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RESEARCH****Research Report****Changes in the alpha and beta amplitudes of the central EEG during the onset, continuation, and offset of long-duration repetitive hand movements[☆]****Nurhan Erbil, Pekcan Ungan****Hacettepe University, Faculty of Medicine, Department of Biophysics, Ankara, Turkey*

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ABSTRACT

Electroencephalographic alpha and beta activities recorded from central electrodes are known to display movement-related suppression or enhancement. We investigated whether the suppression that is known to occur during the onset of a single movement would persist or otherwise habituate when the movement is continuously repeated for a long period of time. Fourteen subjects took part in the experiments. They performed repetitive simultaneous extension–flexions of the fingers II–V in one hand, continuously for a period of at least 30 s. They then stopped this self-paced movement and rested for at least 30 s. Bipolar recording was made from C3–Cz and C4–Cz. Patterns of amplitude changes in the alpha and beta bands were calculated against a resting baseline. Following a bilateral alpha and beta suppression at the movement onset, alpha amplitude gradually but not fully recovered towards the baseline during the 30 s post-onset. Habituation of afferences and transfer of the cortical function were discussed as the two alternative explanations for this gradual recovery. Beta amplitude, however, displayed no recovery as long as the movement continued. Considering the relatively rapid beta recovery reported for sustained movements, this finding demonstrated that the sustained and continuous movements are conducted through quite different processes. A transient contralateral beta rebound was observed only after the end of the long movement period, strengthening the viewpoint that links the beta rebound with the closure of the cortical processes running throughout a motor sequence. Modulation of the beta amplitude, rather than the changes in alpha amplitude, appeared to be more closely correlated with the execution of a continuous movement.

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1. Introduction

It has been known for half a century that self-paced voluntary movements are accompanied in humans by changes in the amplitude of specific cortical rhythms (Jasper and Penfield, 1949; Gastaut et al., 1952). This phenomenon, which is referred

to as ERD/ERS (event-related desynchronization/synchronization) (Pfurtscheller and Aranibar, 1977; Pfurtscheller et al., 1981) or “temporal spectral evolution” (Salmelin et al., 1995a) or “task-related power change” (Gerloff et al., 1998) in the literature, was shown to be closely related to the neural processes involved in preparing and executing the commands

[☆] This report is based on the thesis work of N.E. (2004), Institute of Health Sciences, Hacettepe University, Ankara, Turkey.

* Corresponding author. Department of Biophysics, Faculty of Medicine, Hacettepe University, 06100 Ankara, Turkey. Fax: +90 312 3051492. E-mail address: pekcan@hacettepe.edu.tr (P. Ungan).

to move certain body parts. This relationship has opened the way for designing EEG-based brain–computer interface (BCI) systems, which could eventually provide a new communication and control option for those with motor disabilities and give the totally paralyzed patients a means to communicate with others and even to operate devices via appropriate prostheses (for a review, see [Wolpaw et al., 2002](#)).

During a voluntary finger movement, an amplitude decrease in the 8–14 Hz alpha band occurs over sensorimotor areas ([Pfurtscheller and Berghold, 1989](#); [Leocani et al., 1997](#)). This alpha ERD begins about 1 s before the movement and ends shortly after the termination of movement ([Pfurtscheller et al., 1981](#)). Because it is widely accepted that the amplitude reduction in the alpha band is due to the desynchronization of the arch-shaped central (Rolandic) mu rhythm of the somatomotor cortical areas, this phenomenon is also called the mu ERD. An amplitude decrease before the movement is also observed in the 15- to 25-Hz beta band (beta ERD), even earlier than the alpha ERD. A post-movement rebound over the baseline level (an ERS) generally occurs in the beta band ([Pfurtscheller, 1981](#); [Pfurtscheller et al., 1996](#); [Alegre et al., 2003](#)).

Possible functional correlates of the ERD/ERS phenomena have been the subject of a vast number of studies (for a recent review, see [Pineda, 2005](#)). [Pfurtscheller \(1992\)](#) suggested that the ERD during movement preparation and execution is linked to cortical activation, while post-movement ERS observed in the beta band is a correlate of cortical idling or removal of function. On the other hand, the results of an electrocorticographic spectral analysis performed by [Crone et al. \(1998\)](#) showed that over the sensorimotor areas the topography of beta ERD was often more discrete and somatotopically specific than that of alpha ERD. They further conjectured that the topographical spread of alpha ERD beyond expected functional–anatomical boundaries should invite a re-examination of the presumed role of alpha ERD as an index of cortical activation. Somatotopy of the movement-related changes in beta amplitude as opposed to the relatively stable origin of the 10-Hz rhythm was also reported by [Salmelin et al. \(1995b\)](#), based on their neuromagnetic study. According to these authors, the 10-Hz rhythm reflects lack of relevant sensory input and it is thus suppressed due to afferent signals produced during movement. They presume the post-movement rebound of the 20-Hz rhythm as a signature of active immobilization. A comparison between ERD/ERS and the corticospinal excitability measured by transcranial magnetic stimulation demonstrated that ERD may be associated with both corticospinal facilitation (contralaterally) and inhibition (ipsilaterally) whereas ERS may indicate the removal of excitation or corticospinal inhibition ([Leocani et al., 2001](#)) or motor cortical deactivation ([Salmelin and Hari, 1994](#); [Pfurtscheller et al., 1996](#)). An association of increased cortical excitability and ERD was also reported by [Chen et al. \(1998\)](#). On the other hand, [Conway et al. \(1995\)](#) demonstrated that synchronized cortical activity contributing to MEG activity within the beta range of frequencies during maintained voluntary contractions is coupled to motor-unit activity associated with motor-unit synchronization. This finding was extended by [Salenius et al. \(1997\)](#) who studied the temporal and spatial characteristics of this coherence. [Mima et al. \(2000\)](#) also concluded that the

cortical oscillations are synchronized with the electromyographic activity (EMG) of contracting muscles in a wide range of frequencies and that those in the frequency range of 14 Hz or higher control the EMG rhythm. Since vibratory stimulation of a muscle tendon during tonic contraction had no significant effect on cortical–muscular coherence, they also stated that cortical oscillations in the beta–gamma band reflect motor rather than sensory activity. However, the work of [Alegre et al. \(2002\)](#), where beta ERD was shown to be connected to afferent flow of proprioceptive information, is in apparent contrast with the abovementioned findings that relate the beta band to motor activity.

The use of the terms ERD and ERS has been criticized on the grounds that they may not describe accurately the actual phenomena underlying the observed power changes in the scalp-recorded gross EEG. The terms “movement-related modulation” and “temporal spectral evolution” rather than ERD/ERS have been used by [Salmelin et al. \(1995a\)](#) for the suppression and rebound of cortical rhythms observed in different phases of movement. In the report of [Gerloff et al. \(1998\)](#) the ambiguities brought about by the terms “synchronization/desynchronization” were also mentioned and the use of the terms “coherence” and “power change” was suggested. The same issue has been brought into attention also quite recently by [Hari \(2006\)](#), stating that the disappearance (appearance) of an MEG/EEG rhythm might as well result from inactivation (activation) of a generator population and not necessarily from desynchronization (synchronization) of some continuously functioning oscillators. In the same review she has also recapitulated, by referring to the comb-like shape of the Rolandic mu activity, the previously mentioned ([Salmelin and Hari, 1994](#)) terminological issue related to the mu rhythm and the central alpha and beta activities.

The brief review above shows that a vast amount of detailed studies on the movement-related changes in the central EEG rhythms (or ERD/ERS) have been carried out and that the functional significance of the alpha and beta rhythms and their amplitude variations in different phases of a movement are still not quite clear. Therefore, some new data are needed, and new experiments using different paradigms are to be performed to collect and interpret them. This has been the main motive behind the present work.

The dynamics of movement-related power changes in the alpha and beta bands has also been the subject of several studies. For instance, the mu ERD patterns produced during a brisk movement and a slow one were recorded and compared by [Stancak and Pfurtscheller \(1996\)](#). They found that the mu rhythm fully recovered after the movement and the latency of recovery was correlated with the duration of the extensor muscle contraction. [Cassim et al. \(2000\)](#), on the other hand, compared the ERD/ERS patterns in brief and sustained movements to determine if a different ERD/ERS pattern is displayed when the movement is sustained for a while. They observed that the power in the alpha band returned to its baseline value within 4–5 s, although the movement was sustained for a much longer time. The return of the beta power with a slight overshoot was even faster and took only 1 s. The work of [Alegre et al. \(2004\)](#), in which they studied the mu and beta ERD/ERS patterns in a sequence of two separate movements, describes still another picture. They used a sequence consisted

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