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Motor imagery of walking following training in locomotor attention The effect of 'the tango lesson'

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The hypothesis of this study is that focusing attention on walking motor schemes could modify sensorimotor activation of the brain. Indeed, gait is a learned automated process, mostly regulated by subcortical and spinal structures. We examined the functional changes in the activity of the cerebral areas involved in locomotor imagery tasks, before and after one week of training consisting of physical and mental practice. The aim of the training was to focus the subject's conscious attention on the movements involved in walking. In our training, subjects were asked to perform basic tango steps, which require specific ways of walking; each tango lesson ended with motor imagery training of the performed steps. The results show that training determines an expansion of active bilateral motor areas during locomotor imagery. This finding, together with a reduction of visuospatial activation in the posterior right brain, suggests a decreased role of visual imagery processes in the post-training period in favor of motor-kinesthetic ones.

Keywords: Functional magnetic resonance imaging (fMRI); Locomotor attention; Motor training; Motor imagery; Cortical plasticity; Walking

Introduction

Both cognitive and neurological similarities exist between imagined and executed actions. Time courses of imagined and executed movements are correlated (Jeannerod, 1994; Decety and Jeannerod, 1995) and the brain regions activated during imagined movements overlap with the brain regions of executed movements (Decety et al., 1994; Gerardin et al., 2000; for differences in connectivity networks see Solodkin et al., 2004). However, motor imagery tasks are affected by a theoretical caveat; in principle, two different strategies could be involved in motor imagery tasks: motor mental simulation of movements based on kinesthetic memory of corresponding executed movements, or visualization of corresponding effects of movements from visual kinematic imagery, without actual simulated movements (Sirigu and Duhamel, 2001). Classical motor imagery tasks possibly involve both motor and visual imagery. For instance, in mental rotation tasks, a complex interaction between visual and motor imagery is hypothesized (Wexler et al., 1998). In sports psychology, motor training often involves a visualization of oneself performing a motor action. As regards walking, Miyai et al. (2001) have shown that brain activation during a locomotion task, revealed by near-infrared spectroscopy, is comparable to brain activation in a locomotor imagery task, investigated by fMRI. However, Jahn et al. (2004) found considerable brain activation of the cerebral areas involved in visuospatial navigation, in a walking imagery task. Locomotion is based on a complex pattern of sequential movements based on both automatic spinal cord mechanisms (Dietz, 2003) and cortical and subcortical neurological control. In humans, walking is a learned automated process: people normally walk without being consciously aware of how they are walking. Indeed, the spinal control of locomotion prevents most kinesthetic feelings from accessing a conscious memory system. Thus, when imagining walking, recalling proprioceptive sensations is often difficult, and we therefore tend to make use of visuospatial processes.

Motor learning of new motor skills and motor training for improving learned motor skills require motor attention and are able to produce changes in cortical motor representations. It has been demonstrated that during the learning of new skills, cortical regions associated with sensorimotor functions of the body parts most utilized for the skill gradually start to be represented over larger cortical territories (e.g., Karni et al., 1995; Pascual-Leone et al., 1994; Ioffe, 2004; Sanes, 2003). These effects of motor learning practice emerge also when tested with motor imagery tasks. Lacourse et al. (2005) compared cerebral activation in imagined and executed sequential hand movements before and after 1 week of intensive physical practice. Their results showed that after practice imagined and executed movements elicited increasingly similar activation. The role of "motor expertise" in motor imagery is supported by an fMRI study of the motor imagery of golf players; it showed activation of motor and parietal cortices, supplementary motor area, cerebellum and vermis, and found a correlation between increased number of areas of activation and

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increased handicap of participants (Ross et al., 2003). As far as the lower limbs are concerned, only a few pilot studies have investigated brain activations following motor learning in normal subjects (Perez et al., 2004; Lafleur et al., 2002) and in patients with stroke (Dobkin et al., 2004). Reorganization in the motor cortex was also shown to occur after mentally practicing the corresponding movements (Pascual-Leone et al., 1995; for foot movements, Jackson et al., 2003). Functional changes of combined mental and physical practice while learning foot movements have recently been studied in a patient with stroke (Jackson et al., 2004).

Motor learning and motor training involve a more accurate kinesthetic control of movements and, in principle, a more accurate ability as regards motor simulation in motor imagery tasks. As regards locomotion, a conscious effort has to be made in order to be aware of the movements of the legs and feet when walking. For these reasons, we believe that locomotor practice should be primarily aimed at focusing the patient's attention on walking motor schemes. The present study explores the effect of training in normal subjects that focuses the subject's conscious attention on the movements involved in walking. Some studies have investigated variations in attention to movement through different approaches: varying the automaticity of a movement sequence or thinking about each movement as it is being made (Jueptner et al., 1997); directing attention away from a movement by using a distractor task (Johansen-Berg, 2003; Passingham, 1996); using motor learning where subjects have to generate new responses, monitor movement outcomes, rehearse mentally and keep track of previous moves (Passingham, 1996). All studies confirm that the neural systems supporting motor learning depend on the availability of attentional processes. Rowe et al. (2002) clearly showed that under attention directed to the action, there is increased activity in the prefrontal cortical regions; in particular, it seems that the dorsal prefrontal cortex exerts a cognitive control on action production by mediating the effect of attention on premotor cortical activity.

The training adopted in the present study combined motor learning and motor imagery. In particular, subjects attended basic tango lessons, each lesson ending with a motor imagery rehearsal of the performed steps. The tango was chosen for the intrinsic characteristics of the attention posited on the movements of the lower limbs: steps have to be performed along two pairs of virtual parallel lines, the two pairs being perpendicular to each other, so that only forward-back and right-left directions are allowed; the steps are similar to those of normal walking and the emphasis is on the precision of foot and leg movements. The constraints on locomotor directions and the attention required to perform the steps accurately make the tango a suitable form of training for bringing the subject's conscious awareness onto walking.

Methods

In order to investigate the effect of motor and motor imagery training on motor areas, we devised an fMRI paradigm involving locomotor imagery.

Subjects

Twelve right-handed and right-footed healthy volunteers (five women and seven men; age range = 20.8–34.9, mean age = 27.5 years) took part in the experiment. Limb dominance was determined according to the Edinburgh Handedness Inventory (Oldfield, 1971), to which specific items were added regarding foot preference (Chapman et al., 1987). The ability to form mental images was evaluated by the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973) and the Vividness of Movement Imagery Questionnaire (VMIQ; Isaac et al., 1986); the latter was modified in that motor representations were required in a first rather than third person perspective. All subjects had at least a sufficient ability to form visual and motor images. Exclusion criteria included history of neurological or developmental illness, mental disorders, drug or alcohol abuse, current use of medications known to alter neurological activity. No subject had attended tango lessons before the experiment. All subjects gave informed written consent. The fMRI study was performed at the Ospedale Koelliker in Turin (Italy).

Three males and three females were assigned to the experimental group; the remaining subjects were part of the control group. As regards the vividness of visual and motor imagery, there were no statistical differences between the two groups. The experimental group underwent combined physical and mental training, while the control group underwent no training at all.

Training

Subjects attended a training session every day for 5 consecutive days. Each training session lasted 1 h and consisted of two parts: in the first 45 min, basic tango steps were practiced; in the last 15 min, the practiced steps were rehearsed through the use of motor imagery. Lessons were progressive in difficulty. At the beginning of each lesson, subjects were asked to walk for 5 min timing their steps to the music, which was tango music. After this warm-up period, subjects practiced tango steps: the *academic basic* during the first two lessons and the *turn* in the last two lessons. The *academic basic* is a sequence of eight steps. The man takes one step backward starting with the right foot, one step left, three regular steps forward ending with his feet together. Then he takes another step forward starting with the left foot, one step right ending again with his feet together. The *turn* consists of a three-step sequence along a circular track around the partner. It can start with any one of the steps in the sequence: one step forward, one step left/right and one step backward. Between each step, the dancer has to pivot around the partner on his pivot foot, keeping his balance on just one foot. The trainer arranged the turn sequence so that the same steps were taught to both males and females. The third lesson, the central one, was used to rehearse the sequence that had been learned previously. During all the exercises, the trainer focused subjects' attention on the position of their feet, on proprioceptive inputs coming from the leg muscles (quadriceps and adductors) and on tactile sensations of foot–floor contact. Instead, no attention was placed on the correct position of the hands; thus, subjects were free to embrace their partner in the way they felt most comfortable. At the end of the tango exercises, the trainer asked the subjects to lie down and relax. To induce relaxation the trainer guided the subjects' imagination through a sequence of soothing landscape pictures (e.g., sunset) using background piano music. Then the trainer asked the subjects to progressively relax each part of their body, from head to foot, drawing their attention to their body perceptions. Once the subjects were relaxed, the trainer asked them to visualize the sequence of steps they had learned during the lesson. The trainer described the sequence verbally and counted the step cadence aloud. The trainer's verbal description was aimed at recalling the foot and