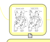
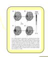
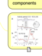
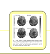
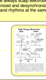
ERD/ERS

- The basic principles of ERD/ERS
  - Event-related potentials/fields vs. event-related EEG/ MEG changes (ERD/ERS)
    - event-related potentials (ERPS)
      - The basic assumption is that the evoked activity, or signal of interest, has a more or less fixed time-delay to the stimulus, while the ongoing EEG/ MEG activity behaves as additive noise
        - Averaging techniques are commonly used
      - ERPs represent the responses of cortical neurons due to changes in afferent activity
    - event-related desynchronization (ERD)
      - ERD/ ERS phenomena can be viewed as generated by changes in one or more parameters that control oscillations in neuronal networks
        - which are the general properties of such oscillations?
          - the intrinsic membrane properties of the neurons and the dynamics of synaptic processes
          - the strength and extent of the interconnections between the network elements, most often formed by feedback loops. Different kinds of feedback loops can be distinguished: involving thalamo-cortical or cortico-cortical either at short or at long distances
          - The modulating influences from general or local neuro transmitter systems
        - 
          - Neuronal networks can display different states of synchrony, with oscillations at different frequencies
      - ERD/ERS reflect changes in the activity of local interactions between main neurons and interneurons that control the frequency components of the ongoing EEG
        - when referring to ERD/ERS of the EEG/MEG it is necessary to specify the frequency band
        - the term ERD is only meaningful if the baseline measured some seconds before the event represents a rhythmicity seen as a clear peak in the power spectrum Similarly, the term ERS only has a meaning if the event results in the appearance of a rhythmic component and therewith in a spectral peak that was initially not detectable
  - Frequency-specificity of brain oscillations
    - In general, the frequency of brain oscillations is nega tively correlated with their amplitude
      - Because the amplitude of oscilla- tions is proportional to the number of synchronously active neural elements
        - slowly oscillating cell assem blies comprise more neurons than fast oscillating cells
  - Quantification of ERD/ERS in time and space
    - Time course of ERD/ERS
      - the EEG/MEG power within identified frequency band is displayed relative (as percentage) to the power of the same EEG/ MEG derivations recorded during the reference or baseline period a few seconds before the event occurs
        - the interval between two consecutive events should last at least some seconds
          - In the case of voluntary limb movement studies, an inter-event-interval of at least approximately 10 s is recommended
          - in the case of a foreperiod reaction time task, the interval should be even longer
      - The classical method to compute the time course of ERD
        - bandpass filtering of all event-related trials
        - squaring of the amplitude samples to obtain power samples
        - averaging of power samples across all trials
        - averaging over time samples to smooth the data and reduce the variability
        - obtaining percentage values for ERD/ERS
          - the power within the frequency band of interest in the period after the event is given by A whereas that of the preceding base line or reference period is given by R. ERD or ERS is defined as the percentage of power decrease or increase respectively, according to the expression ERD%= (A-R)/R×100.
      - The different methods used today for ERD/ ERS quantification
        - 
    - Spatial mapping of ERD/ERS
      - To convert the reference-dependent raw data in reference-free data. different methods are available
        - Common average reference
        - Laplacian reference
          - Reference-free maps (e.g. surface Laplacian) generally show a more focal pattern as compared to referential maps and are especially recommended when data corresponding to a movement task are analyzed
        - L ocal average reference
      - For spatial mapping of ERD/ERS, different methods are availlable
        - surface Laplacian
        - cortical Imaging
        - distributed source imaging
        - Others
          - 
      - 
  - Determination of subject-specific frequency bands
    - detection of the most reactive frequency band based on the comparison of two short-term power spectra
      - One spectrum is calculated for the reference period (R)chosen some seconds before an event occurs
      - the other is calculated for the activity period (A)
      - The difference curve between the 2 loga- rithmic power spectra of periods A and R, together with 95% confidence interval. can be used to determine significant frequency components
      - 
    - continuous wavelet transform(CWT)
      - 
        - The amount of dilation of the wavelet is represented by the scale a and the shifting of the wavelet by parameter b
      - 
      - 
    - definition of frequency bands relative to the spectral peak frequency
      - The use of a mean alpha peak center of gravity (centroid) frequency f(i) as an anchor point to adjust frequency bands individually
  - ERD in memory and movement tasks
    - Lower alpha desynchronization (in the range of about 7-10 HZ) is obtained in response to almost any type of task
      - topographically widespread over wide areas of the scalp
      - probably reflects general task demands and attentional processes
    - Upper alpha(mu) desynchronization (in the range of about 10-12 Hz)
      - very often topographically restricted
      - develops during the processing of sensory-semantic information above parieto-occipital areas
    - memory
      - The degree of desynchronization is closely linked to semantic memory processes
    - Voluntary movement
      - Voluntary movement results in a circumscribed desynchronization in the upper alpha and lower beta bands, localized close to sensorimotor areas
      - This desynchronization starts about 2 s prior to movement-onset over the contral ateral Rolandic region and becomes bilaterally symmetrical immediately before execution of movement
      - the topography of beta ERD was often more discrete and somatotopically specific than that of alpha ERD
      - The contralateral dominant pre-movement mu ERD is not only independent of movement duration, but also similar with index finger, thumb and hand movement
      - While a circumscribed hand area mu ERD can be found in nearly every subject, a foot area mu ERD localized close to the primary foot area between both hemi- spheres is less frequent
        - 
          - This can be interpreted as follows: the mu rhythm is generated mainly in the post-rolandic somatosensory area and the central beta rhythm (at least some components of it) in the pre-rolandic motor area
      - a variety of Rolandic mu thms exist.
        - mu rhythms not only selectively blocked with arm and leg movements, but also with face movement
  - Simultaneous occurrence of ERD and ERS in the alpha and lower beta bands
    - A visual input results not only in a desynchronization of occipital alpha rhythms but also in an enhancement or synchronization of central mu rhythms
    - The opposite, an enhancement of occipital alpha rhythms and desynchronization of central mu rhythms, is found, e.g. during self-paced, voluntary hand movement
    - 
  - Post-movement beta ERS
    - These induced beta oscillations are found in the first second after termination of a voluntary movement, when the Rolandic mu rhythm still displays a desynchronized pattern of low amplitude
      - 
    - features
      - The post-movement beta ERS is a relatively robust phenomenon and is found in nearly every subject after finger, hand, arm and foot movement
        - the beta ERS is significantly larger with hand as compared to finger movement
        - For finger movement the largest beta ERS was found in the 16-21 Hz band, and for foot movement in the slightly higher 19-26 Hz band
      - the beta ERS has a somatotopic organization
        - It is dominant over the contralateral primary sensorimotor area and has a m around 1000 ms after movement-offset
          - the maximum of the beta ERS coincides with a reduced excitability of motor cortex neurons
            - For the activation of a larger muscle mass, a relatively larger population of cortical is required
        - 
        - the beta ERS may be related to a deactivated state of the motor cortex
      - the beta ERS is found not only after a really executed but also after an imagined movement
  - Interpretation of ERD and ERS in the alpha and lower beta band
    - RED
      - Increased cellular excitability in thalamo-cortical systems results in a low amplitude desynchronized EEG
        - ERD can be interpreted as an electrophysiological correlate of activated cortical areas involved in processing of sensory or cognitive information or production of motor behavior
      - An increased and/or more widespread ERD could be the result of the involvement of a larger neural network or more cell assemblies in information processing
        - increased task complexity
          - Once the movement sequence has been learned and the movement is performed more'automatically', the ERD is reduced
            - activity in primary sensorimotor areas Increases in association wit learning a new motor task and decreases after the task has been learned
            - The involvement of primary motor area in learning motor sequences was also suggested
        - more efficient task performance
        - more effort and attention as needed in patients
        - elderly or lower IQ subjects
    - ERS
      - amplitude enhancement is based on the cooperative or synchronized behavior of a large number of neurons
        - Large alpha or mu waves in the EEG/MEG need coherent activity of cell assemblies over at least several square centimeters
        - When patches of neurons display coherent activity in the alpha band, an active processing of information is very unlikely and it may be assumed that the corresponding networks are in a deactivated state
          - It is of interest to note that about 85% of cortical neurons are excitatory, with the other 15%o being inhibitory
      - occipital alpha rhythms can be considered as'idling rhythms of the visual areas and mu rhythms as 'idling rhythms' of sensorimotor areas
      - lat there are also reports on induced (synchronized)alpha band rhythms before omitted stimuli
    - there are always scalp electrodes showing synchronized and desynchronized alpha (beta) band rhythms at the same moment of time
  - ERS in the gamma band (40Hz)
    - Difference
      - 
    - Separate foci of synchronized gamma activities occurring in cortical regions which are widely separated-often even in different lobes-can display high correlation during the performance of cognitive or motor tasks
      - an increase in gamma band coherence is functionally related to the performed task
  - ERD/ERS in neurological disorders
    - The quantification of movement-related desynchronization can improve the diagnosis of functional deficits in patients with cerebrovascular disorders and Parkinsons disease (PD)
      - Based on ERD measurements during voluntary hand movement it was, for example, possi ble to differentiate between superficial and deep vascular lesions
      - In case of PD. the pre movement ERD is less lateralized over the contralateral sensorimotor area and starts later than in control subjects
      - The beta ERS is of smaller magnitude and it is delayed as compared to controls
    - ERD changes in epilepsy with focal motor seizures were reported by Derambure et al

/ ERD/ERS / The basic principles of … / Event-related potentials… / event-related potentials… / The basic assumption is …

Phase-locked?
evoked potentials (EPS) can be considered to result from a reorganization of the phases of the ongoing EEG signals Sayers et al 1974).

/ ERD/ERS / The basic principles… / Event-related potent… / event-related potent… / The basic assumption… / Averaging techniques…

Not enough

/ ERD/ERS / The basic principles of ERD/ER… / Event-related potentials/field… / event-related desynchronizatio…

event-related synchronization (ERS)

/ ERD/ERS / The basic principles… / Event-related potent… / event-related desync… / ERD/ ERS phenomena c…

Fig. 1. Schema for the generation of induced (ERD/ERS) and evoked (ERP) activity whereby the former is highly frequency-specific. TCR thala mic relay cells: RE reticular thalamic nucleus
What do induced and evoked mean?

/ ERD/ERS / The basic principles of … / Determination of subject… / detection of the most re…

Fig. 5. (a)Superimposed logarithmic 1 s reference period (R) and the activity period (A) during cue-triggered finger movement as well as the difference between the two spectra with 95% confidence intervals indicated by the dotted lines. The frequency range displaying significant power increase is marked. (b) Band power time course calculated for the frequency band indicated in (a) triggered according to cue-onset (vertical line) and significance level (sign test P from 10^-2 to 10^-8) for power changes (step function). A power decrease indicates ERD and a power increase ERS. The horizontal line marks the band power in the reference period

/ ERD/ERS / The basic principles of ERD/ERS / Determination of subject-specific frequency bands / continuous wavelet transform(CWT)

(c) Scalogram displaying the squared and over all trials averaged wavelet coefficients for the time interval 2 to 8 s (axis). Scale (left axis)running from 24 to 64 corresponds to a frequency range(right axis) from 12 to 32 Hz. Color-scale from ’black' (minimum) to red (maximum)

Time evolution of band power changes calculated in the indicated frequency bands (right side). Brisk movement-offset is marked with a vertical line at second 7. In addition to the power changes (thick line), the significance levels of power changes(thin line)are indicated. The scale on the right indicates significance levels 10" to 10(sign test); the scale on the left gives percentage power changes

/ ERD/ERS

Invited review

Event-related EEG/MEG synchronization and desynchronization: basic principles

G. Pfurtscheller, F.H. Lopes da Silva

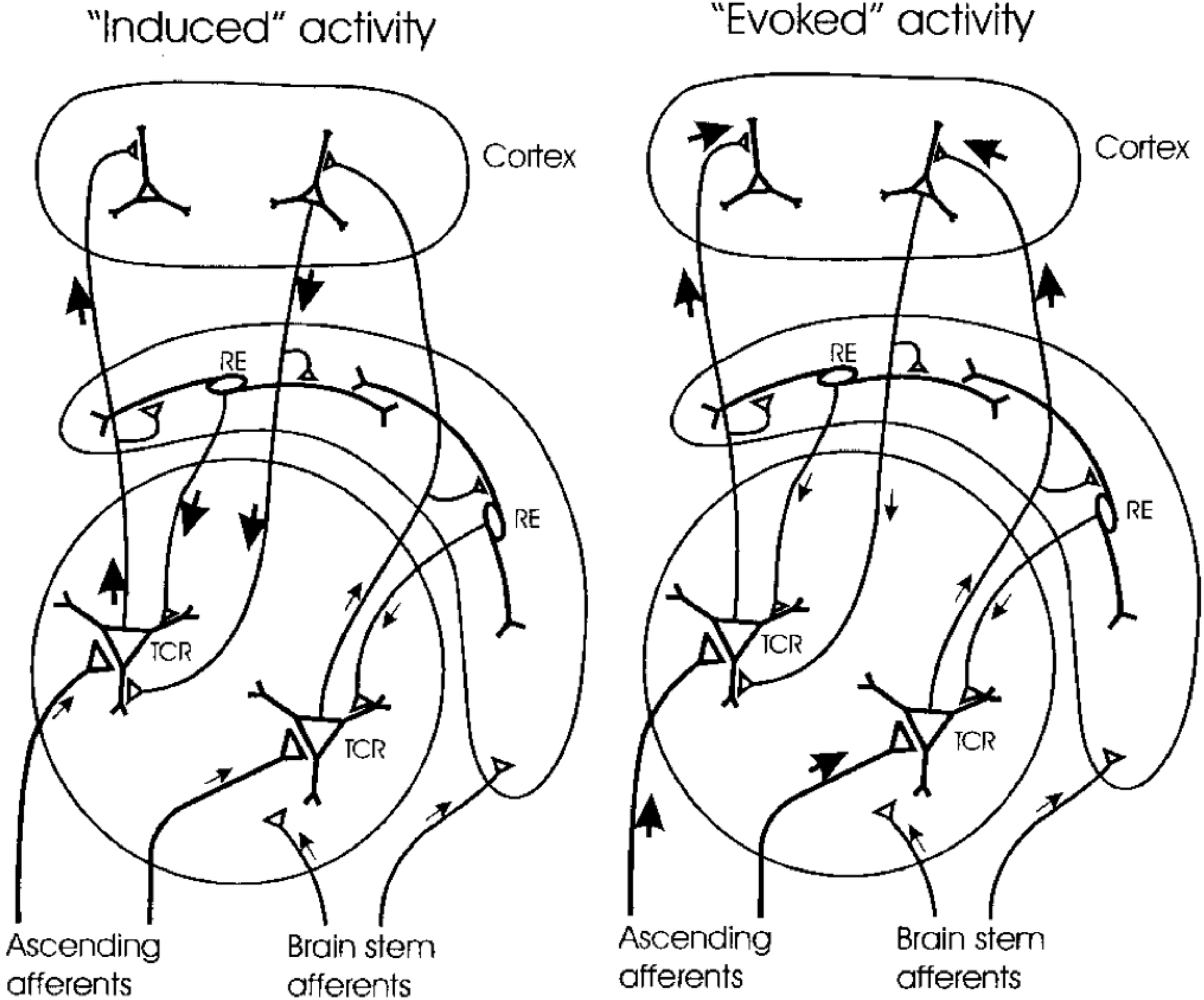

"Induced" activity
"Evoked" activity
Cortex
RE
RE
TCR
TCR
Ascending afferents
Brain stem afferents
Cortex
RE
RE
TCR
TCR
Ascending afferents
Brain stem afferents

Table 1
Quantification of ERD/ERS in the time domain used in different labs. (Modified fromPfurtscheller et al., 1999)

ERD quantification method	References
Band power method	Pfurtscheller and Aranibar (1979); Boiten et al. (1992); Dujardin et al. (1993); Klimesch et al. (1994); Toro et al. (1994); Aftanas et al. (1996); Defebvre et al. (1996); Krause et al. (1996); Sterman et al. (1996); Zhuang et al. (1997); Magnani et al. (1998)
Intertrial variance method	Kalcher and Pfurtscheller (1995); Klimesch et al. (1998)
Autoregressive models and spectral decomposition	Florian and Pfurtscheller (1995)
Hilbert transformation	Burgess and Gruzelier (1996); Clochon et al. (1996)
Complex demodulation	Nogawa et al. (1976)
Temporal-spectral evolution method (TSE)	Salmelin et al. (1995)
Event-related spectral pertubation (ERSP)	Makeig (1993); Wei et al. (1998)
Task-related power increase (TRPI), task-related power decrease (TRPD)	Gerloff et al. (1998)

Table 2
Methods for mapping of EEG/MEG parameters (modified from van Burik et al., 1999)

Method	Reference
Surface Laplacian	
Source derivation	Hjorth (1975)
Local average reference	Thickbroom et al. (1984)
Local estimate on realistic surface	Huiskamp (1991); Le et al. (1994)
Spherical splines	Perrin et al. (1987)
3d Splines on spherical and ellipsoidal surface	Law et al. (1993)
3d Splines on realistic surface	Babiloni et al. (1996)
Cortical imaging	
Spherical volume conductor	Kearfott et al. (1991); Edlinger et al. (1998)
Realistic head model, FEM	Gevins et al. (1991)
Distributed source imaging	
First introduction for MEG	Hämäläinen and Ilmoniemi (1984)
Applied to spontaneous MEG	Wang et al. (1993)
Applied for ERD/ERS analysis	van Burik et al. (1998); van Burik and Pfurtscheller (1999)

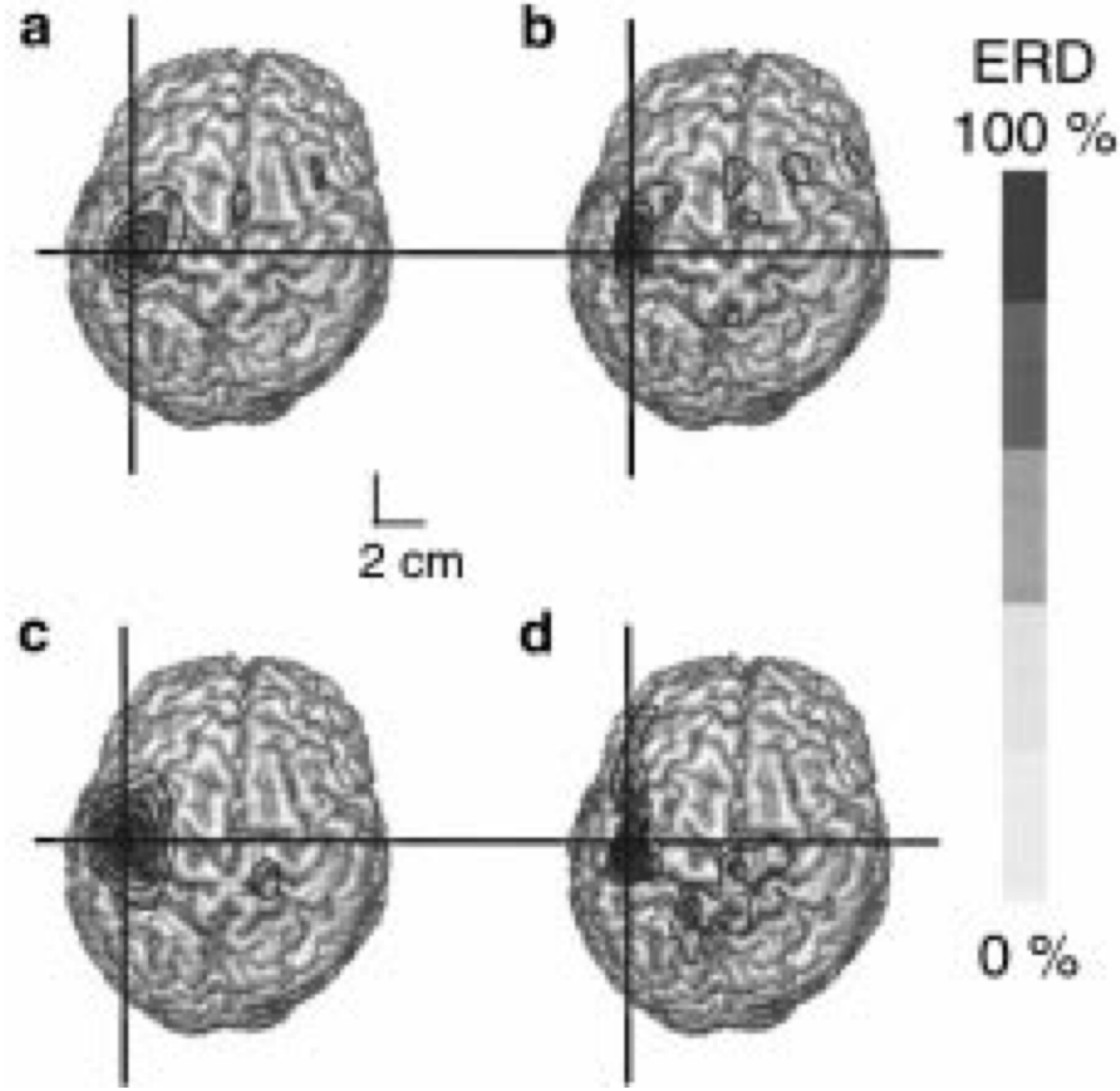
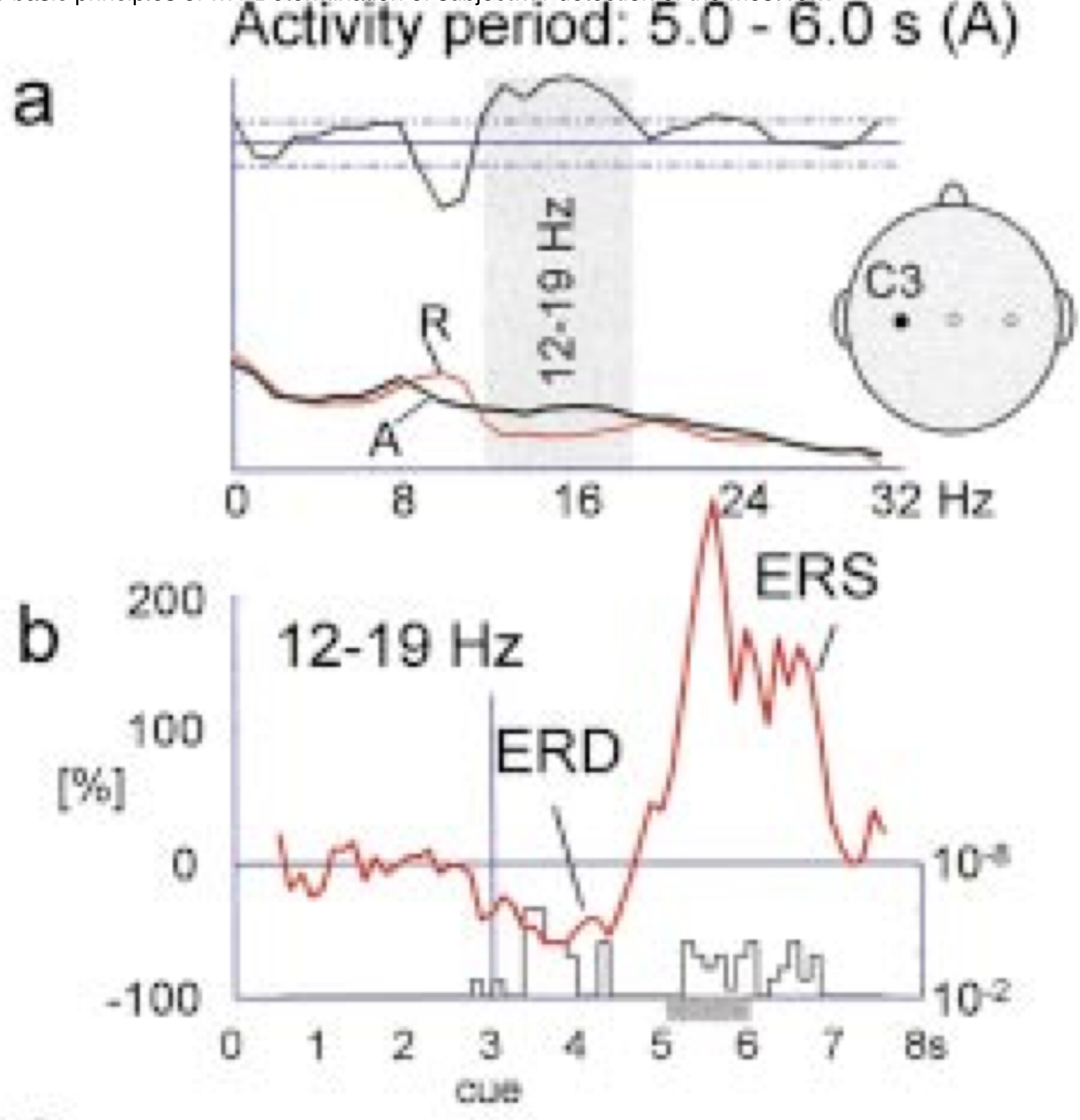
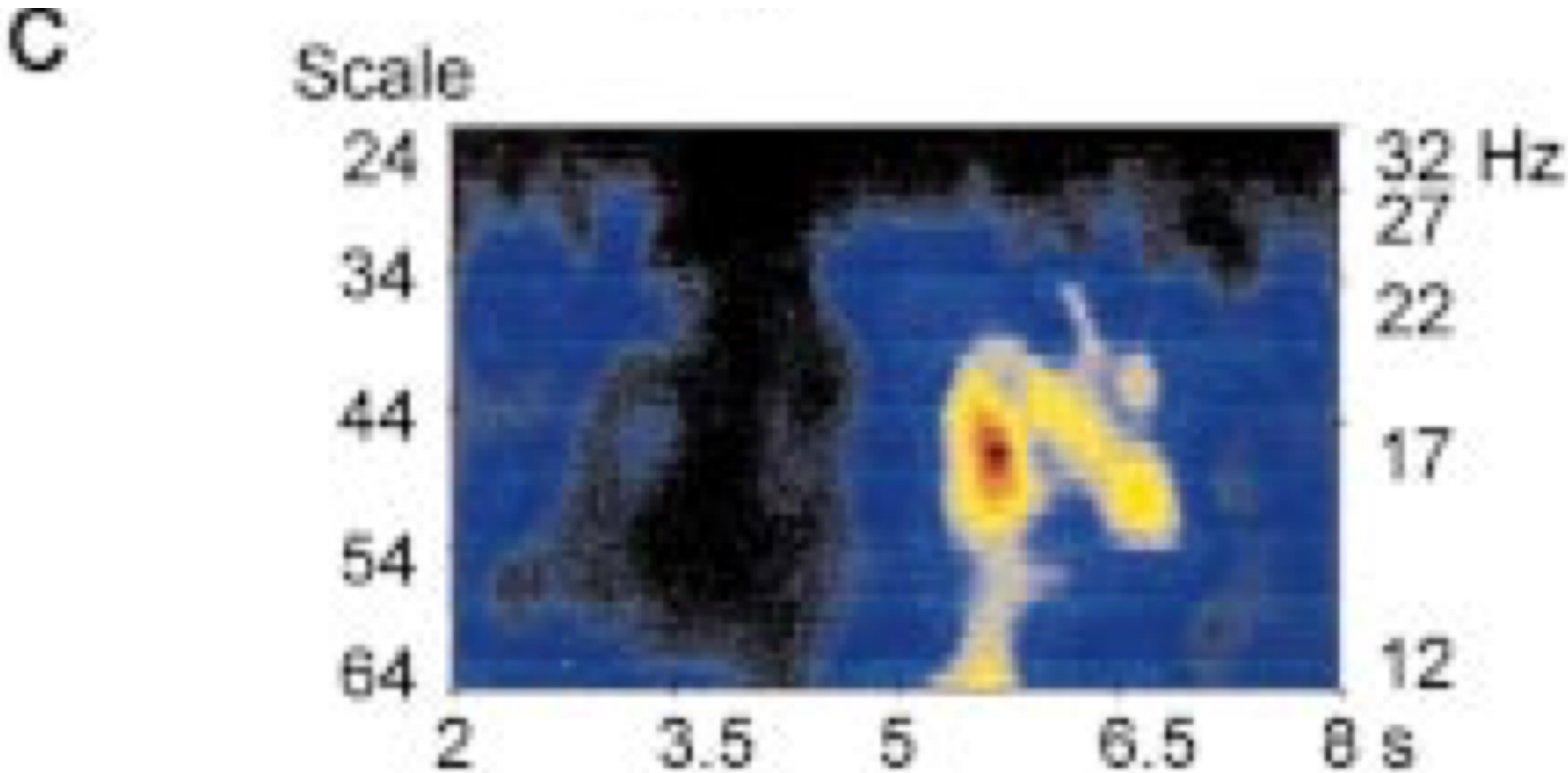


Fig. 4. ERD distributions calculated prior to a right hand movement. Maps are viewed from above. (a) Spline surface Laplacian calculated on a realistic head model. (b) Spline surface Laplacian calculated on a spherical head model and displayed over a realistic head model. Note the focus of ERD over the cortical representation area of the left hemisphere. (c) Linear estimation results based on a realistic head model. (d) Linear estimation results based on a spherical head model and displayed on the realistic head model. The maximum ERD value in (d) is found 0.5 cm posterior compared to (c). The ERD is scaled to its maximal value for each method, (modified from van Burik et al., 1999).


Activity period: 5.0 - 6.0 s (A)
a
12-19 Hz
R
A
C3
0
8
16
24
32 Hz
b
200
100
[%]
0
-100
12-19 Hz
ERD
ERS
10^{-8}
10^{-2}
0
1
2
3
4
5
6
7
8s
cue

$$\left(W_{\psi}f\right)(b,a)=\int_{-\infty}^{+\infty}f(t)\psi_{b,a}^{*}(t)dt.$$

The unique characteristics of the CWT are revealed by the time and frequency resolution of the transform at a specific scale a. When ω_o is the center frequency of the


C
Scale
24
34
44
54
64
32 Hz
27
22
17
12
2
3.5
5
6.5
8 s

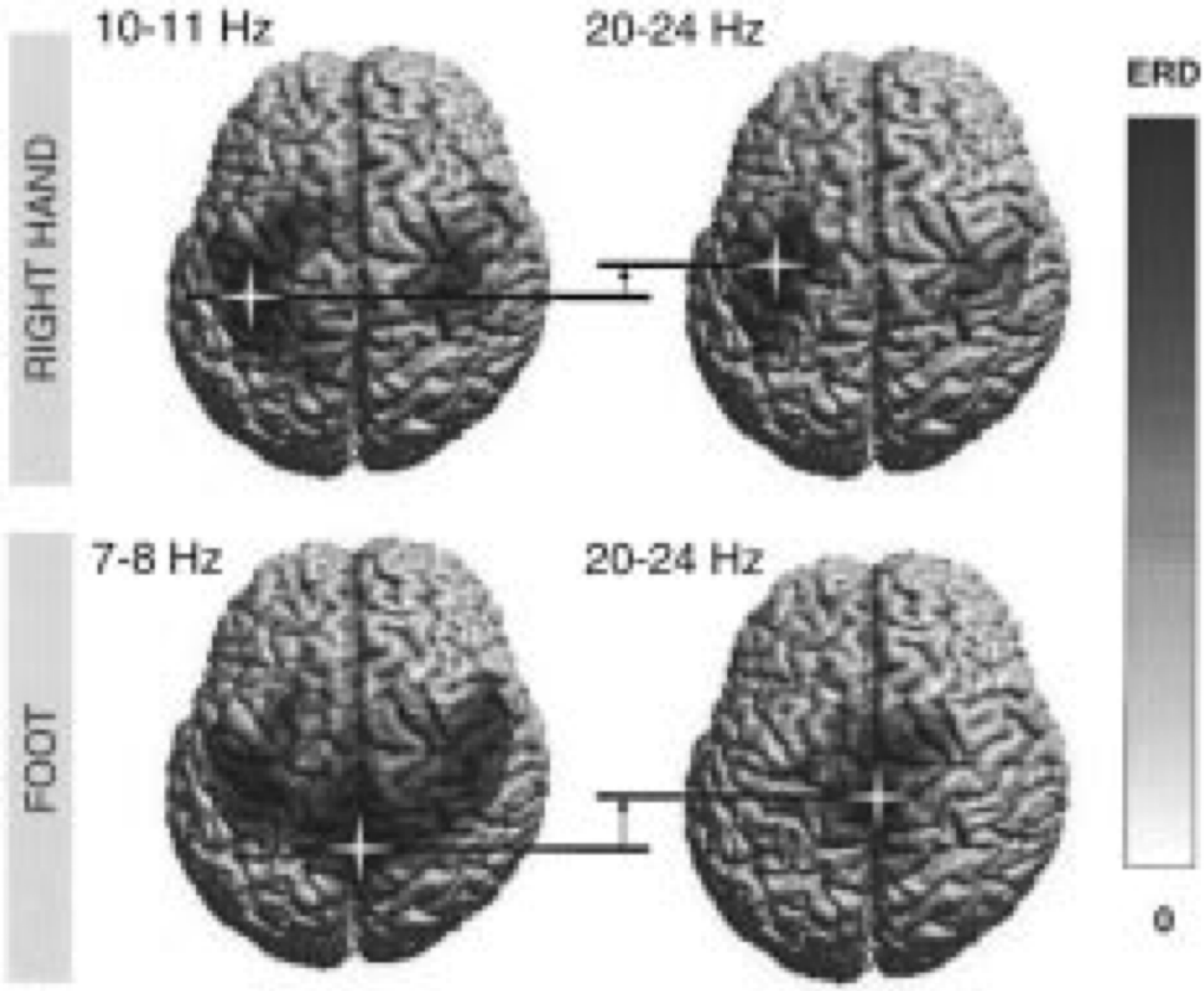


Fig. 7. ERD maps on a realistic head model from one subject during voluntary right hand (upper panel) and voluntary foot movement (lower panel). Data are displayed for subject-specific frequency bands showing largest power decrease. The maps represent a time interval of 125 ms. The white cross marks the maximum ERD.

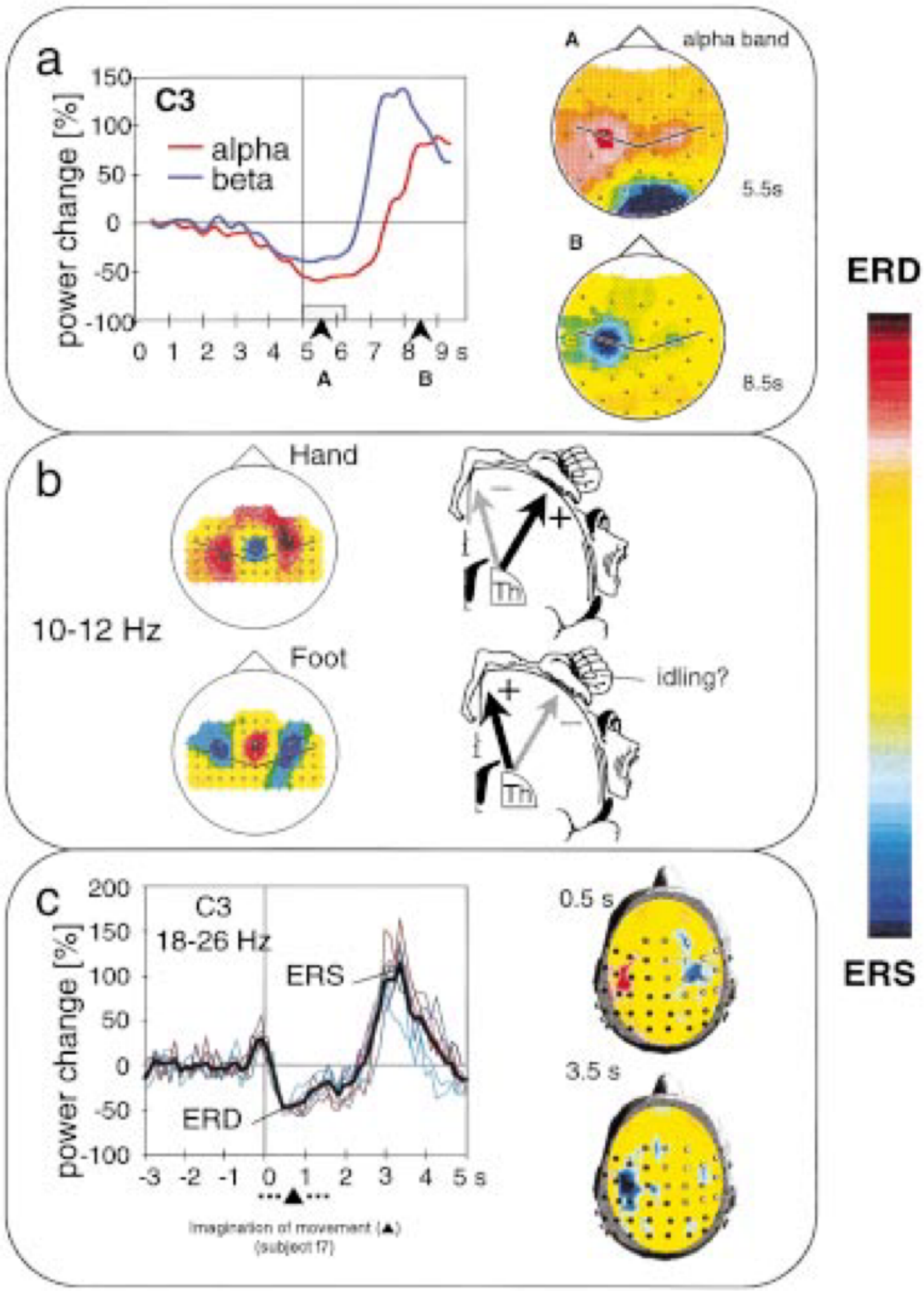
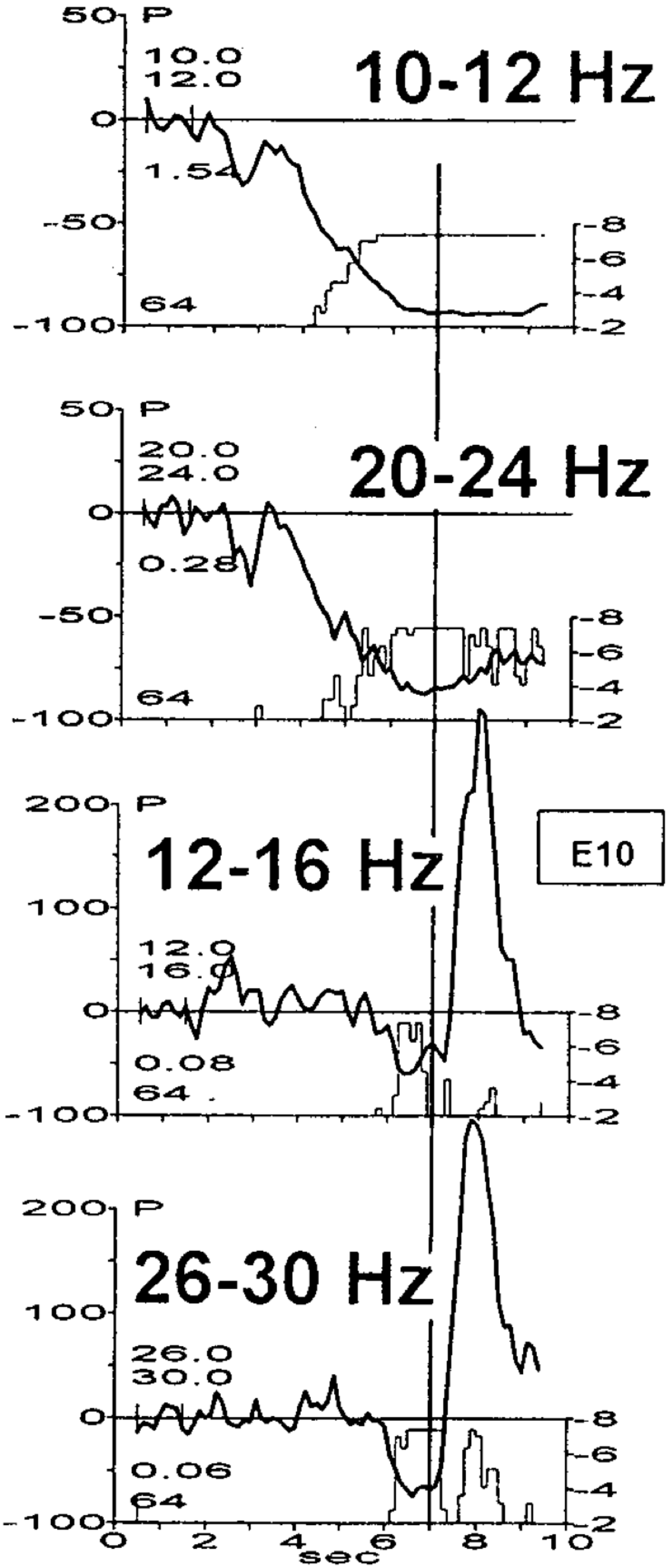
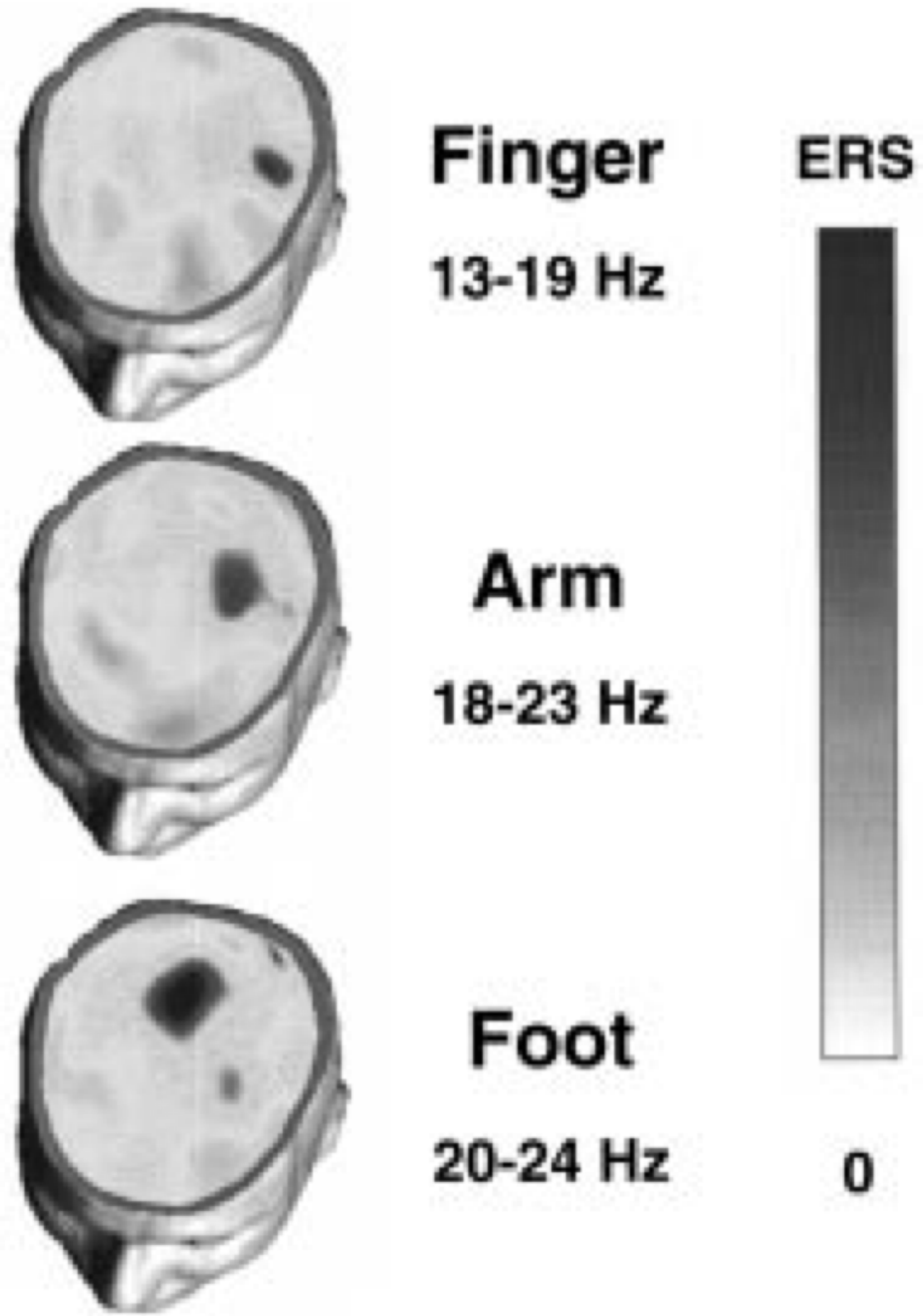


Fig. 8. (a) Grand average ($n = 9$) ERD curves calculated in the alpha and beta bands in a right hand movement task (left side). Grand average maps calculated for a 125 ms interval during movement (A) and after movement-offset in the recovery period (B) (right side). (b) Maps displaying ERD and ERS for an interval of 125 ms during voluntary movement of the hand (left, upper panel) and movement of the foot (left, lower panel). The motor homunculus with a possible mechanism of cortical activation/deactivation gated by thalamic structures is shown on the right. (c) Superimposed ERD curves with beta rebound from eight sessions with right motor imagery in one subject. Analyzed frequency band 18–26 Hz, EEG recorded from electrode position C3. In addition to the individual curves also the grand average ERD curve is plotted (left side). ERD maps from one session displaying simultaneous contralateral ERD and ipsilateral ERS during and contralateral ERS after motor imagery (right side). The scalp electrode positions are marked, (modified from Pfurtscheller et al., 1997c). 'Red' indicates power decrease or ERD and 'blue' power increase or ERS.



10-12 Hz
20-24 Hz
12-16 Hz
26-30 Hz
E10
P
10.0
12.0
1.54
64
20.0
24.0
0.28
12.0
16.0
0.08
26.0
30.0
0.06
sec


Finger
13-19 Hz
Arm
18-23 Hz
Foot
20-24 Hz
ERS
0

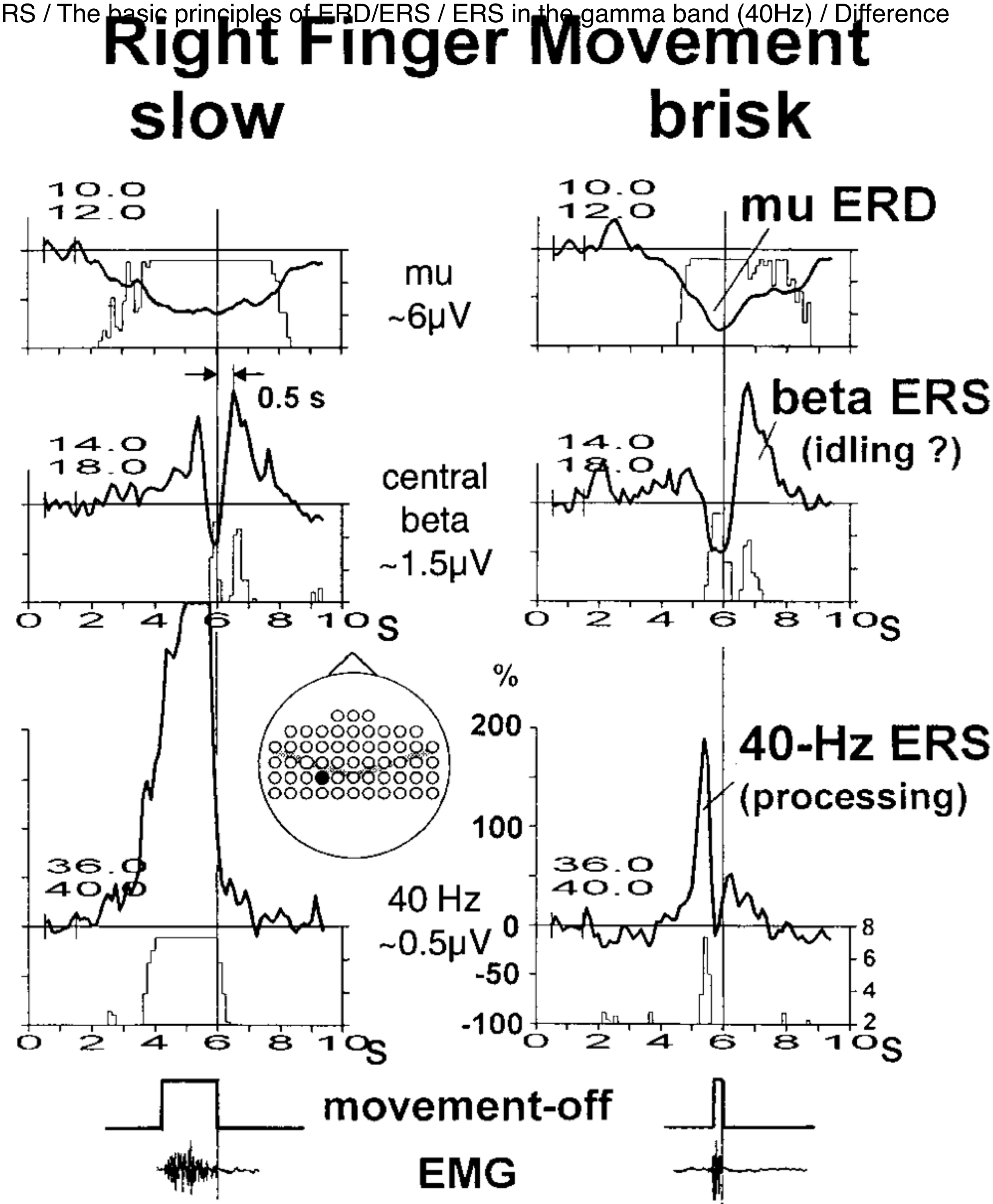


Fig. 11. ERD/ERS time courses from one subject computed during self-paced voluntary slow (left side) and brisk finger movement (right side). Data of three frequency bands (10–12, 14–18 and 36–40 Hz) are displayed. The data are triggered with respect to movement-offset (vertical line at second 6). Note the different time courses and duration of mu ERD, beta ERS and gamma ERS. The approximate amplitudes (square root of band powers) for the mu, beta and gamma bands are 6, 1.5 and 0.5 µV, respectively.