cortex 48 (2012) 593–603

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Journal homepage: www.elsevier.com/locate/cortex

Research report

Extension of mental preparation positively affects motor imagery as compared to motor execution: A functional near-infrared spectroscopy study

Lisa Holper [a,b,*], *Felix Scholkmann* [a], *Diego E. Shalóm* [c] *and Martin Wolf* [a]

[a] *Biomedical Optics Research Laboratory (BORL), Division of Neonatology, Department of Obstetrics and Gynecology, University Hospital Zurich, Switzerland*

[b] *Institute of Neuroinformatics (INI), University of Zurich and ETH Zurich, Switzerland*

[c] *Laboratory of Integrative Neuroscience, Physics Department, Faculty of Exact and Natural Sciences, University of Buenos Aires, Argentina*

ARTICLE INFO

Article history:
Received 24 August 2010
Revised 18 October 2010
Accepted 31 January 2011
Action editor Pia Rotshtein
Published online 9 February 2011

Keywords:
Wireless functional near-infrared spectroscopy (fNIRS)
Mental preparation
Motor imagery
Motor execution
Oxy-hemoglobin
Neurorehabilitation

ABSTRACT

Motor imagery (MI) is widely used to study cognitive action control. Although, the neural simulation theory assumes that MI and motor execution (ME) share many common features, the extent of similarity and whether it spreads into the preparation phase is still under investigation. Here we asked, whether an extension of physiological mental preparation has a comparable effect on MI and ME.

Data were recorded using wireless functional near-infrared spectroscopy (fNIRS) in a two-stage task design where subjects were cued with or without preparatory stimuli to either execute or imagine complex sequential thumb-finger tasks.

The main finding is that the extended mental preparation has a significant positive effect on oxy-hemoglobin ($\Delta[O_2Hb]$) in response to MI, which is proportionally larger as that found in response to ME. Furthermore, fNIRS was capable to discriminate within each task whether it was preceded by preparatory stimuli or not. Transition from mental preparation to actual performance (ME or MI) was reflected by a dip of the fNIRS signal presumably related to underlying cortical processes changing between preparation and task performance. Statistically significant main effects of 'Preparation' and 'Task' showed that $\Delta[O_2Hb]$ during preparation was preparation-specific, i.e., positively affected by the presence of preparatory stimuli, whereas during task performance $\Delta[O_2Hb]$ was both preparation- and task-specific, i.e., additionally affected by the task mode.

These results are particularly appealing from a practical point of view for making use of MI in neuroscientific applications. Especially neurorehabilitation and neural interfaces may benefit from utilizing positive interactions between mental preparation and MI performance.

* *Corresponding author*. Biomedical Optics Research Laboratory (BORL), Division of Neonatology, Department of Obstetrics and Gynecology, University Hospital Zurich, Frauenklinikstrasse 10, 8091 Zurich, Switzerland.

E-mail address: holper@ini.phys.ethz.ch (L. Holper).

0010-9452/$ – see front matter

doi:10.1016/j.cortex.2011.02.001

1. Introduction

1.1. Motor imagery (MI)

MI has been described as the mental rehearsal of voluntary movement (Jeannerod, 2001). According to the so-called simulation hypothesis (Rizzolatti et al., 2001; Jeannerod, 1994), MI activates a cortical network located in primary motor cortex (M1) and secondary motor areas, such as premotor cortex (PMC), supplementary motor area (SMA) and parietal cortices (Fadiga et al., 1995) which is thought to overlap with that responsible for the actual execution of the same motor action (Decety, 1996a; Lotze et al., 1999).

Likewise motor execution (ME), it is suggested, that the cognitive processes underlying MI comprise two consecutive phases (Cunnington et al., 2005; Thoenissen et al., 2002). While the first phase consists of mental preparation to set up planning for a given task, the second phase involves the actual performance of the task, e.g., execution or imagery. Though extensive evidence has been provided that MI and ME share many common features (Decety, 1996b), the extent of similarity and whether it spreads into the mental preparation phase has only recently attracted the attention of researchers.

1.2. Mental preparation

So far, mental preparation preceding MI has been investigated using traditional methods such as functional magnetic resonance imaging (fMRI) (Hanakawa et al., 2008; Johnson et al., 2002) and electroencephalography (EEG) (Kranczioch et al., 2009, 2010; Caldara et al., 2004; Cunnington et al., 1996). These studies indicate that in the early stages of preparatory processes both, mental preparation of ME and MI generate comparable values of signal amplitudes possibly involving similar cortical areas (Kranczioch et al., 2009). In particular, the pre-supplementary motor area (pre-SMA) has been suggested to play the relevant role in encoding motor actions during mental preparation. This area is thought to generate motor representations of the related movement pattern which are then maintained in readiness for action (Cunnington et al., 2005). However, at the late stage of preparatory processes differences in signal amplitudes between actual and imagined motor actions emerge, presumably consisting of a quantitative modulation of the activity of the associated motor structures (Caldara et al., 2004). The resulting cortical activation measured by traditional neuroimaging methods is thereby usually lower during MI as compared to ME (Porro et al., 1996).

It is known that mental preparation increases signal amplitudes and performance of ME (Biddle, 1985; Feltz and Landers, 1983). One obvious question is whether the same effect of mental preparation can be observed for MI. Further, the process of mental preparation following the physiological time course is usually a very short-lived and rather unconscious process happening within milliseconds. Hence, a second question is whether there is an option to make use of a manipulation of the preparation phase to make mental preparation accessible and thereby measurable. A possible and feasible manipulation would be a temporal extension of the duration of the preparation phase.

In this study we aimed to answer these two questions: 1) Does mental preparation have the same effect on MI as on ME, i.e., an increase in signal amplitudes and in performance? 2) Does an extension of the preparation phase to several seconds preceding MI and ME have an influence on the resulting cortical oxygenation?

To test this we studied MI and ME proceeded by an extended preparation time interval while providing mental preparatory stimuli and compared this to the absence of preparatory stimuli. To record cortical oxygenation changes we used functional near-infrared spectroscopy (fNIRS), an optical brain imaging method, that has been previously shown to be a suitable tool for monitoring MI (Coyle et al., 2004, 2007; Kanoh et al., 2009; Sitaram et al., 2007). We hypothesized that using this approach we would be able 1) to separate the neural processes underlying this preparatory activation and the following performance, i.e., motor or imagery performance; 2) to provide insights into topographical aspects and the physiological time course from mental preparation to MI performance reflected in the fNIRS signal; and 3) to suggest how possible neural components reflecting preparatory processes could be used to improve current neurorehabilitative strategies.

2. Methods

2.1. Subjects

15 healthy subjects were included (8 males, mean age 28 years, range 23–35 years). One subject was excluded from analysis due to missing signal acquisition. All subjects were right-handed as assessed by the Edinburgh Handedness Inventory (EHI) (Oldfield, 1971), with mean Laterality Quotient (LQ) of 79, range 69–100; mean deciles level of 5.6, range 2–10. Exclusion criteria were any history of visual, neurological or psychiatric disorders or any current medication. All subjects gave informed consent. All subjects had normal or corrected-to-normal vision. The study was approved by the ethics committee of the Canton of Zurich and was in accordance with the latest version of the Helsinki declaration.

2.2. Experimental protocol

Each subject participated in one session. All experiments were conducted in a quiet room at the Institute of Neuroinformatics, University of Zurich and ETH Zurich. Subjects were asked to sit in front of a LCD monitor (94 cm diagonal, 1366 × 768 pixels) at a comfortable distance of approximately 60 cm from the eyes.

The experimental design consisted of a two-stage task design S1–S2 in which each trial comprised two phases (preparation phase and production phase) cued by two stimuli (S1 and S2) (Fig. 1). Stimuli were presented using white numbers on the screen generated by the software Presentation® (Neurobehavioral systems, Albany, USA). The following four task conditions were presented: 1) Prep-ME: preparatory stimuli (Prep, S1) followed by motor execution (ME, S2), 2) NoPrep-ME: no preparatory stimuli (NoPrep, S1)