Neuroscience 297 (2015) 231–242

LATERALITY EFFECTS IN MOTOR LEARNING BY MENTAL PRACTICE IN RIGHT-HANDERS

R. J. GENTILI [a,b,c]* AND C. PAPAXANTHIS [d,e]

[a] *Department of Kinesiology, School of Public Health, University of Maryland, College Park, MD, USA*

[b] *Neuroscience and Cognitive Science Graduate Program, University of Maryland, College Park, MD, USA*

[c] *Maryland Robotics Center, University of Maryland, College Park, MD, USA*

[d] *Université de Bourgogne, Unité de Formation et de Recherche (UFR) en Sciences et Techniques des Activités Physiques et Sportives (STAPS), Dijon, France*

[e] *Institut National de la Santé et de la Recherche Médicale (INSERM), UMR 1093, Cognition, Action et Plasticité Sensorimotrice (CAPS), Dijon, France*

Abstract—Converging evidences suggest that mental movement simulation and actual movement production share similar neurocognitive and learning processes. Although a large body of data is available in the literature regarding mental states involving the dominant arm, examinations for the nondominant arm are sparse. Does mental training, through motor-imagery practice, with the dominant arm or the nondominant arm is equally efficient for motor learning? In the current study, we investigated laterality effects in motor learning by motor-imagery practice. Four groups of right-hander adults mentally and physically performed as fast and accurately as possible (speed/accuracy trade-off paradigm) successive reaching movements with their dominant or nondominant arm (physical-training-dominant-arm, mental-training-dominant-arm, physical-training-nondominant-arm, and mental-training-nondominant-arm groups). Movement time was recorded and analyzed before, during, and after the training sessions. We found that physical and mental practice had a positive effect on the motor performance (i.e., decrease in movement time) of both arms through similar learning process (i.e., similar exponential learning curves). However, movement time reduction in the posttest session was significantly higher after physical practice than motor-imagery practice for both arms. More importantly, motor-imagery practice with the dominant arm resulted in larger and more robust improvements in movement speed compared to motor-imagery practice with the nondominant arm. No such improvements were observed in the control group. Our results suggest a superiority of the dominant arm in motor learning by mental practice. We discussed these findings from the perspective of the internal models theory.

Key words: motor imagery, forward model, mental practice, internal model, arm reaching movement.

INTRODUCTION

During motor imagery practice subjects internally simulate a movement without any motor output. This mental process implies that individuals feel themselves performing a movement in a first-person perspective (e.g., imagined the sensation of shooting a basketball). Neurophysiological and psychophysical studies have revealed that mental and actual states of action trigger similar motor representations and share overlapping neural substrates (Jeannerod, 2001; Guillot and Collet, 2005; Lorey et al., 2009; Munzert et al., 2009). For instance, common activations of the parietal and prefrontal cortices, the supplementary motor area, the premotor and primary motor cortices, the basal ganglia, and the cerebellum have been repeatedly reported. Furthermore, the activation of the autonomic nervous system, such as heart and respiration rate, increases proportionally to the mental effort produced by subjects during mental movements (Decety et al., 1993; Demougeot et al., 2009; Collet et al., 2013). Lastly, mental actions preserve the same spatiotemporal characteristics and obey the same motor rules as their overt counterparts (Decety and Jeannerod, 1995; Papaxanthis et al., 2002, 2012; Gentili et al., 2004; Bakker et al., 2007).

Mental training, by means of motor-imagery, is a potential tool in sports and motor rehabilitation, because it was shown to improve motor function. In particular, mental training enhances muscular force (Yue and Cole, 1992; Zijdewind et al., 2003; Ranganathan et al., 2004) and improves movement kinematics (Yágüez et al., 1998; Gentili et al., 2006, 2010; Allami et al., 2008; Avanzino et al., 2009). The concept of internal model provides the theoretical basis to understand the positive effects of mental training on motor performance (e.g., Wolpert and Miall, 1996; Gentili et al., 2010). Forward internal models mimic the causal flow of the physical process, that is the mapping from motor commands to sensorimotor consequences, by predicting the future sensorimotor state (e.g., position, velocity) given the efferent copy of the motor command and the current state

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*Correspondence to: R. J. Gentili, Department of Kinesiology, 2144 School of Public School Building (#255), University of Maryland, College Park, MD 20742, USA. Tel: +1-301-405-2490; fax: +1-301-405-5578.
E-mail address: rodolphe@umd.edu (R. J. Gentili).
Abbreviations: ANOVA, analysis of variance; RMS, root mean square; rMSE, root mean square of the error.

http://dx.doi.org/10.1016/j.neuroscience.2015.02.055

(Wolpert and Miall, 1996). During physical training, the estimated state of the motor system can be employed to refine future motor commands by generating an internal training signal that modifies plastic neural processes (Wolpert et al., 1995; Kawato, 1999; Desmurget and Grafton, 2000). In addition, noisy and delayed sensory feedback is thought to be combined with forward model output to provide accurate and precise state estimation (Wolpert et al., 1995). During mental training, a similar plastic neural mechanism based on the estimated state of the motor system can be utilized (Wolpert and Miall, 1996; Gentili et al., 2006, 2010). Motor learning by mental training is associated with changes in brain activation both in healthy individuals (Lafleur et al., 2002; Jackson et al., 2003) and stroke patients (Page et al., 2009). However, since during mental training the state estimation derives from the forward model alone, the training signal is presumably less accurate and less precise than during physical training. This may explain in part why mental training is, in general, less efficient than physical training (Gentili et al., 2006, 2010).

Though a large body of work regarding mental states related to the dominant arm performance is available, research for the nondominant arm is still relatively limited. Neurophysiological and clinical investigations (Fadiga et al., 1999; Lotze et al., 1999; Sabaté et al., 2004; Stinear et al., 2006a), as well as psychophysical studies examining the temporal aspects of imagined arm movements (Maruff et al., 1999; Skoura et al., 2008, 2009), have shown that lateralization also emerges in mental imagery. An intriguing question, however, is whether mental training with the dominant or nondominant arm is equally efficient for motor learning.

Previous studies have suggested that the left hemisphere/right arm control system would be predominantly involved in movement organization and selection (Haaland and Harrington, 1996; Schluter et al., 1998; Rushworth et al., 2001), in movement representation and learning (Grafton et al., 2002; Kuhtz-Buschbeck et al., 2003), and in body state estimation (Wolpert et al., 1998; Mutha et al., 2011), suggesting its important role in feedforward control processes (Sainburg, 2002; Agnew et al., 2004; Mutha et al., 2011, 2012). On the other hand, the right hemisphere/left arm control system appears to have reduced higher order planning functions (Amunts et al., 1996; Serrien et al., 2006), with preferential involvement in feedback control processes (Sainburg, 2002; Mutha et al., 2012). According to this potential mechanism, (i.e., the dynamic-dominant hypothesis) one could expect better learning by mental practice for the right than the left arm, because mental practice is based on feedforward process, since there is no movement feedback. Laterality effects in motor learning by mental practice may also emerge because the predictions of the nondominant arm control system would be relatively crude due to a lack of experience or use compared with the right arm (i.e., experience-dependent arm-dominance training). The previous theoretical considerations would predict that state estimation during mental actions should be more accurate and precise (i.e., more tightly related to actual state estimation) for the dominant arm than for the nondominant arm, leading thus to better and faster motor learning for the former.

In the current study, we aimed to investigate laterality effects in motor learning by motor-imagery practice. We asked four groups of right-hander adults to mentally and physically perform as fast and accurate as possible (speed/accuracy trade-off paradigm) successive reaching movements with their dominant or nondominant arm toward multiple targets following a pre-determined path. Based on the previously mentioned lateralization motor processes, we predicted that dominant arm mental training, compared to nondominant arm mental training, should result in higher enhancement of motor performance. As such, this study contributes to expand our knowledge regarding the underlying learning processes of the dominant and nondominant arms during mental practice.

EXPERIMENTAL PROCEDURES

Participants

Sixty healthy young adults participated in this experiment. All were right-handers (average score: 0.85 ± 0.04), as determined by the Edinburgh Handedness inventory (Oldfield, 1971), and good imagers (average score: 46 ± 3, maximum score 57) as determined by the French version of the Movement Imagery Questionnaire (Hall and Martin, 1997). Participants were randomly assigned into five groups (see Fig. 1): (i) the physical-training dominant arm group (Pd group, mean age 23.2 ± 2.0 yrs, five males and seven females), (ii) the mental training dominant arm group (Md group, mean age 23.3 ± 2.1 yrs, seven males and five females), (iii) the physical training nondominant arm group (Pnd group, mean age 24.1 ± 1.6 yrs, eight males and four females), (iv) the mental training nondominant arm group (Mnd group, mean age 22.8 ± 2.5 yrs, eight males and four females), and (v) the control-group (C group, mean age 22.1 ± 1.9 yrs, six males and six females). Handedness and imagery scores did not differ between groups (respectively, $F(4,55) = 0.13$, $p = 0.97$ and $F(4,55) = 0.3$, $p = 0.99$; between-subject one-way analysis of variance (ANOVA)). All the participants gave their informed consent. The experimental protocol was approved by the Ethics committee of the Université de Bourgogne and carried out in agreement with legal requirements and international norms (Declaration of Helsinki, 1964).

Experimental device and motor task

The experiment device was similar to that used in the study of Gentili et al. (2010). Two aluminum dowels (length: 75 cm, diameter: 1 cm) were fixed on a vertical bar (height: 86 cm, width: 10 cm) 44 cm one above the other. On each dowel, we symmetrically placed four targets, two on the left and two on the right side of the vertical bar (Fig. 2). The horizontal distance that separated the near (3, 4, 5, 6) and farther (1, 2, 7, 8) targets from the vertical bar was 10 cm and 35 cm, respectively. The eight targets were switches (diameter of 5 mm) and were all linked to an electronic stopwatch. Another target (target