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Short-term learning of a visually guided power-grip task is associated with dynamic changes in EEG oscillatory activity

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Abstract

Objective: Performing a motor task after a period of training has been associated with reduced cortical activity and changes in oscillatory brain activity. Little is known about whether learning also affects the neural network associated with motor preparation and post movement processes. Here we investigate how short-term motor learning affects oscillatory brain activity during the preparation, execution, and post-movement stage of a force–feedback task.
Methods: Participants performed a visually guided power-grip tracking task. EEG was recorded from 64 scalp electrodes. Power and coherence data for the early and late stages of the task were compared.
Results: Performance improved with practice. During the preparation for the task alpha power was reduced for late experimental blocks. A movement execution-related decrease in beta power was attenuated with increasing task practice. A post-movement increase in alpha and lower beta activity was observed that decreased with learning. Coherence analysis revealed changes in cortico-cortical coupling with regard to the stage of the visuomotor task and with regard to learning. Learning was variably associated with increased coherence between contralateral and/or ipsilateral frontal and parietal, fronto-central, and occipital brain regions.
Conclusions: Practice of a visuomotor power-grip task is associated with various changes in the activity of a widespread cortical network. These changes might promote visuomotor learning.
Significance: This study provides important new evidence for and sheds new light on the complex nature of the brain processes underlying visuomotor integration and short-term learning.

Keywords: ERD; Desynchronisation; ERS; Synchronisation; Motor system; Power; Beta-rebound; Visual force-feedback; Coherence

1. Introduction

The ability to continuously adapt motor output based on visual feedback requires the integration of activity in a network of frontal, parietal and sensorimotor brain regions (Floyer-Lea and Matthews, 2004; Vaillancourt et al., 2003). The electrophysiological signature of visuomotor integration is a decrease in oscillatory activity, in particular in the alpha and lower beta (8–21 Hz) frequency bands (Classen et al., 1998; Rearick et al., 2001). Another variable to which visuomotor integration has been related to is long-range oscillatory neuronal synchronisation in the beta and gamma frequency ranges (13–80 Hz) (Aoki et al., 1999; Babiloni et al., 2006; Baker et al., 1999; Lee, 2003; Ohara et al., 2000). In particular, the finding of high-frequency synchronisation between visual, parietal, and motor cortices (Classen et al., 1998; Roelfsema et al., 1997) suggests that the synchronisation or coherence of neuronal activity across distant brain regions might be the neural mechanism by which visuomotor integration is implemented.

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Oscillatory activity and coherence may not only reflect integration per se, but also subserve visuomotor learning, that is, an increase in the automaticity by which sensory information and motor parameters are integrated. This is suggested by recent research associating performance improvements in bimanual coordination tasks with an increase in long-range synchronisation between prefrontal areas, but also decreased synchronisation between primary sensorimotor regions and the midline area (Andres et al., 1999; Serrien and Brown, 2003). Smith et al. (1999) report a task-specific enhancement in alpha activity over somatomotor areas following several days of practicing a visuomotor tracking task, reflecting a decrease in cortical activation after practice. They propose that regional changes in alpha activity might reflect the development of task-specific neurocognitive strategies. It has also been shown on various occasions that repetition of a visuomotor task leads to improved performance and increased automaticity, and is accompanied by changes in brain activity as reflected in the event-related potential (ERP) and blood-oxygen level-dependent functional magnetic resonance imaging (BOLD fMRI) (Floyer-Lea and Matthews, 2004; Halder et al., 2005; Staines et al., 2002). A potential role of oscillatory brain activity and coherence in learning is also illustrated by a study on associative visuotactile learning (Miltner et al., 1999) that showed an increase of coherence with learning between brain regions involved in the associative learning task.

Aim of the present study was to investigate whether activity within the network active during the different stages of a visuomotor integration or motor adaptation (Doyon and Benali, 2005) task is affected by learning. Learning was defined as an improvement in task performance (Ungerleider et al., 2002), that is, a reduction in errors, in the late phase as compared to the early phase of the experiment. This definition of learning is compatible with the notion of short-term learning, that is, the early, fast learning stage of a motor skill in which considerable improvement in performance can be seen within a single training session (Floyer-Lea and Matthews, 2005; Ungerleider et al., 2002). We studied local and long-range oscillatory brain responses by means of the electroencephalogram (EEG) in a visually guided power-grip task designed to incorporate real-world motor system requirements. This was achieved by including a continuous adjustment of the force exerted on a power grip while monitoring the visual feedback of the force output. We hypothesised that any effect of learning should be primarily reflected in increased long-range coherence as indicated by studies on the learning of bimanual coordination tasks (Andres et al., 1999; Serrien and Brown, 2003) and visuotactile learning (Miltner et al., 1999). With regard to local oscillatory activity we expected an attenuation in the movement-related power decrease (event-related desynchronisation, ERD) (Pfurtscheller, 1977) following task practice, as visuomotor learning has been found to go along with reduced cortical activity (Floyer-Lea and Matthews, 2004; Smith et al., 1999). Moreover, we aimed to explore whether oscillatory activity observed in preparation for a motor task (Babiloni et al., 2006; Gomez et al., 2004) or following a motor task is also affected by learning. Effects of learning on preparatory brain responses have been previously described for the ERP (Staines et al., 2002). Oscillatory brain activity following a motor task is usually characterised by a prominent event-related synchronisation (ERS) (Pfurtscheller, 1992) over sensorimotor brain areas in the beta-frequency range, also known as beta-rebound (Parkes et al., 2006). Pre-movement changes have been reported in terms of an ERD of the sensorimotor alpha rhythm (Labyt et al., 2003). To the best of our knowledge short-term learning effects have neither been described for preparatory oscillatory brain activity nor for oscillatory brain activity following a movement.

2. Methods

2.1. Participants

Participants ($n = 13$) were recruited from the student population of the University of Surrey. Data from two participants were discarded because of poor EEG data quality. The final sample size was $n = 11$ (3 male), mean age 25.8 years (range 19–34, SD = 4.6). One participant was ambidextrous (handedness score 53.85), all other participants were predominantly right handed with scores of 62.50 and above in the Edinburgh handedness inventory (Oldfield, 1971).

Written informed consent was obtained prior to the experiment. The study complied with the declaration of Helsinki and was approved by the University of Surrey Ethics Committee. All participants were free of known past or present mental health or neurological problems and received monetary compensation for their participation.

2.2. Procedure and setup

The task consisted of trailing a target force by applying a varying force to a power grip. Continuous feedback on force output was presented on a screen placed 1 m in front of the participant. The force–feedback display consisted of a vertical thermometer-like scale, with 0% representing no force, and 100% representing maximum target force (MTF), a blue vertical bar representing the force exerted when squeezing the power grip, and a red horizontal bar representing the target force, all presented on a black background. MTF refers to the maximum value the pre-specified force track could take on. Trial layout, power grip, and force track are illustrated in Fig. 1.

The maximum force level (MFL) measurable with the power-grip's force sensors was 3 kg or 29.42 N. Preliminary tests indicated that this force level could be reached by healthy participants without problems. For this reason maximum voluntary contraction was not measured. Rather, the MTF was set to 2.1 kg or 20.6 N for all participants.