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The Effects of Motor Expertise on Sensorimotor Rhythm Desynchronization during Execution and Imagery of Sequential Movements

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Abstract—The purpose of the study was to investigate sensorimotor rhythm desynchronization during the performance of a motor execution and motor imagery task of different complexity, while varying motor musical expertise of subjects. We compared EEG patterns of professional pianists and non-pianists, who either executed or imagined finger tapping movements of different complexity. Results show that the power in alpha (8–12 Hz) and beta (13–30 Hz) rhythms decreases with the complexity of both performed and imagined movements. Motor expertise influenced alpha rhythm desynchronization in the motor execution task – in the group of pianists there were differences in alpha power decrease depending on the complexity of the performed movement. There was no such relationship among non-pianists. In the imagery task, there was a tendency toward an interaction of motor expertise and low and high alpha rhythm components. In the beta band, there was an interaction of frequency and area of the skull occurring in the movement execution condition – high and low beta rhythm components had different topography.

Key words: motor imagery, motor execution, motor expertise, event-related desynchronization, alpha band, BETA band.

INTRODUCTION

Motor cortex activity related to movement execution, observation, or imagery is manifested with the phenomenon of desynchronization (ERD, event-related desynchronization) of sensorimotor rhythm (SMR), which includes alpha (8–12 Hz) and beta (13–30 Hz) bands (Pfurtscheller and Aranibar, 1977; Decety, 1996a, b; Pfurtscheller and Neuper, 1997; Manganotti et al., 1998; Pfurtscheller and Lopes da Silva, 1999; Grèzes and Decety, 2000; McFarland et al., 2000; Neuper and Pfurtscheller, 2001; Neuper et al., 2006). The ERD is the power decrease of rhythmic EEG activity and has been previously registered when subjects performed or imagined the movement of hands, feet, or tongue (Pfurtscheller and Lopes da Silva, 1999; Pfurtscheller et al., 2006; Morash et al., 2008). The most prominent ERD is observed over the contralateral sensorimotor cortex in response to hand movement execution or imagery (Stancak and Pfurtscheller, 1996), and it is viewed as an index of cortical activation. The opposite phenomenon—the synchronization (ERS, event-related synchronization) of SMRs—is the power increase of rhythmic EEG activity and is considered to be an index of cortical deactivation or inhibition (Pfurtscheller et al., 1997 Pfurtscheller and Lopes da Silva, 1999). The ERS occurs over the motor cortex when the movement is finished (Neuper et al., 2006).

There are two components of alpha rhythm (mu) distinguished: a low alpha component ranging 8–10 Hz and a high alpha component ranging 11–13 Hz (Klimesch, 1999; Pfurtscheller et al., 2000). The low alpha component might indicate the existence of a neural network in the motor cortex activated by any motor behavior and is widespread over the whole sensorimotor area. The low alpha component reflects the general motor preparation, as well as the attentional demands of the task, but is not critical to support a specific movement (Pfurtscheller and McFarland, 2012). The high alpha component is more restricted topographically and is considered to be more somatotopically specialized than the low alpha component, which reflects the task-specific aspects of motor processing (Pfurtscheller et al., 2000). In the beta rhythm, two components can also be discriminated based on their frequency: low beta about 16–20 Hz and high beta about 21–30 Hz; however, their functional role remains unclear (Pfurtscheller et al., 1997; Pineda, 2005).

Most research has been conducted on event-related power changes in mu rhythm in simple hand movements, and only rarely in complex motor tasks.

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Abbreviations: EMG, electromyographic activity; SMR, sensorimotor rhythm.

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Simple movements, like opening and closing a hand (executed and/or imagined), have been investigated in brain-computer interface studies (Pfurtscheller and McFarland, 2012), which rely on SMRs recorded during motor imagery. On the other hand, complex movements have mostly been studied in PET and fMRI experiments concerning both movement execution and imagery task (Ingvar and Philipson, 1977; Roland et al., 1980; Shibasaki et al., 1993; Leonardo et al., 1995; Sadato et al., 1996; Sadato et al., 1997; Catalan et al., 1998; Verstynen et al., 2005). Event-related power patterns in movements of different complexity were studied by Manganotti and colleagues (1998). The motor task was to perform finger tapping sequences with the right hand, consisting of 4, 8, 12, or 16 taps (with four fingers but not the thumb). The results showed that EEG power in the alpha and beta bands decreased, compared to the rest condition, when sequential movements were performed with a preponderance over the contralateral hemisphere. The power decrease in the alpha band was greater for the most complex, mainly longer, movements than for the simple ones. However, differences were only observed between the shortest sequence (4 taps) and each of the longer sequences (8, 12, 16 taps), but not for the other comparisons. This means that the major increase in complexity was between the 4-tap sequence and the other sequences respectively. There were no significant differences registered across the sequences in the beta band.

The neural representation of executed and imagined movements has also been studied in the context of motor expertise of musicians or athletes. Complex finger movements have been investigated in groups of musicians (Krings et al., 2000; Lotze et al., 2003; Meister et al., 2004; Meister et al., 2005). Musicians showed more focused fMRI brain activations during a complex task of motor execution within the contralateral motor cortex and the ipsilateral anterior cerebellar hemisphere (Krings et al., 2000; Lotze et al., 2003) and within superior left parietal and anterior ipsilateral cerebellar regions during a motor imagery task (Lotze et al., 2003) than non-musicians. The results also indicated that there is a differential activation in the presupplementary motor area and dorsal premotor cortex between complex and simple movement execution in non-experts, but not in musicians (Meister et al., 2005).

Del Percio and colleagues (2008) tested the hypothesis that elite athletes have reduced cortical activity compared to non-athletes. They measured the potentials related to the movement preparation (readiness potential, RP) and initiation (motor potential, MP). The potentials were higher in amplitude in non-athletes than in athletes at the sites overlying supplementary motor and contralateral sensorimotor areas regarding right-hand movement. In another study, Del Percio et al. (2010) investigated the cortical activation reflected in alpha rhythm (8–12 Hz) during a simple voluntary movement by elite karate athletes and non-experts. Execution of the right-hand movements was related to lower ERD amplitude in athletes than in non-athletes, in the lower alpha (8–10 Hz) and high alpha (10–12 Hz) component in the primary motor area lateral and medial premotor areas. For the left-hand movement, only the high alpha component ERD was lower in athletes than in non-athletes during the movement execution. Zapaa and colleagues (2015) investigated the dependence of SMR patterns on short-term kinesthetic training in simple movement imagery by expert jugglers and non-jugglers. The performance of short kinesthetic training increased the power of alpha rhythm in the imagery task only for amateurs. The research mentioned above (Del Percio et al., 2008, 2009, 2010; Zapaa et al., 2015) refers to the neural efficiency hypothesis, which assumes that cortical activity is spatially focused in experts, who display reduced cortical activation in the visuo-motor tasks related to their field of expertise.

Taking all the results into consideration, there is only one study (Meister et al., 2005) concerning the issue of neural representation of both simple and complex movements depending on motor expertise, but in the motor execution condition only. Other studies refer either to complex or simple movement in the motor execution task, but not in the motor imagery task. Despite a considerable number of studies concerning motor execution and imagery of movement, to our knowledge no study has investigated both simple and complex movements in motor execution and imagery tasks in the context of motor expertise. Such an approach provides an opportunity to study the effects of interaction of these variables on brain activity patterns, since motor repertoire of the hands consists of both simple and complex movements for amateurs as well as for experts.

The goal of this study is to analyze the patterns of power decrease in alpha and beta rhythms' desynchronization during execution and imagery of finger-tapping movements by expert pianists and non-pianists. We are interested in the differences in the SMR desynchronization between pianists and non-pianists depending on the movement complexity during movement execution and imagery. Although the phenomenon of alpha rhythm desynchronization has been well described in the literature, beta rhythm has been investigated mainly in the aspect of synchronization or rebound (Pfurtscheller et al., 2005; Erbil and Ungan, 2007). Therefore, we focused in our study on the desynchronization of beta rhythm as the less recognized phenomenon. Furthermore, we wanted to explore SMRs in their sub-bands, mainly the low and high components of alpha and beta rhythms, due to their functional differences.

We hypothesize that the patterns of ERD in the alpha and beta band will depend on the complexity of the movement in the motor execution and motor imagery task. The ERD in alpha and beta band will be greater for the most complex movement in both tasks. Also, we expect that motor expertise will influence the ERD in the alpha and beta band when subjects perform or imagine movements, depending on the complexity of the motor task. We also want to test whether there will be differences in the desynchronization of low and high alpha or beta rhythm for motor execution and imagery of sequential finger movements.