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Research Report

Brain activity during observation and motor imagery of different balance tasks: An fMRI study

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ARTICLE INFO

Article history:
Received 27 March 2014
Reviewed 22 June 2014
Revised 14 August 2014
Accepted 30 September 2014
Action editor Georg Goldenberg
Published online 27 October 2014

Keywords:
Functional magnetic resonance imaging
Action observation
Motor imagery during action observation
Non-physical balance training

ABSTRACT

After immobilization, patients show impaired postural control and increased risk of falling. Therefore, loss of balance control should already be counteracted during immobilization. Previously, studies have demonstrated that both motor imagery (MI) and action observation (AO) can improve motor performance. The current study elaborated how the brain is activated during imagination and observation of different postural tasks to provide recommendations about the conception of non-physical balance training. For this purpose, participants were tested in a within-subject design in an fMRI-scanner in three different conditions: (a) AO + MI, (b) AO, and (c) MI. In (a) participants were instructed to imagine themselves as the person pictured in the video whereas in (b) they were instructed simply to watch the video. In (c) subjects closed their eyes and kinesthetically imagined the task displayed in the video. Two tasks were evaluated in each condition: (i) static standing balance and (ii) dynamic standing balance (medio-lateral perturbation). In all conditions the start of a new trial was indicated every 2 sec by a sound.

During AO + MI of the dynamic task, participants activated motor centers including the putamen, cerebellum, supplementary motor area, premotor cortices (PMv/d) and primary motor cortex (M1). MI showed a similar pattern but no activity in M1 and PMv/d. In the SMA and cerebellum, activity was generally higher in the dynamic than in the static condition. AO did not significantly activate any of these brain areas.

Our results showed that (I) mainly AO + MI, but also MI, activate brain regions important for balance control; (II) participants display higher levels of brain activation in the more demanding balance task; (III) there is a significant difference between AO + MI and AO. Consequently, best training effects should be expected when participants apply MI during AO (AO + MI) of challenging postural tasks.

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http://dx.doi.org/10.1016/j.cortex.2014.09.022

1. Introduction

After several days of involuntary immobility patients show impaired postural control and increased risk of falling (Visschedijk, Achterberg, van Balen, & Hertogh, 2010). It is therefore important to take steps to counteract loss of postural control during the period of immobility. Motor imagery (MI) of balance tasks has been shown to improve static postural control in elderly people (Hamel & Lajoie, 2005). Similarly, action observation (AO) was shown to improve performance in a sitting-to-standing-to-sitting task and in walking (Tia et al., 2010). These findings provide evidence that both MI and AO can improve postural control, but the neural sites responsible for this improvement have not so far been identified.

It is commonly agreed that the positive effects of MI and AO on physical task performance are probably explained by activation of overlapping brain areas during motor execution and MI as well as during motor execution and AO (Grezes, Armony, Rowe, & Passingham, 2003; Jeannerod, 1995, 2001; Olsson, Jonsson, & Nyberg, 2008). Jeannerod postulated the well accepted hypothesis that "the motor system is part of a simulation network that is activated under a variety of conditions in relation to action, either self-intended or observed from other individuals" (Jeannerod, 2001). This simulation network may differently be activated by different covert actions such as MI or AO although Jeannerod assumed a core network that pertains to all stimulation states (Jeannerod, 2001).

Previous studies investigating actual execution of postural tasks with neurophysiological (Beck et al., 2007; Schubert et al., 2008; Taube et al., 2007, 2006) and imaging methods (Ouchi, Okada, Yoshikawa, Nobezawa, & Futatsubashi, 1999; Taubert et al., 2010; Taubert, Lohmann, et al., 2011; Taubert, Villringer, et al., 2011) concluded that primary motor cortex (M1), visual cortex, the anterior and posterior cerebellar lobes, the basal ganglia (especially the putamen) and the brainstem are all involved in balance control in humans. Studies have also shown that physical execution of more demanding postural tasks was associated with higher activity in the supraspinal centers associated with postural control such as the cerebellum, the putamen, the brainstem and various neocortical structures (Ouchi et al., 1999). However, brain activity during MI and AO of balance tasks is rarely known. Jahn et al., (2004) used functional magnetic resonance imaging (fMRI) to demonstrate that activity of the thalamus, basal ganglia (left putamen), left frontal gyrus and spinocerebellum (cerebellar vermis) was increased when participants imagined they were standing rather than lying down. Furthermore, the pattern of activity during imagined standing was different from the pattern of activity obtained during imagined walking and running, in which a six times larger activity of the cerebellum could be detected. The authors therefore concluded that control of an undisturbed upright stance involves low intensity cerebellar activity and sensorimotor control via the thalamus and basal ganglia (Jahn et al., 2004). However, so far no previous study has investigated brain activity during MI or AO of balance tasks which require participants to counteract external perturbation.

Therefore, the first aim of the current study was to compare brain activity during a dynamic balance task (mediolateral perturbation) with activity in a less demanding static balance task (maintaining an upright stance). It is well known from non-postural tasks that MI (Gerardin et al., 2000; Grezes & Decety, 2001; Hallett, Fieldman, Cohen, Sadato, & Pascual-Leone, 1994; Jeannerod, 2001; Kimberley et al., 2006; Lotze et al., 1999; Sirigu et al., 1995; Stephan et al., 1995) and AO (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Grezes & Decety, 2001; Neuper, Scherer, Reiner, & Pfurtscheller, 2005) activate brain regions that are also active during actual task execution. Ouchi et al., (1999) have further demonstrated that execution of more challenging standing tasks increased brain activity; we therefore hypothesized that activity in motor centers would be higher in the more demanding dynamic task than during static standing.

The second main aim of the current study was to explore differences in brain activity according to the way participants mentally involved in the balance task. In a recent review article, Vogt, Rienzo, Collet, Collins, and Guillot (2013) have pointed out that MI and AO have been largely studied in isolation from each other but that combining both seems very promising. This statement was based on studies using electroencephalography (Berends, Wolkorte, Ijzerman, & van Putten, 2013) and fMRI (Macuga & Frey, 2012; Nedelko, Hassa, Hamzei, Schoenfeld, & Dettmers, 2012; Villiger et al., 2013; Vogt et al., 2013) to demonstrate higher brain activity during AO + MI compared with AO and MI, respectively, in non-postural tasks. In order to clarify whether this phenomenon can also be applied to balance tasks, differences in neural activation between a) 'motor imagery' (MI), b) 'actively' (AO + MI) and c) 'passively' (AO alone) observed balance tasks were investigated by instructing participants either to a) imagine the balance task (MI), b) imagine themselves as the person displayed in the video (AO + MI) or c) simply to watch the video (AO). In analogy to observations in voluntary hand movements (Berends et al., 2013; Macuga & Frey, 2012; Nedelko et al., 2012) we expected the activity to be greater during AO + MI than during AO or MI in both the static and dynamic balance task.

In summary, the overall goal of this study was to identify differences in the pattern of neural activity evoked by MI, AO and AO + MI of differently demanding balance tasks that can be used to develop recommendations for the non-physical training of immobilized patients.

2. Materials and methods

2.1. *Study participants*

Sixteen healthy participants (6 females) aged between 20 and 37 years (mean ± SD = 27 ± 4.81) free from neurological and orthopedic disorders participated in this study. They had normal or corrected-to-normal vision. All participants were briefed on the experiments and gave written informed consent to the experimental procedure before testing. The study was approved by the local ethics committee and was in accordance with the Declaration of Helsinki.