Neuroscience 290 (2015) 398–405

CORTICOSPINAL EXCITABILITY DURING IMAGINED AND OBSERVED DYNAMIC FORCE PRODUCTION TASKS: EFFORTFULNESS MATTERS

F. HELM,[a]* W. MARINOVIC,[b,c] B. KRÜGER,[a] J. MUNZERT[a] AND S. RIEK[b]

[a] *Neuromotor Behavior Laboratory, Justus-Liebig-University Giessen, Germany*

[b] *School of Human Movement Studies, The University of Queensland, Brisbane, Australia*

[c] *School of Psychology, The University of Queensland, Brisbane, Australia*

Abstract—Research on motor imagery and action observation has become increasingly important in recent years particularly because of its potential benefits for movement rehabilitation and the optimization of athletic performance (Munzert et al., 2009). Motor execution, motor imagery, and action observation have been shown to rely largely on a similar neural network in motor and motor-related cortical areas (Jeannerod, 2001). Given that motor imagery is a covert stage of an action and its characteristics, it has been assumed that modifying the motor task in terms of, for example, effort will impact neural activity. With this background, the present study examined how different force requirements influence corticospinal excitability (CSE) and intracortical facilitation during motor imagery and action observation of a repetitive movement (dynamic force production). Participants were instructed to kinesthetically imagine or observe an abduction/adduction movement of the right index finger that differed in terms of force requirements. Trials were carried out with single- or paired-pulse transcranial magnetic stimulation. Surface electromyography was recorded from the first dorsal interosseous (FDI) and the abductor digiti minimi (ADM). As expected, results showed a significant main effect on mean peak-to-peak motor-evoked potential (MEP) amplitudes in FDI but no differences in MEP amplitudes in ADM muscle. Participants' mean peak-to-peak MEPs increased when the force requirements (movement effort) of the imagined or observed action were increased. This reveals an impact of the imagined and observed force requirements of repetitive movements on CSE. It is concluded that this effect might be due to stronger motor neuron recruitment for motor imagery and action observation with an additional load. That would imply that the modification of motor parameters in movements such as force requirements modulates CSE.

Key words: corticospinal excitability, intracortical facilitation, dynamic force production, effort, motor imagery, action observation.

INTRODUCTION

There is a broad body of literature underpinning the concept of a functional equivalence between mental simulation states (S states) and the execution of actions (see Grèzes and Decety, 2001; Jeannerod, 2001, for reviews). One comprehensive account of the underlying brain mechanisms assumes that these cognitive motor states are based on one's own motor representations in the brain (Grush, 2004; Jeannerod, 1994, 2001). Jeannerod proposed an explanation for this in his mental simulation theory. This reveals that a movement possesses a covert action stage involving its characteristics as the goal, the means to achieve it, and its consequences (Jeannerod, 2001). Due to their covert nature, these actions are not executed but rather, mentally simulated. Exemplary situations for such covert activity are the conscious, self-intended simulation of one's own actions (motor imagery) or the perception of actions by others (action observation). However, the main difference between these two cognitive motor states is that motor imagery is generated internally, whereas action observation is driven by external stimuli (Munzert et al., 2008; Vogt et al., 2013). Therefore, the assumption of a functional equivalence between S states does not always imply a total congruency of the underlying processes (e.g., Lorey et al., 2013).

On a neural level, early positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) studies showed that these processes rely on a similar neural network in motor and motor-related cortical areas (Jeannerod, 2001; Porro et al., 1996; Lotze et al., 1999; Munzert et al., 2008), and that the neural activation patterns of these S states overlap with those of movement

*Corresponding author. Address: Neuromotor Behavior Laboratory, Justus-Liebig-University Giessen, Kugelberg 62, 35394 Giessen, Germany.

E-mail addresses: fabian.helm@sport.uni-giessen.de (F. Helm), w.marinovic@uq.edu.au (W. Marinovic), britta.krueger@sport.uni-giessen.de (B. Krüger), joern.munzert@sport.uni-giessen.de (J. Munzert), sriek@hms.uq.edu.au (S. Riek).

Abbreviations: ADM, abductor digiti minimi; ANOVA, analysis of variance; CSE, corticospinal excitability; EMG, electromyography; FDI, first dorsal interosseous; fMRI, functional magnetic resonance imaging; IC, imagery control; ICF, intracortical facilitation; IHF, imagery high force; IMF, imagery minimal force; M1, primary motor cortex; MEPs, motor-evoked potentials; MVC, maximal voluntary contraction; OBS, movement observation; rMT, resting motor threshold; S state, covert stages of action that share common representations with motor execution; SMA, supplementary motor area; TMS, transcranial magnetic stimulation; VC, visual control; VMIQ-2, vividness of movement imagery questionnaire 2.

http://dx.doi.org/10.1016/j.neuroscience.2015.01.050
0306-4522/

execution. Brain imaging research has provided considerable evidence for neural activation of motor and motor-related brain areas during motor imagery and action observation (Filimon et al., 2007; Gazzola and Keysers, 2009; Munzert et al., 2009; Zentgraf et al., 2011; Lorey et al., 2013). This has indicated that specific action features such as accuracy affordances (Grosjean et al., 2007; Lorey et al., 2010) and effort (Decety and Jeannerod, 1996; Guillot et al., 2007) are also represented on a neural level.

Although the reported fMRI studies offer a comprehensive picture of activation for the frontoparietal motor network as well as for subcortical regions during S states, some limitations are obvious, especially for primary motor cortex (M1) activation during motor imagery, for instance. The often reported level of 30–50% activation during motor imagery compared to movement execution may lead to no significant neural activations being found in M1 in fMRI studies, particularly when conservative thresholds are applied (Lotze and Zentgraf, 2010). These limitations may be overcome by studying corticospinal excitability (CSE) during cognitive motor states. Until now, several transcranial magnetic stimulation (TMS) studies have examined CSE during motor imagery and action observation within the same study. In general, they have demonstrated corticospinal facilitation for S states, even when specific results differ due to the application of different motor tasks, different instructions, and sometimes even different evaluation methods (Clark et al., 2003; Stinear et al., 2006; Léonard and Tremblay, 2007; Roosink and Zijdewind, 2010; Bianco et al., 2012). Nonetheless, these task-related result patterns illustrate a possible modulation of CSE during motor imagery and action observation.

Given the fact that S states are a covert stage of an action, it can be assumed that modulations of the motor task such as effort or accuracy will have an impact on neural activation as already reported in several fMRI studies (e.g., Winstein et al., 1997; Lorey et al., 2010). This makes it meaningful to ask whether different force requirements of imagined and observed actions will influence CSE in M1. The literature has already demonstrated that a higher force level within the same movement facilitates CSE (Alaerts et al., 2010; Mizuguchi et al., 2013). However, current evidence on this issue is inconsistent. Park and Li (2011) asked their participants to execute isometric finger flexions and extensions graded by force levels of 10–60% of the maximal voluntary contraction (MVC) followed by an imagery trial on which they had to imagine the same force level after a short delay. Whereas all imagined force levels showed corticospinal facilitation compared with a rest condition, there were no differences between imagined force levels. It has been argued that the missing effect for a graded corticospinal facilitation might be due not only to the time sequence of physically performed and imagined trials but also to a possible after effect of the physical contractions (Mizuguchi et al., 2013). This is why Mizuguchi and colleagues trained their participants to first produce 10%, 30%, and 60% of MVC in an isometric elbow flexion task. This training session was followed by a separate imagery session of the respective force task. They found an increase of motor-evoked potential (MEP) amplitudes in the agonist muscles for higher force levels and significant differences between the 10% and the 60% force levels. This study provided evidence that the level of imagined isometric contraction modulates CSE.

To further clarify the influence of different force requirements, the present study aims to replicate and extend previous findings on movement simulation by investigating changes in M1 excitability and facilitation. The main objectives of the present study were as follows: First, we used a repetitive abduction/adduction movement of the right-index finger to be characterized as a dynamic force production task in the first dorsal interosseous (FDI). Second, we investigated CSE during motor imagery and action observation in the same experiment. Third, we applied single- and paired-pulse TMS to examine intracortical facilitation (ICF).

We applied a design with a total of three experimental conditions. Participants had to imagine the repetitive finger movement with two different force requirements. In addition, we implemented an observation condition with only high-force requirements of the same dynamic movement. Two control conditions (one each for the imagery and observation tasks) were applied in order to control the influence of perceptual-cognitive processes. We predicted that we would observe an increase in CSE and ICF during imagery of trials with higher mental force requirements. For the observation condition, we expected to observe an increase of CSE and ICF when compared to a visual control condition.

EXPERIMENTAL PROCEDURES

Participants and design

Eleven right-handed (Oldfield, 1971) participants with normal or corrected-to-normal vision volunteered to participate in this study (nine male, mean age = 25 years, *SD* = 4.3). Imagery ability was assessed with the Vividness of Movement Imagery Questionnaire 2 (VMIQ-2, Roberts et al., 2008). All participants reported no history of neurological disorders and no history and/or current use of psychoactive medication. The study was approved by the local ethics committee of the University of Queensland in accordance with the National Health and Medical Research Council's guidelines. All participants gave their informed written consent in accordance with the Declaration of Helsinki.

There were three experimental conditions: Two kinesthetic imagery conditions in which two levels of force were required to be imagined (imagery high force: IHF; imagery minimal force: IMF) and only one movement observation (OBS) condition in which the force requirements reflected those of the high-force condition of the imagery trials as changes in movement kinematics are difficult to recognize during observation tasks in general. These imagined or observed actions consisted of 10 repetitive movements (1 Hz) of horizontal abduction/adduction of the right index finger resulting in a dynamic force production in FDI. In the