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Research report

Prism adaptation by mental practice

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ABSTRACT

The prediction of our actions and their interaction with the external environment is critical for sensorimotor adaptation. For instance, during prism exposure, which deviates laterally our visual field, we progressively correct movement errors by combining sensory feedback with forward model sensory predictions. However, very often we project our actions to the external environment without physically interacting with it (e.g., mental actions). An intriguing question is whether adaptation will occur if we imagine, instead of executing, an arm movement while wearing prisms. Here, we investigated prism adaptation during mental actions. In the first experiment, participants ($n = 54$) performed arm pointing movements before and after exposure to the optical device. They were equally divided into six groups according to prism exposure: Prisms-Active, Prisms-Imagery, Prisms-Stationary, Prisms-Stationary-Attention, No Conflict-Prisms-Imagery, No Prisms-Imagery. Adaptation, measured by the difference in pointing errors between pre-test and post-test, occurred only in Prisms-Active and Prisms-Imagery conditions. The second experiment confirmed the results of the first experiment and further showed that sensorimotor adaptation was mainly due to proprioceptive realignment in both Prisms-Active ($n = 10$) and Prisms-Imagery ($n = 10$) groups. In both experiments adaptation was greater following actual than imagined pointing movements. The present results are the first demonstration of prism adaptation by mental practice under prism exposure and they are discussed in terms of internal forward models and sensorimotor plasticity.

1. Introduction

Since the 19th century, adaptation to the deviation of the visual field through prisms constitutes a robust experimental paradigm investigating short-term sensorimotor plasticity (Redding et al., 2005; Stratton, 1896). At the beginning of prism exposure, subjects produce endpoint errors in the direction of the optical shift when pointing to a visual target. On the basis of the visual error signal, subjects gradually adapt their motor commands until they achieve an accurate movement. When prisms are removed, sensorimotor correlations developed during prism exposure become inappropriate and subjects' pointing movements are shifted in the direction opposite to the prismatic deviation. These errors, termed *after-effects*,

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testify the development of sensorimotor adaptation. Note that conscious error detection/correction is not primordial for prism adaptation. For example, exposure to growing optical displacements, where there is no 'conscious' correction, leads to significant adaptation (Jakobson and Goodale, 1989; Michel et al., 2007). Likewise, neglect patients (e.g., Halligan et al., 2003) show substantial after-effects without detecting any visual perturbation (Calabria et al., 2004; Rossetti et al., 1998).

The theory of internal models (Kawato, 1999; Miall and Wolpert, 1996) suggests that the internal representation of the relationship between motor commands and sensory signals is critical for the development of adaptation. During sensorimotor conflict, the difference between the actual and the predicted visual location of the hand with respect to the target location (i.e., the sensory prediction error) and the corrective motor command are responsible for after-effects (Tseng et al., 2007; see also Bastian, 2008 for a review). Frequently, we project our actions into the external environment without physically interacting with it. This is the case in mental actions during which we internally simulate a movement without any motor output. Several investigations have provided robust evidences that mental and actual movements trigger similar motor representations and share overlapping neural substrates (Ehrsson et al., 2003; Guillot and Collet, 2005; Jeannerod, 2001; Sirigu et al., 1996). It is now well admitted that internal forward models are engaged in motori magery process (Miall and Wolpert, 1996; Wolpert and Flanagan, 2001). Forward models mimic the causal flow of the process by predicting the future sensorimotor state (e.g., position, velocity) given the efferent copy of the motor command and the current state of the motor system. While mental practice improves motor performance (Gentili et al., 2010; Ranganathan et al., 2004), there is no information about its efficiency to guide adaptation under sensorimotor conflicts. This can be experimentally investigated by taking advantage of the well-known paradigm of prismatic adaptation. Does sensorimotor adaptation occur during mental practice under prism exposure? One plausible hypothesis is that adaptation will not arise. Because in mental practice we don't actually move, there is no error detection and consequently no training signal to adapt motor commands. However, exposure to prisms generates a discrepancy between visual and proprioceptive information (i.e., an intersensory conflict) that the brain solves by sensory realignment or weighting (Block and Bastian, 2012). As during motor imagery the initial state is used as an input to the forward model, one could postulate that exposure to intersensory conflict could be a critical variable for the development of sensorimotor adaptation. This idea is in agreement with recent investigations showing that making pointing movements under a visuoproprioceptive conflict, but without any observation of reaching errors (i.e., subjects did not receive visual feedback of their pointing movement), was sufficient to develop sensory realignment and thus after-effects (Block and Bastian, 2012).

Here, we hypothesized that motor imagery under prism exposure will favour the realignment between proprioception and vision and consequently will allow the development of adaptation. Our reasoning was the following: under prism exposure, the brain uses an intermediary hand position between the visual-shifted and the proprioceptive-non-shifted hand locations (Rossetti et al., 1995) to generate motor commands. Furthermore, it has been shown that during mental practice the internal forward model makes sensorimotor predictions by receiving as inputs the efferent copy of the motor command and the perturbed (intersensory conflict created by the prisms) initial state of the hand (Cerritelli et al., 2000; Demougeot and Papaxanthis, 2011; Gentili et al., 2004; Naito et al., 2002; Papaxanthis et al., 2002). Accordingly, we assumed that mental practice by using the intersensory conflict will reinforce the sensory realignment between proprioception and vision. After prism removal, the consecutive misestimating of the initial hand position, due to sensory realignment, will cause pointing movement in the direction opposite to the prismatic deviation (i.e., after-effects). We carried out two experiments. The first was a preliminary experiment, in which we tested the development of sensorimotor adaptation under several conditions to prism exposure. In the second experiment, we clarified the contribution of sensory realignment in the development of prism adaptation by motor imagery and we evaluated the time-course of adaptation.

2. Experiment 1

2.1. *Materials and methods*

2.1.1. *Participants*

Fifty-four normal-sighted healthy subjects participated in the first experiment. All were right-handed, except one ambidextrous participant in Prisms-Stationary-Attention group. They were completely naïve concerning prism adaptation paradigm and had never been exposed to prisms. All participants were selected based on their capacity to produce vivid imagined arm pointing movements. Precisely, before the experiment, they had to perform several times a ballistic movement to a visual target. Then, they were asked to imagine several times the same movement and to report trail-by-trail whether they were able to generate vivid kinaesthetic images close to those of actual movements. All participants reported that it was easy or very easy to perform the motor-imagery task.

Participants were randomly divided into six groups of nine participants: **'Prisms-Active'** (five males; mean age: 28 $\pm$ 1.96 years), **'Prisms-imagery'** (six males; 23.11 $\pm$ .68 years), **'Prisms-Stationary'** (seven males; 26.78 $\pm$ 1.16 years), **'Prisms-Stationary-Attention'** (seven males; 26.00 $\pm$ 1.46 years), **'No Prisms-Imagery'** (four males; 25.22 $\pm$ 2.09 years) and **'No Conflict-Prisms-Imagery'** (height males; 29.11 $\pm$ 2.12 years). All participants gave their informed consent and the study was carried out in agreement with legal requirements and international norms (Declaration of Helsinki, 1964) and approved by the regional ethics committee of Burgundy (C.E.R.).

2.1.2. *Apparatus*

The apparatus used in this experiment was similar to that employed by Rossetti et al. (1998) (see Fig.1 for details). This apparatus produced measurements for pointing movements with an accuracy of .1°.