Spatiotemporal Analysis of Alpha Frequency Components with the ERD Technique

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Summary: EEG data from 30 channels were recorded during movement and reading tasks and analyzed in the three frequency bands 6- 8 Hz, 8-10 Hz and 10-12 Hz. For each frequency band, the ERD (event-related desynchronization) was quantified and displayed in the form of time courses and maps. The results show that the ERD pattern varies with the frequency component analyzed. In general, upper alpha components (10-12 Hz) demonstrate a short-lasting, task-specific and localized ERD; the ERD of lower alpha components is long-lasting (> 1 sec) and widespread. The ERD can be interpreted as a sign of cortical activation, whereby desynchronization of upper alpha components may reflect more task-specific processes, and desynchronization of middle and lower alpha components may be related to the level of expectancy and attention.

Key words: EEG mapping; ERD mapping; Cognitive processes; Movement; Reading

Introduction

One feature of the human brain is its ability to generate rhythmic components within the alpha frequency band. However, there exist not only one alpha rhythm with one frequency, but a great variety of different alpha rhythms characterized by different frequencies and reactivity patterns (discussion remark of Grey Walter in Mulholland, 1969).

The dominance of alpha band activity depends on the activation pattern of underlying cortical structures. When the brain is idle or resting, alpha band activity displays a large amplitude over wide areas of the scalp. Excitation of cortical structures results in an amplitude attenuation or desynchronization of this alpha pattern (Steriade and Llinas 1988). Classical examples of it are alpha blocking with visual processing (Jasper and Penfield 1949) and the desynchronization of the central mu rhythm (Chatrian et al. 1959) during voluntary movement.

Because this alpha or mu amplitude attenuation is related to an externally or internally paced event, we have named this phenomenon "Event-Related Desynchronization" (ERD, Pfurtscheller and Aranibar 1977). ERD was reported with voluntary movement (Pfurtscheller and Aranibar 1979), visual-verbal classification (Klimesch et al. 1988) and cognitive processing (Sergeant et al. 1987). This close relationship of alpha band activity and activation of cortical structures makes it important to analyze and study the spatial and temporal aspects of different alpha frequency components in multichannel EEG data.

This paper is focused on the temporal and spatial aspects of the ERD when narrow alpha frequency bands are analyzed.

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Quantification of ERD

The ERD is an event-related phenomenon that can be evaluated in parallel to all types of event-related potentials (ERPs). This means that the prerequisite of ERD measurements is an ERP paradigm where one event (stimulus, movement, cognitive process, etc.) must be repeated N times in intervals of at least several seconds. Event-synchronous EEG segments are sampled and digi-

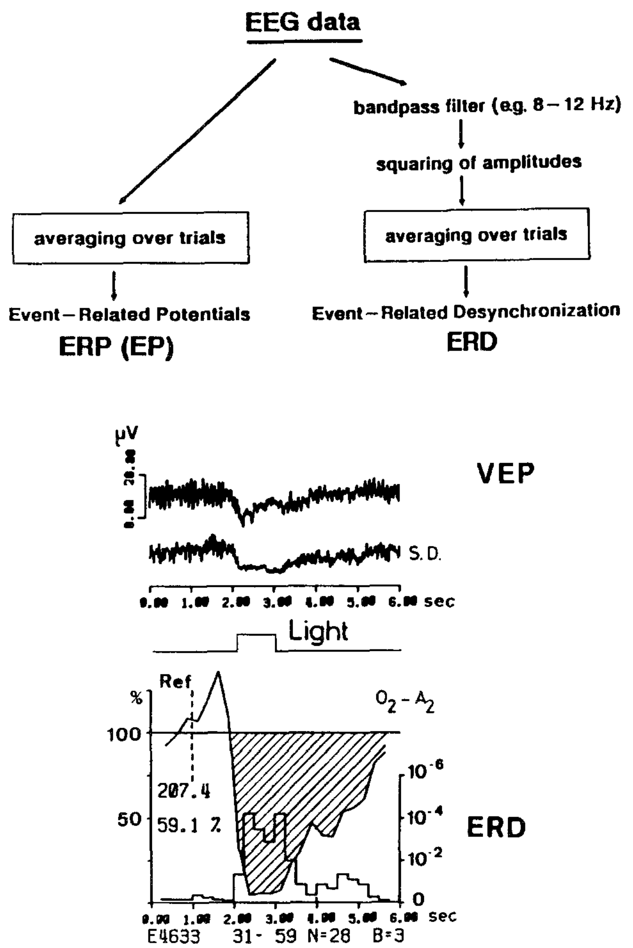

Figure 1: Upper panel: Comparison of ERP and ERD processing. Lower panel: Averaged EEG trials with VEP and intertrial standard deviation (S.D.) computed during 1 sec light stimulation. From the same data, the ERD and the probabilities for the alpha power decreases were calculated. These data indicate that, during visual stimulation, there was a significant ($p < .0001$, Dixon Mood test) alpha power decrease of about 90%. Note the similar shape of the S.D. curve and the ERD curve.

tally band pass filtered; then, amplitudes are squared and averaged over the N trials. The result is an average alpha power versus time diagram representing the time course of ERD at one location of the scalp. The principle of ERP and ERD measurements together with a characteristic example is documented in Figure 1. Details about the data processing can be found elsewhere (Pfurtscheller and Aranibar 1979).

ERD time course during motor behavior

Volunteers were instructed to press a microswitch 60 times in self-paced intervals not shorter than 10 sec. No warning stimulus was given. EEG was recorded 4 sec before movement and 2 sec afterwards. From this movement-synchronous EEG data, the ERD was calculated in intervals of 125 ms for different scalp locations. Typical ERD time courses obtained from central and parietal recordings are plotted in Figure 2. As can be seen in this figure, the ERD starts more than 2 sec before movement onset and reaches its largest magnitude on the contralateral side (channel 7). The maximal desynchronization is found during the execution of movement, with approximately symmetrical magnitudes over both hemispheres. The data show that the ERD is not a generalized phenomenon of the whole cortex, because different cortical regions can display a different time course and magnitude of desynchronization. Details about the recording technique and type of derivation most sensitive to ERD measurements during a movement task are reported elsewhere (Pfurtscheller et al. 1988, Pfurtscheller and Berghold 1989).

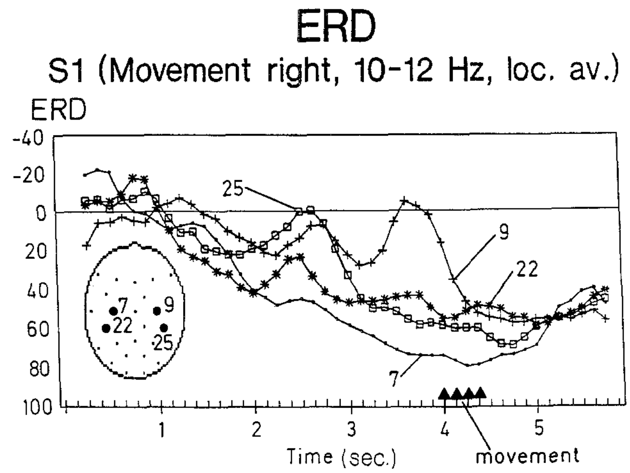

Figure 2: ERD time courses obtained in one subject during a voluntary right hand movement task. Each curve represents data from one electrode. The electrode positions are indicated in the insert with the electrode configuration. Positive ERD (0 - 100%) represents alpha power decrease.

ERD time course during a visual-verbal task

In another experiment, ten right-handed subjects had to perform a simple reading and semantic/numerical judgement task. The presentation of a verbal stimulus (word or number) was preceded by a randomly varied warning stimulus. EEG data were recorded 4 sec before the verbal stimulation and 3 sec thereafter (further details of this study are presented elsewhere: see Klimesch et al. 1989a, 1989b). The ERD was calculated in the 10-12 Hz band for four different electrodes on each subject. Grand average ERD curves from ten subjects computed for these

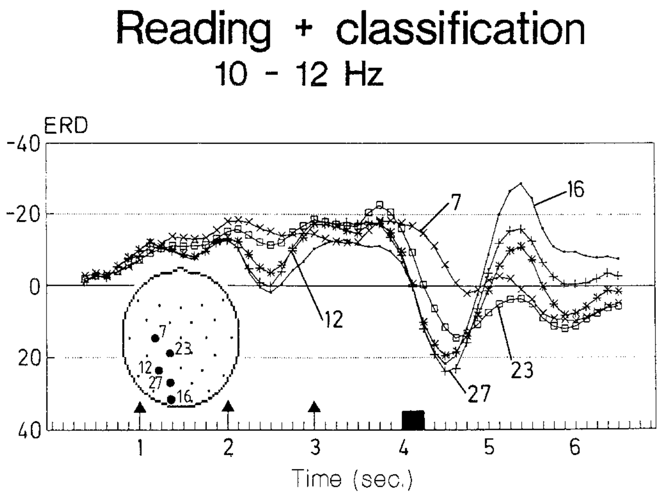

Figure 3: Anterior-posterior distribution of ERD time courses from a visual-verbal task. The electrode numbers indicated below the diagram correspond to the following regions: 7: central left; 23: post-central left; 12: centro-parietal left; 27: parieto-occipital left; and 16: occipital left. Data from the 10-12 Hz band. Word presentation on a video display at a time of 4 sec is marked with the black bar on the time axis. The arrows at 1, 2 and 3 sec mark the warning stimuli at different interstimulus intervals. Data from 10 subjects, averaged.

electrodes in central, parietal and occipital regions are displayed in Figure 3.

In Figure 3, it can be noted that the ERD displays a maximum in the occipital area first, about 125 msec later in the parietal region and again about 125 msec later in the central region. The time delay of alpha desynchronization between occipital and central areas in reading experiments is therefore about 250 msec when the upper alpha frequency band is analyzed. These data can be interpreted to mean that alpha components originating in the striate area are desynchronized initially, and this desynchronization spreads thereafter to parietal and central areas. Whether or not this topographical spread of the alpha desynchronization corresponds to the sequential activation of higher cortical areas involved in the processing of visual information can only be speculated.

It is of interest, however, that the time course is not only dependent on the cortical location studied, but also on the frequency band analyzed. ERD data from electrodes overlying specific cortical areas were averaged and displayed as a function of time (see Figures 4 and 5, upper panels). The 10-12 Hz band was analyzed for the occipital region, the 6-8 Hz band for the parietal region, and the 8-10 Hz band for the centro-parieto-temporal areas.

An ERD in the 10-12 Hz and 6-8 Hz band was only observed after (and not before) reading; the former was short-lasting (< 1 sec; Figure 4, upper panel) and the latter long-lasting (> 2 sec; Fig 5, upper panel). Only the 8-10 Hz band displayed a desynchronization before and after reading with a clear dominance over the left hemisphere (Klimesch et al. 1989a).

Topographical ERD pattern and cortical activation

ERD maps represent the topographical distribution of alpha desynchronization. The ERD is assumed as a sign of cortical activation, comparable to the increase of metabolic rate and regional cerebral blood flow (Roland and Widen 1988). Therefore, ERD maps can be interpreted as patterns of cortical activation. This can be proved with simple experiments where relatively well-known and localized anatomical structures and systems are involved, such as single finger movements and reading of words. Because of the relatively good time resolution of the ERD method (theoretically, equal to the sampling frequency; practically, 8 or 16 maps/sec), it is possible to discriminate very clearly the phases of planning and execution of movements as well as among anticipation, reading and cognition of words. Examples of ERD maps, calculated for intervals of 125 ms or 250 ms, are given in Figures 4 and 5, lower panels, and in Figure 6.

It is of interest to note that planning of one-sided finger movements is accompanied by a localized contralateral ERD close to the scalp projection of the hand area (electrode position C_3 when right hand movements are planned), whereas the execution of the motor act results in a bilateral symmetrical ERD pattern (Figure 6). This data gives evidence that, during movement, not only contralateral but also ipsilateral sensorimotor areas are activated (Pfurtscheller and Berghold 1989). Recently reported PET studies during one-sided movements confirm this bilateral activation (Roland and Widen 1988).

A quite different topographical ERD pattern is obtained in a visual information processing task. Here, the frequency band analyzed plays an important role. The reading of words displayed for 250 msec on a video terminal is accompanied by an occipital localized ERD of the 10-12 Hz frequency components (Figure 4, lower panel). This ERD probably represents encoding processes, including the encoding of lines, letters, the word and its semantic context, lasting altogether about 450 msec (Klimesch 1988). The phasic (< 1 sec) and occipital focused upper alpha band ERD is followed by a parietal localized lower frequency band ERD which lasts more than 1 sec (Figure 5, lower panel). This ERD component probably reflects cognitive and memory retrieval processes in the parietal region and is in accordance with the findings of Roland et al. (1987), who reported an increase

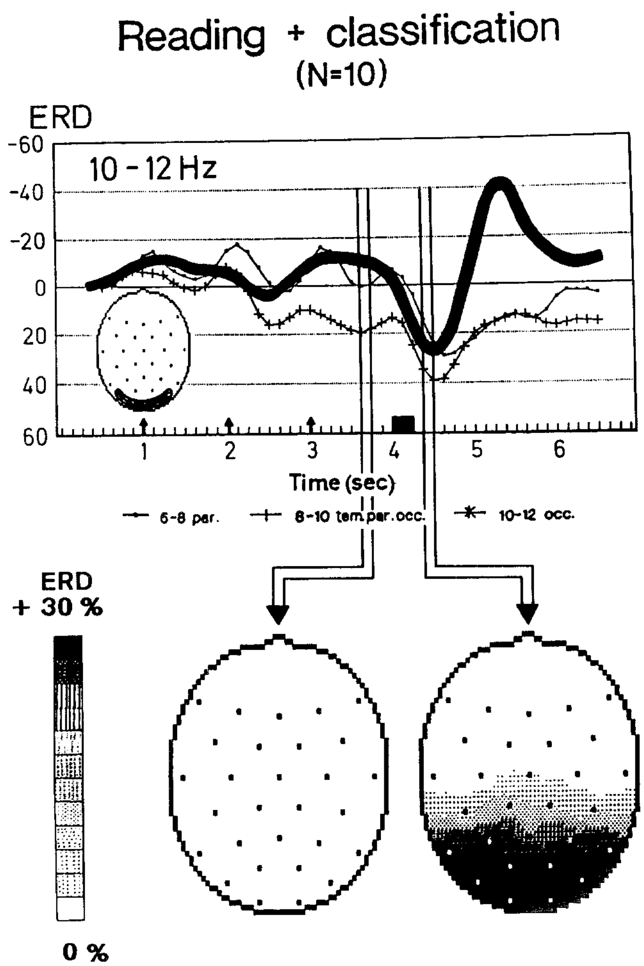

Figure 4: Upper panel: Grand average ERD time courses (10 subjects) for different cortical regions and frequency bands as indicated. Note the short-lasting (< 1 sec) ERD with the occipital 10-12 Hz band and the long lasitng ERD with the temporal 8-10 Hz components. For further explanation see Figure 3.
Lower panel: Grand average ERD maps calculated in the intervals as marked in the time course in the upper panel. Black indicates regions with larger ERD in the 10-12 Hz band.

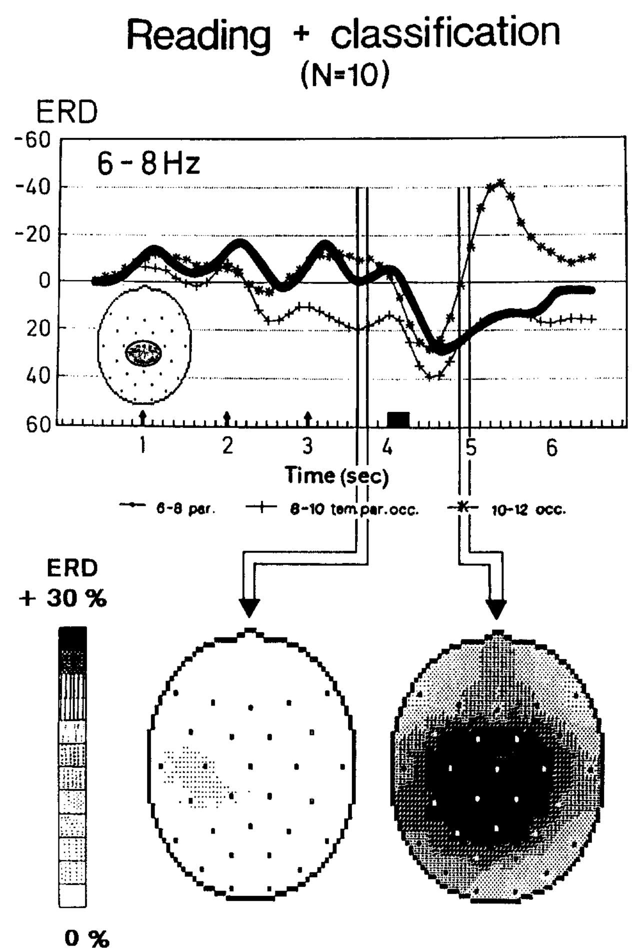

Figure 5: ERD time courses for different frequency bands and ERD maps for the 6-8 Hz band calculated in the intervals as marked in the diagram. For further explanation, see Figures 3 and 4.

of regional cerebral oxidative metabolism in the posterior superior parietal cortex during a visual imagination task.

The ERD in the 8-10 Hz band was widespread, involving all cortical areas and starting before visual stimulation. In contrast to the task-specific post stimulus ERD in the 10-12 Hz band, this prestimulus ERD seems to be a correlate of attentional, anticipational and expectational processes.

Final comments

The field of EEG mapping is given a new dimension when an event-related experimental paradigm is used and the reactivity of alpha frequency components is studied in space and time. The dynamic ERD mapping method allows the computation of topographic maps in intervals of about 100 msec. With such a series of ERD maps, the time course of cortical activation in different regions of the scalp can be studied during voluntary motor behavior and cognitive activity.

In recently performed measurements of the electromagnetic field of alpha spindles with the SQUID technique (Williamson and Kaufman 1989, in this volume) during a visual imagination task, alpha field suppression was reported in the occipital, temporal and parietal cortex. This alpha field suppression had a duration of about 1 sec and gives first evidence that the primary visual area is activated not only during visual encoding but also during cognitive processes. We can therefore speculate that both the occipital alpha field suppression and the occipital alpha desynchronization during a visual task reflect the excitation of similar neuronal mass in visual areas.

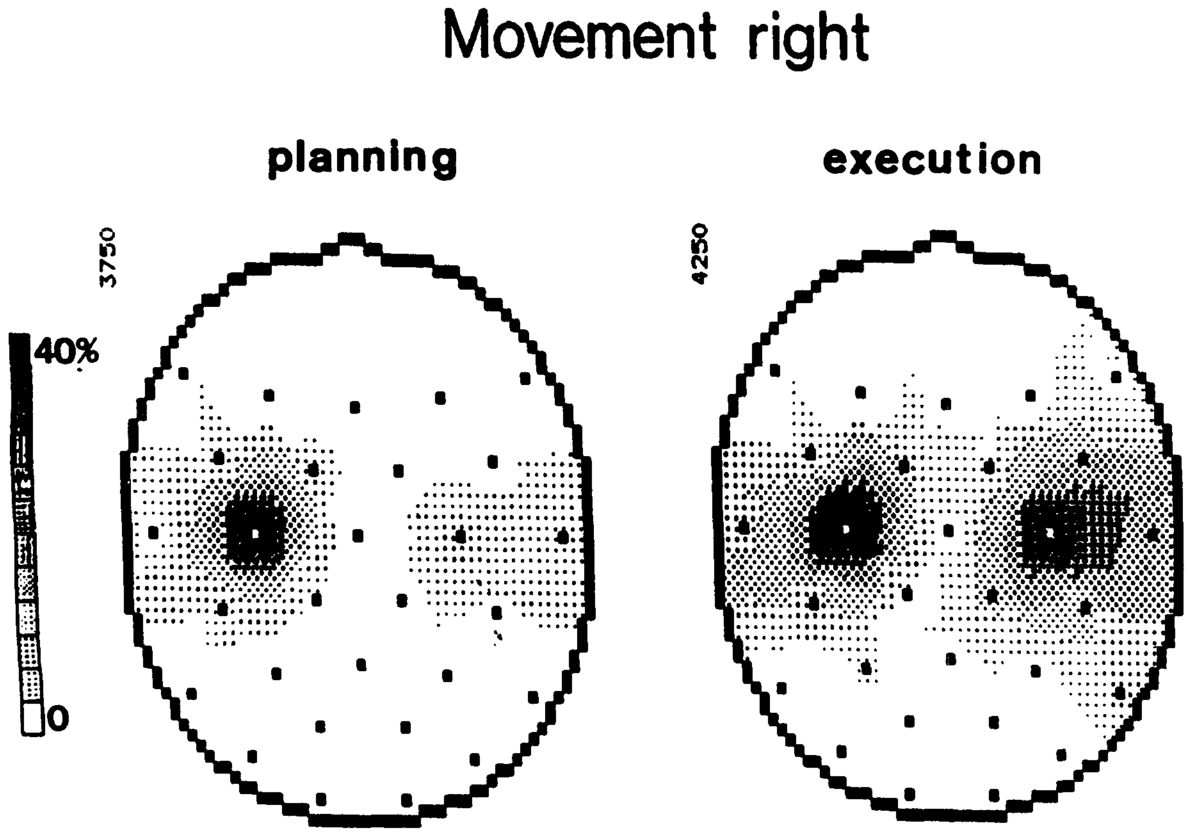

Figure 6: Grand average ERD maps (8 subjects) from a voluntary movement task. The left map is obtained during planning and the right during execution of movement. Each map represents a time interval of 250 msec. The scale on the left marks the percentage ERD; black indicates areas with pronounced desynchronization.

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