B BRAIN ACTIVITY MEASUREMENT

INTRODUCTION

Electroencephalograms (EEGs) from the human scalp were first recorded in 1924 by Hans Berger. It is assumed that they are generated by brain activity related to information processing. EEG is mainly caused by nerve cell activity, whereas other brain imaging methods are more related to blood flow and metabolic parameters. Moreover, the direct coupling of EEG with biological flow of information allows a continuous and chronometric approach to the basis of cognitive processing. Variations of EEG require synchronous and massive parallel activity in wide-ranging populations of neurons and the measures are done in a great distance to the generators. Thus spatial resolution is less than in other brain imaging techniques.

Actually EEG potentials occur in several locations with alternating polarity. This finding is consistent with models of information processing assuming separate modules of cognitive functioning, which interact continously in terms of uptake, processing and passing on of information.

The main fields of the psychological use of EEG are in *cognition*, in search of cognitive relevant modules in the brain and their temporal interaction. Distortion of common spatial or temporal regularity in potential dynamics (such as dimensional complexity) can be interpreted as a sign of uncommon or *emotional processing*. Brain activity is present when awake as well as during sleep, in which a number of *sleep stages* and sleep parameters can be differentiated by using certain criteria. Deviant patterns of EEG activity can be used to characterize *psychopathological states* or could be caused by *drug effects*.

PARAMETERS

Neurophysiological Basis

It is widely accepted that most of the time both, excitatory and inhibitory postsynaptic potentials simultaneously are present in the pyramidal cells of the upper and middle cortical layers. Usually they are in balance without releasing considerable action potentials. It is assumed that this is particularly true when a module became charged without immediate output. A negative potential on the surface is measured because excitatory synapses are predominant in upper layers (negative interstitium in the upper layers). The release of action potentials (negative interstitium far below) will change the dipole causing a positive potential.

Basic Activity

Negative and positive potentials in EEG alternate with main fluctuations within about 0.1 s (equivalent around 10 Hz). Dominant frequencies in the range of about 8–12 Hz are called *EEG alpha*. Alpha is observed in awake but resting subjects without demanding memory load. Alpha is generated by burst activity produced by loops between thalamic nuclei and the related cortical areas in case of attenuated stimulation. A lower portion of the alpha band (8–10 Hz) is discussed as reflecting attenuation of cortical activity during mental load while attending stimuli actively, for example in a time series resulting in partial loss of feature-related activation. The upper portion of alpha seems to be closer related to a more general attenuation of mental load mainly in processing stimuli, even by exogenous stimulation. Frequencies of 12–14 Hz (*EEG spindles*) seem to be indicative of active suppression of sensory stimuli during sleep.

Frequency 4–8 Hz (*EEG theta*) is discussed as indicative for extension of receptive fields, for example in coarse classification of stimuli. Theta is found to be increased during drowsiness and undirected memory search (flight of thought) as well as during top down or effortful processes causing directed memory search. The latter findings gave rise to the view that theta reflects involvement of hippocampal memory functions. Theta power can be found in posterior locations as well as above the premotor cortex indicating activated wide motor concepts. In learning response concepts, frontal theta is increased in good learners compared to poor learners.

Frequencies < 4 Hz (*EEG delta*) are found in slow wave sleep. Frequencies in the range of 40 Hz (*EEG gamma*) correspond to activities of neuronal ensembles, where some particular stimulus features are bound together building up a cognitive representation of an object or a gestalt. It is discussed that frequencies of 6 Hz may give rise to about seven oscillations of 40 Hz representing about seven distinct information chunks per second. There is a broad range of irregular frequencies between 14 and 40 Hz contributing to the shape of raw EEGs of awake subjects, which is called *EEG beta*.

Analysis of EEG basic activity needs data processing in the frequency domain and is useful for characterizing widespread cortical processes. It can be done for any time range as conceded by resolution and lower limit of the frequencies of interest, such as for mental states or for epochs chosen in relation to certain events.

Event-Related Potentials

Information processing can often be related to external events, such as the onset of a stimulus or a response. EEG potentials in the time domain corresponding to assumptions on expecting or processing of stimuli as well as preparing or evaluating of responses allow a kind of mental chronometry.

The most common potential observed before stimulus onset is a *contingent negative variation* (CNV) in the case of so-called imperative stimuli (which request fast responses) revealing increasing motor preparation. Consecutive to the onset of a stimulus, negative potentials reflect the load of certain brain areas stimulated by individual significant stimulus features. Physical features produce a load in modal specific areas in a time range of about 150 ms after onset, called *processing negativity* (N1). More abstract or related features lead to a load mainly depending on context information, for example in case of similar stimuli, in the context of a task or in case of other kinds of involuntary or voluntary attention. Under these circumstances mental load mostly can be interpreted as a kind of mismatch and the related potential in the time range between 200–300 ms after onset is called *mismatch negativity* (N2).

Information load in individual brain areas is mostly followed by passing forward information to related or higher order areas, as revealed by a positive potential. An early positive deflection P1 (circa 100 ms) reflects forward processing of prepared (biological or overlearned) stimulation. A positive potential P2 (circa 200 ms) in the time range between N1 and N2 could be interpreted as forward processing from physical to psychological relevant features. Extraction of the psychological content ('semantics') means classification and relating to an abstract concept. Forward processing after this by a P3 or P300 (> 300 ms after onset) is discussed as cognition of the stimulus in terms of upgrading of the hitherto model of the environmental context. While most of the processes up to P3, even automatic respondings, are unconscious, forward processing after mismatch is assumed to be obligatory for being aware of the stimulus.

Longer lasting processing increases P3 latency and widens the peak. Peak amplitude increases with task relevance and stimulus uncertainty. Important properties of stimulus processing can be studied by the odd ball paradigm. This paradigm consists of at least two classes of stimuli appearing randomly in time, where the instances of one stimulus are rare (20–30%) and a task should be done by using the rare stimuli (for example counting). Under these circumstances rare stimuli are responded by potentials with high P3s.

In case of mismatch of the extracted meaning of a stimulus compared to its semantic context, late negative and positive potentials can occur. S*emantic mismatch* occurs if a sentence ends with unexpected words or phrases (N400). Conducting information processing to a *reanalysis* is discussed in cases when a late positive potential follows (P600).

DATA ACQUISITION

The EEG Laboratory

EEG raw data have to be obtained in a laboratory protected against vibration and noise. Recording can be done without electric field protection, if external field generators are weak and well known (50/60 Hz). Usually a separate space for subjects (including display and response devices) and acquisition apparatus (amplifier and monitoring) should be provided. The electrical potentials recorded from the scalp are of low amplitude and have to be preamplified close behind the electrodes and amplified by high quality amplifiers. A/D converter is used to convert the analogue time-continuous voltage-time series into a digitalized time-discrete signal. Analog–digital conversion rate (sampling rate) has to be at least twice as high as the highest frequency of interest in the signal to be measured to prevent the appearance of frequencies not present in the original signal. Preparation of derivation should be conducted by trained personnel. Otherwise all requirements, instruction, supervision and data acquisition by an examiner and/or computer has to be done as it is usual in psychological experiments.

Electrode-Skin Interface

In the brain, a great variety of processes takes place continuously continuously generating time varying (bio)electric potential fields over the scalp. EEG signals are voltage time series reflecting the potential difference between two field points derived from the scalp by electrodes. Analyses of human EEG are usually based on frequencies of 0 to 100 Hz containing magnitudes approximately of 0 to 200 μV.

Employing high input impedance EEG amplifiers, a variety of different electrode materials (Ag/AgCl, tin, silver, gold) in combination with electrode jelly may be used. Caps with embedded electrodes permit simple handling and replication. Impedances up to 40 kΩ are permitted (Ferree et al., 2001), but less than 5000 Ω are usually preferred. This can be attained by abrading slightly the surface or even scratching the skin surface with a sterile needle. However, injuries have to be avoided.

Points of Derivation

Referential recording is based on the assumption that one electrode site is an inactive reference site and the active site of interest is recorded with respect to that reference. Reference sites with minor electrical activity such as the earlobes, mastoids, nose are preferred.

A reference-independent measure of the potential field is required for studying scalp topography and for source localization. One approach to overcome the reference-site problem is to use the so called average-reference using the mean of all recording channels at each time point to approximate an inactive reference. (Recording) problems arise because electrodes are not evenly distributed over the head surface. Another approach is to use reference-free transformations, such as current source density analysis (CSD) which is based on the second derivative of the interpolated potential distribution (Laplacian operator). The latter method accentuates local sources and masks interelectrode correlations. In order to get valid approximations, both approaches require a sufficient spatial electrode density.

Due to the prerequisites especially for successful topographic mapping and source localization a standardized system of electrode placement with up to 74 electrodes is usually used (10–10 system or '10% system'). Depending on certain research questions, a fewer number is used and/or interpolated sites are chosen. Advanced derivations use a 5% system with up to 345 electrodes (Oostenveld & Praamstra, 2001).

Common Steps in Artifact Rejection

The raw EEG signal may be contaminated by both technical (as power supply) and biological electric fields (electric activity of eyes, heart, muscle tension etc.). Parts of the EEG signal which are not generated by distinct brain processes are called 'artifacts'. Artifacts are not easy detectable and there are no common methods of artifact rejection. Thus contaminations of the brain signals have to be avoided by careful planning of the derivation setting (avoiding technical carelessness and unnecessary muscular activity as well as eyeblinks). After derivation the experimenter should do some 'eyeballing' on the signals. With DC-derivations it is useless to define an amplitude criterion for rejection (for example +80 μV). Noisy parts of the signal should be removed. Within one experiment the same criteria have to be applied for all subjects. Correction of ocular artifacts could be done in some cases (for uneasy children or patients) by use of special algorithms. Zero phase-shift low pass filters (about 20 Hz) are used for signal smoothing in ERP analyses.

DATA ANALYSIS

Signal Characteristics

Event-related potential (ERP) analysis is based on the assumption that part of the electrical brain activity is in a stable time relationship responding to a stimulus and the remaining brain activity is considered to be stationary noise. Hence segment-averaging is used to reduce variance depending on the ratio of time-locked to non-time-locked signal portion.

In general EEG signals are considered to be generated by stochastic processes with unknown probability density functions. Hence the processes are characterized by moments and moment functions. Usually EEG time series are studied up to second order of moments (mean, variance) and moment functions (covariance functions). *Higher-order statistics* (HOS) have to be used to analyse signal properties which deviate from Gaussian amplitude distribution (signal skewness, signal kurtosis). Given a signal of interest with non-zero HOS noised by Gaussian noise, then HOS is less affected by noise than second-order analyses.

Apart from the stochastic approach attempts have been made to describe EEG signals as the output of a complex *deterministic process* by use of nonlinear difference equations. The corresponding mathematical base originates from the field of 'deterministic chaos'. One frequently used measure is called *EEG dimensional complexity* (DCx) and this yields information regarding the complexity of processes in the brain.

Methods of Spectral Estimation

One widely used method when analysing EEG time series is spectral analysis, which means analysing a given signal with respect to its properties within the frequency domain. (Problems arise in analysing rapid amplitude changes within low frequency bands.)

Spectra can be obtained by filtering the signal with a set of narrow bandpass filters. This procedure is common in determining *event-related desynchronization* (ERD) where activated cortical areas are assumed to be desynchronized compared to an idling state. After averaging over trials to discriminate between event-related and non-event-related power changes a standardized difference term between signal power in the analysed interval (A) and in a reference interval (R) is calculated:

$$\mathrm{ERD} = ((R - A)/R) \times 100\%.$$

Fourier transform (FT) and wavelet transform (WT) are linear transformations of the signal from time to frequency domain. The most widely used approach for spectral estimation based on FT is the periodogram. Here the estimation is achieved by decomposing the signal recorded over time T in sines and cosines. To get reliable spectral estimates when analysing short epochs in the range of a few seconds (*short time Fourier transform* STFT), a correction of the data segments is required. This could be done by tapering functions in the time domain (for example Hanning window). Additionally segment-averaging or smoothing is used to reduce variance. Note that frequency resolution (in hertz) is inverse proportional to the epoch length T (in seconds). With STFT, dynamics over time can be displayed in a time-frequency plane.

The idea behind *wavelets* is simply to have more appropriate functions than sines and cosines when dealing with non-stationary impulse-like events (spikes and transients, for example high-frequency bursts and K-complexes). The principle way of wavelet analysis is to define a wavelet prototype function $W(t)$ as an analysis template. The corresponding wavelet basis, $W_{s,l}$ (t), is obtained from the mother wavelet $W(t)$ by varying the scaling parameter s and the locating parameter l. Thus, the wavelets $W_{s,l}$ (t) are time shifted (l) and scaled (s) derivations of $W(t)$. Each analysis template $W_{s,l}$ (t) represents a band pass function with a central frequency f_0, localized in the time-frequency plane at $t = 1$ and $f = f_0/s$. At any scale s the wavelet has not one frequency, but a band of frequencies, and the bandwidth is inverse proportional to s. The finer the resolution in time domain (small s) the less is the resolution in frequency domain and vice versa. The output can be displayed in the time–frequency plane analogous to STFT, reaching a maximum when the signal of interest most resembles the analysis template. Summing up, it may be said that the short-time Fourier transform is well adapted for analysing all kinds of longer lasting oscillatory like waveforms, whereas wavelets are more suited for the analysis of short duration pulsations and for signal detection, for instance in ERPs.

With *model based methods of spectral estimation* the raw EEG is interpreted as the output of a linear filter excited by white noise. EEG signal modelling and hence spectral estimation is based on derivates of the autoregressive moving average model (ARMA), which is described by a linear difference equation:

$$X_t = a_1 X_{t-1} + \cdots + a_p X_{t-p} + b_1 \mathrm{e}_{\mathrm{t-1}} + \cdots + b_q e_t - q + et \quad (1)$$

where p denotes autoregressive lags and q denotes moving average lags. Terms containing e characterize white noise.

A multitude of models similar to Equation (1) is used. All of them are based on assumptions concerning the underlying stochastic processes rather than describing a certain biophysical model. Successful spectrum estimation depends critically on the selection of the appropriate model, the model order and the fitting method for estimating the coefficients (for example least-square-methods, maximum-likelihood-methods). Model-based spectral estimation compared to the Fourier transform approach is useful when dealing with very short segments.

Generally Used Spectral Estimations

The *power spectrum* (auto-spectral density function) displays the signals distribution of variance or power over frequency. The *cross-power spectrum* (cross-spectral density function) reflects the covariance between two EEG channels as a function of frequency.

A frequently used quantity is the cross-power spectrum normalized by the autospectra, the so called *coherence spectrum Coh*. EEG coherence analysis is regarded as a tool for studying interrelationships with respect to power and phase between different cortical areas during a certain psychological manipulation (such as sensory stimulation, voluntary movements). The values of the coherence function lie in the range from 0 to 1. It is assumed that a strong functional relationship between two brain regions is reflected by a high coherence value. To avoid trivial results (volume conduction) coherence should only be interpreted if the phase lag between the two channels is nonzero. Erroneous estimations may be caused for example by A/D converters producing artificial phase lag while sampling the data or by reference electrode effects.

The *bispectrum Bi* (the product of two spectra) and its normalized derivate *bicoherence* are third order measures in the frequency domain related to the signal skewness. They are tools for detecting the presence of non-linearity, particularly quadratic phase-coupling, i.e. two oscillatory processes generate a third component with a frequency equal to the sum (or difference) of two frequencies f1 and f2. As compared to the power spectrum, more data is usually needed to get reliable estimates.

Non-Invasive Localization of Neuronal Generators

The EEG can be used as a method for functional neural imaging. Its advantage is to display dynamic brain processes on a millisecond time scale. The problem of determination of intra-cerebral current sources from a given scalp surface potential is a so called inverse problem with no unique solution. It is necessary to make additional assumptions in order to choose a distinct three-dimensional source distribution among the infinite set of different possible solutions. Regularization methods are:

- *Equivalent dipole*/dipole layer localization: Scanning the head volume with the model source until an error function is minimized.
- *Weighted minimum norm*: Among all possible solutions, choosing the one containing the least energy.
- *Low resolution electromagnetic tomography* (Loreta): Assumes that neighbouring neurons are simultaneously and synchronously activated. Its aim is to find out the smoothest of all possible solutions.

High resistance of the skull is responsible for reduced spatial resolution. It has been shown (Cuffin et al., 2000) that best average localization that can be achieved is approximately 10 mm using a spherical head model consisting of concentric spheres as brain, skull, and scalp.

FUTURE PERSPECTIVES AND CONCLUSIONS

Due to wavelet transform, there exists a great number of wavelet families. Selecting a certain wavelet depends on previous knowledge of the biophysics of brain processes. It would be desirable to build up a wavelet library for different EEG phenomena.

The reason for the use of a great number of EEG channels is to attain maximum spatial resolution of the scalp voltage distribution to improve topographic mapping considering the inverse estimate problem in neural imaging. A further goal might be to attain realistic head models, and to get individual parameters for the size of brain and skull.

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Related Entries

Psychophysiological Equipment & Measurements, Equipment for Assessing Basic Processes

B BURNOUT ASSESSMENT

INTRODUCTION

Job burnout is a prolonged response to chronic interpersonal stressors on the job. It has been recognized as an occupational hazard for various people-oriented professions, such as human services, education, and health care. Recently, as other occupations have become more oriented to customer service, and as global economic realities have changed organizations, the phenomenon of burnout has become relevant in these areas as well. Burnout is defined by the three dimensions of exhaustion, cynicism, and inefficacy. The standard measure that is used to assess these three dimensions is the Maslach Burnout Inventory (MBI).

Burnout is a prolonged response to chronic emotional and interpersonal stressors on the job. It is defined by the three dimensions of exhaustion, cynicism, and inefficacy. As a reliably identifiable job stress syndrome, burnout places the individual stress experience within a larger organizational context of people's relation to their work. Interventions to alleviate burnout and to promote its opposite, engagement with work, can occur at both organizational and personal levels. The social focus of burnout, the solid research basis concerning the syndrome, and its specific ties to the work domain make a distinct and valuable contribution to people's health and well-being.

CONCEPTUALIZATION

Burnout is a psychological syndrome of exhaustion, cynicism, and inefficacy in the workplace. It is an individual stress experience embedded in a context of complex social relationships, and it involves the person's conception of both self and others on the job. Unlike unidimensional models of stress, this multidimensional model