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Research Report

Motor imagery facilitates force field learning

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ABSTRACT

Humans have the ability to produce an internal reproduction of a specific motor action without any overt motor output. Recent findings show that the processes underlying motor imagery are similar to those active during motor execution and both share common neural substrates. This suggests that the imagery of motor movements might play an important role in acquiring new motor skills. In this study we used haptic robot in conjunction with motor imagery technique to improve learning in a robot-based adaptation task. Two groups of subjects performed reaching movements with or without motor imagery in a velocity-dependent and position-dependent mixed force field. The groups performed movements with motor imagery produced higher after effects and decreased muscle co-contraction with respect to no-motor imagery group. These results showed a positive influence of motor imagery on acquiring new motor skill and suggest that motor learning can be facilitated by mental practice and could be used to increase the rate of adaptation.

1. Introduction

Humans can acquire new set of skills by modifying their behavior even in diverse and complex environments. The adaptation of human motor system to a new environment has been studied by generating external perturbation forces in a known milieu. These perturbation forces ('force fields'), generated by haptic devices, may be made dependent on position, speed and/or acceleration, thus allowing to simulate specific dynamic environments (Burdet et al., 2006; Franklin et al., 2003; Krakauer et al., 1999; Milner and Franklin 2005; Shadmehr and Mussa-Ivaldi 1994; Shadmehr and Wise 2005). When central nervous system (CNS) experiences a force field that systematically disturbs arm motion, it can acquire a neural representation (internal model, IM) of the relation between motor commands and external dynamics. For example, subjects show a perturbed trajectory when expose to a velocity-dependent force field, but with practice they are capable of gradually recovering their original movements. A neural representation of the relation between motor command and movement helps them to cancel the disturbance by generating pre-planned patterns of forces. If the force field is removed after recovering original movements, the resulting trajectories show a compensatory response (after effects) which is a mirror image of the perturbed trajectory. The presence of after affects indicate that the subjects have acquired the internal models with practice (Shadmehr and Mussa-Ivaldi 1994). In some cases where the movements are made under unstable dynamics, the subjects do not learn the IM and use an alternate strategy for compensation i.e. by increasing the mechanical impedance of the arm (Burdet et al., 2001). This strategy is called impedance control, and it does

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not need to acquire models of the physical environment. Recent studies have shown that the CNS uses both IM and impedance control during learning. The choice of the controller is depended on the external dynamics. The CNS prefers using IM when the external dynamics are stable, but when the external dynamics are unstable it uses impedance control or both (Burdet et al., 2001; Franklin et al., 2003; Milner and Franklin 2005).

In addition, a physiological measure of neural output (electromyography, EMG) could also provide insight into the formation of IMs. Previous work has reported variation in the EMG activity during learning. These variations in the muscle activation are closely related to the adaptive changes in joint torques required to produce the necessary compensatory forces. As subjects move in novel dynamics, the co-contraction of flexors and extensors significantly increases from null field to the force field. The increased co-contraction level tends to reduce with learning (Franklin et al., 2003; Osu et al., 2002; Thoroughman and Shadmehr 1999). On the basis of these results one might predict that the CNS increases the limb's stiffness to ensure the stability early in the learning process and then reduces as dynamics are learned, as a result co-activation level starts high but declines as the internal model is acquired.

A previous study reported that by observing another individual learning to move in a novel mechanical environment, the observers could move more accurately themselves because neural representations of novel environments can be acquired visually on the basis of observation (Mattar and Gribble 2005). In relation with observation, motor imagery (MI) is an internal simulation of a specific motor action without any overt motor output. Generally MI represents conscious access to the content of the intention of a movement (Mulder et al., 2005). Mental rehearsal has long been used in the field of sports to optimize the performance of athletes in sports. In general, mental practice improves motor performance in a variety of tasks where different variables are measured including muscle contraction, movement speed and accuracy (Gentili et al., 2006; Jackson et al., 2001; Mulder et al., 2004; Ranganathan et al., 2004; Yaguez et al., 1998; Yue and Cole 1992). Moreover, the mental practice with MI, at least initially, improves or facilitates performance by acting on the preparation and anticipation of movements (Gentili et al., 2006; Jackson et al., 2003). There are also previous investigations that mental practice generates changes in brain activation during and after the mental training period (Jackson et al., 2003). Several studies suggest that movement imagery and movement execution share common neural mechanisms (Caldara et al., 2004; Jeannerod 1995; Lotze et al., 1999) and the cerebral blood flow and metabolic activity increases during motor imagery in the supplementary, premotor, and primary motor areas similar to motor execution (Lotze et al., 1999; Stippich et al., 2002). These studies suggest that if motor imagery and movement execution share common neural mechanisms, then like physical practice, the internal reproduction of a specific motor action without any overt motor output (motor imagery) can be used with the intention to improve motor performance.

The motor imagery aimed at motor learning, together with haptic robots is a new area to explore and in the present study we investigated the effect of motor imagery on learning external dynamics. In Anwar et al.(2009) we hypothesized that motor imagery with the intention of learning a novel dynamics positively influences the motor performance, and the present study is an extension of that preliminary work. We used a haptic robot to generate controlled perturbations in ongoing movements. These perturbations are a mixed force field which is the sum of a velocity-dependent force field (V) and a position-dependent force field (P). The subjects produced point-to-point movements after imagining the forthcoming movement. We examined the effects of motor imagery on the kinematic performance and also investigated the EMG correlates of learning. We found a positive effect of MI i.e. presence of higher after effects and decreased co-contraction in the MI group after learning, which suggests that motor imagery with rehabilitation robots may find immediate application in fields like neuromotor rehabilitation and motor skill learning.

2. Results

At first performance of both groups was compared at the start and end of force field adaptation, the learning was assessed by errors during the movement (trajectory errors and maximum deviation), endpoint error (target errors) and changes in the

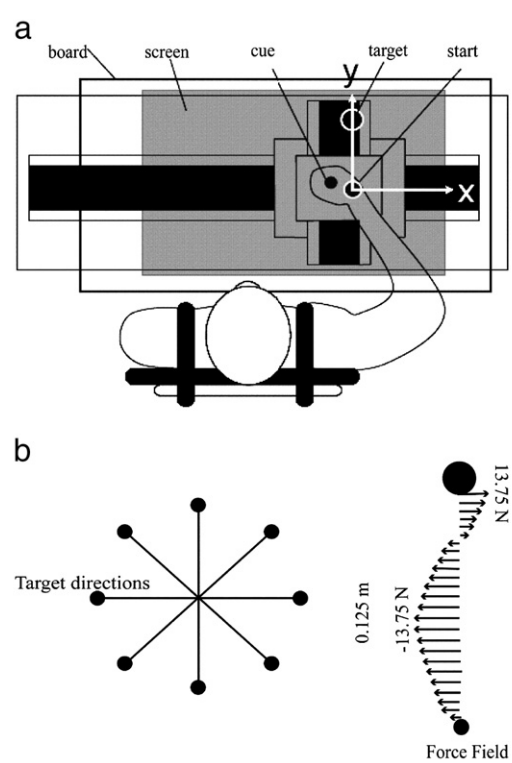

Fig. 1 – Experimental setup: A robotic manipulandum was used to deliver the forces during the movements in eight directions. The forces was generated first toward left (perpendicular to the target direction) and then toward right. (Fig. 1 is similar to but modified slightly from our previous paper (Anwar et al., 2009)).