1 and in Table 3 and Fig. 2, respectively. Table 4 shows the comparisons of activated clusters for the effect of the mirror in all subjects ($P<0.005$, voxel size>30). X is negative indicates the activation in the contralateral hemisphere.

3. Discussion

Our study attempted to unravel the potential neural network associated with mirror therapy of ankle movements. A direct comparison of the 2 conditions in the experiment revealed that the illusion of left ankle movements induced ipsilesional sensorimotor cortex activation both in healthy controls and stroke patients. The results demonstrated that the neuronal activation correlated with lower-limb mirror therapy, which as an experimental substrate of mirror therapy to facilitate motor rehabilitation.

Many studies have researched the effect of mirror therapy as an intervention for upper limb function rehabilitation after stroke (Invernizzi et al., 2013; Samuelkamaleshkumar et al., 2014). Radajewska et al. (2013) explored the effect of mirror