FUNDAMENTALS OF EEG MEASUREMENT

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Abstract:
Electroencephalographic measurements are commonly used in medical and research areas. This review article presents an introduction into EEG measurement. Its purpose is to help with orientation in EEG field and with building basic knowledge for performing EEG recordings. The article is divided into two parts. In the first part, background of the subject, a brief historical overview, and some EEG related research areas are given. The second part explains EEG recording.

Keywords: **Electroencephalography, EEG, brain waves, EEG recording, EEG amplifiers**

1. Introduction

Modern medicine applies variety of imaging techniques of the human body. The group of electrobiological measurements comprises items as electrocardiography (ECG, heart), electromyography (EMG, muscular contractions), electroencephalography (EEG, brain), magnetoencephalography (MEG, brain), electrogastrography (EGG, stomach), electrooptigraphy (EOG, eye dipole field). Imaging techniques based on different physical principles include computer tomography (CT), magnetic resonance imaging (MRI), functional MRI (fMRI), positron emission tomography (PET), and single photon emission computed tomography (SPECT).

Electroencephalography is a medical imaging technique that reads scalp electrical activity generated by brain structures. The electroencephalogram (EEG) is defined as electrical activity of an alternating type recorded from the scalp surface after being picked up by metal electrodes and conductive media [1].
The EEG measured directly from the cortical surface is called electrocortiogram while when using depth probes it is called electrogram. In this article, we will refer only to EEG measured from the head surface. Thus electroencephalographic reading is a completely non-invasive procedure that can be applied repeatedly to patients, normal adults, and children with virtually no risk or limitation.

When brain cells (neurons) are activated, local current flows are produced. EEG measures mostly the currents that flow during synaptic excitations of the dendrites of many pyramidal neurons in the cerebral cortex. Differences of electrical potentials are caused by summed postsynaptic graded potentials from pyramidal cells that create electrical dipoles between soma (body of neuron) and apical dendrites (neural branches). Brain electrical current consists mostly of Na+, K+, Ca++, and Cl- ions that are pumped through channels in neuron membranes in the direction governed by membrane potential [2]. The detailed microscopic picture is more sophisticated, including different types of synapses involving variety of neurotransmitters. Only large populations of active neurons can generate electrical activity recordable on the head surface. Between electrode and neuronal layers current penetrates through skin, skull and several other layers. Weak electrical signals detected by the scalp electrodes are massively amplified, and then displayed on paper or stored to computer memory [3]. Due to capability to reflect both the normal and abnormal electrical activity of the brain, EEG has been found to be a very powerful tool in the field of neurology and clinical neurophysiology. The human brain electric activity starts around the 17-23 week of prenatal development. It is assumed that at birth the full number of neural cells is already developed, roughly 10^{11} neurons [4]. This makes an average density of 10^4 neurons per cubic mm. Neurons are mutually connected into neural nets through synapses. Adults have about 500 trillion (5.10^{14}) synapses. The number of synapses per one neuron with age increases, however the number of neurons with age decreases, thus the total number of synapses decreases with age too. From the anatomical point of view, the brain can be divided into three sections: cerebrum, cerebellum, and brain stem. The cerebrum consists of left and right hemisphere with highly convoluted surface layer called cerebral cortex. The cortex is a

dominant part of the central nervous system. The cerebrum obtains centres for movement initiation, conscious awareness of sensation, complex analysis, and expression of emotions and behaviour. The cerebellum coordinates voluntary movements of muscles and balance maintaining. The brain stem controls respiration, heart regulation, biorythms, neurohormone and hormone secretion, etc.[5]. The highest influence to EEG comes from electric activity of cerebral cortex due to its surface position.

There are some theoretical and practical differences between EEG and MEG. Although the MEG is produced by the same electrical currents, it can provide complementary information to EEG [6].

2. EEG: History, brain waves, applications

History

During more than 100 years of its history, encephalography has undergone massive progress. The existence of electrical currents in the brain was discovered in 1875 by an English physician Richard Caton. Caton observed the EEG from the exposed brains of rabbits and monkeys. In 1924 Hans Berger, a German neurologist, used his ordinary radio equipment to amplify the brain's electrical activity measured on the human scalp. He announced that weak electric currents generated in the brain can be recorded without opening the skull, and depicted graphically on a strip of paper. The activity that he observed changed according to the functional status of the brain, such as in sleep, anaesthesia, lack of oxygen and in certain neural diseases, such as in epilepsy. Berger laid the foundations for many of the present applications of electroencephalography. He also used the word *electroencephalogram* as the first for describing brain electric potentials in humans. He was right with his suggestion, that brain activity changes in a consistent and recognizable way when the general status of the subject changes, as from relaxation to alertness [7]. Later in 1934 Adrian and Matthews published the paper verifying concept of “human brain waves” and identified regular oscillations around 10 to 12 Hz which they termed “alpha rhythm” [7].

Brain waves classification

For obtaining basic brain patterns of individuals, subjects are instructed to close their eyes and relax. Brain patterns form wave shapes that are commonly sinusoidal. Usually, they are measured from peak to peak and normally range from 0.5 to 100 μV in amplitude, which is about 100 times lower than ECG signals. By means of Fourier transform power spectrum from the raw EEG signal is derived. In power spectrum contribution of sine waves with different frequencies are visible. Although the spectrum is continuous, ranging from 0 Hz up to one half of sampling frequency, the brain state of the individual may make certain frequencies more dominant. Brain waves have been categorized into four basic groups (Figure 1):

- beta (>13 Hz),
- alpha (8-13 Hz),
- theta (4-8 Hz),
- delta (0.5-4 Hz).

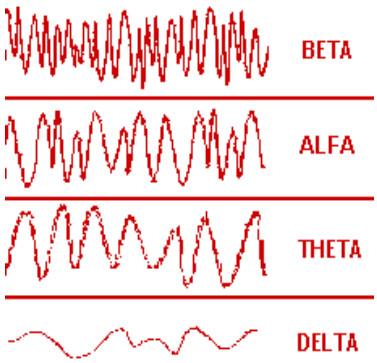

Figure 1. Brain wave samples with dominant frequencies belonging to beta, alpha, theta, and delta band.

The best-known and most extensively studied rhythm of the human brain is the normal alpha rhythm. Alpha can be usually observed better in the posterior and occipital regions with typical amplitude about 50 μV (peak-peak). According to our experiences alpha was also significant between posterior and central regions in comparison to other regions. Alpha activity is induced by closing the eyes and by relaxation, and abolished by eye opening or alerting by any mechanism (thinking, calculating). Most of the people are remarkably sensitive to the phenomenon of "eye closing", i.e. when they close their eyes their wave pattern significantly changes from beta into alpha waves. The precise origin of the alpha rhythm is still not known. Alpha waves are usually attributed to summated dendrite potentials. Evoked potentials (e.g. generated in brain stem) often consist of fibre potentials (axonal) and synaptic components [8].

EEG is sensitive to a continuum of states ranging from stress state, alertness to resting state, hypnosis, and sleep. During normal state of wakefulness with open eyes beta waves are dominant. In relaxation or drowsiness alpha activity rises and if sleep appears power of lower frequency bands increase. Sleep is generally divided into two broad types: nonrapid eye movement sleep (NREM) and REM sleep. NREM and REM occur in alternating cycles. NREM is further divided into stage I, stage II, stage III, stage IV. The last two stages corresponds to deeper sleep, where slow delta waves show higher proportions. With slower dominant frequencies responsiveness to stimuli decreases.

Various regions of the brain do not emit the same brain wave frequency simultaneously. An EEG signal between electrodes placed on the scalp consists of many waves with different characteristics. A large amount of data received from even one single EEG recording presents a difficulty for interpretation.

Individual's brain wave patterns are unique. In some cases, it is possible to distinguish persons only according to their typical brain activity. For example, subjects who regard themselves as rational types or as holistic/intuitive types may demonstrate certain higher activity in their frontal left and frontal right hemisphere respectively.

Applications

The greatest advantage of EEG is speed. Complex patterns of neural activity can be recorded occurring within fractions of a second after a stimulus has been administered. EEG provides less spatial resolution compared to MRI and PET. Thus for better allocation within the brain, EEG images are often combined with MRI scans. EEG can determine the relative strengths and positions of electrical activity in different brain regions.

According to R. Bickford [8] research and clinical applications of the EEG in humans and animals are used to:

(1) monitor alertness, coma and brain death;
(2) locate areas of damage following head injury, stroke, tumour, etc.;
(3) test afferent pathways (by evoked potentials);
(4) monitor cognitive engagement (alpha rhythm);
(5) produce biofeedback situations, alpha, etc.;
(6) control anaesthesia depth ("servo anaesthesia");
(7) investigate epilepsy and locate seizure origin;
(8) test epilepsy drug effects;
(9) assist in experimental cortical excision of epileptic focus;
(10) monitor human and animal brain development;
(11) test drugs for convulsive effects;
(12) investigate sleep disorder and physiology.

Symmetry of alpha activity within hemispheres can be monitored. In cases of restricted lesions such as tumour, hemorhage, and trombosis, it is usual for the cortex to generate lower frequencies. EEG signal distortion can be manifested by reduction in amplitude; decrease of dominant frequencies beyond the normal limit; production of spikes or special patterns. Epileptic conditions produce stimulation of the cortex and the appearance of high-voltage waves (up to 1000 μV) referred to as "spikes" or "spike and wave" [8]. EEG patterns have been shown to be modified by a wide range of variables, including biochemical, metabolic, circulatory, hormonal, neuroelectric, and behavioural factors [7]. By tracking

changes of electric activity during such drug abuse-related phenomena as euphoria and craving, brain areas and patterns of activity that mark these phenomena can be determined.

As the EEG procedure is non-invasive and painless, it is being widely used to study the brain organization of cognitive processes such as perception, memory, attention, language, and emotion in normal adults and children. For this purpose, the most useful application of EEG recording is the ERP (event related potential) technique.

Evoked potentials

Evoked potentials or event-related potentials (ERPs) are significant voltage fluctuations resulting from evoked neural activity. Evoked potential is initiated by an external or internal stimulus [8]. ERPs are suitable methodology for studying the aspects of cognitive processes of both normal and abnormal nature (neurological or psychiatric disorders [9]).

Mental operations, such as those involved in perception, selective attention, language processing, and memory, proceed over time ranges in the order of tens of milliseconds. Whereas PET and MRI can localize regions of activation during a given mental task, ERPs can help in defining the time course of these activations [10].

Amplitudes of ERP components are often much smaller than spontaneous EEG components, so they are not to be recognised from raw EEG trace. They are extracted from set of single recordings by digital averaging of epochs (recording periods) of EEG time-locked to repeated occurrences of sensory, cognitive, or motor events [11]. The spontaneous background EEG fluctuations, which are random relatively to time point when the stimuli occurred, are averaged out, leaving the event-related brain potentials. These electrical signals reflect only that activity which is consistently associated with the stimulus processing in a time-locked way. The ERP thus reflects, with high temporal resolution, the patterns of neuronal activity evoked by a stimulus.

Quantitative electroencephalography

Technological advances increased ability of encephalography to read brain activity data from the entire head simultaneously. Quantitative EEG (QEEG) applies multi channel measurements that can better determine spatial structures and localize areas with brain activity or abnormality. The results are often used for topographic brain mapping represented with colour maps in 2D and 3D to enhance visualization.

Brain computer interface

Brain computer interface (BCI) is a communication system that recognizes user's command only from his or her brainwaves and reacts according to them. For this purpose PC or/and subject is trained. Simple task can consist of desired motion of an arrow displayed on the screen only through subject's imaginary of the motion of his or her left or right hand. As the consequence of imaging process, certain characteristics of the brainwaves are raised and can be used for user's command recognition, e.g. motor mu waves (brain waves of alpha range frequency associated with physical movements or intention to move) or certain ERPs.

EEG Biofeedback

So-called mindmaschines or brainmaschines are devices for induction of different mind states (e.g. relaxation, top performance) by entrainment of the brain waves into desired frequency bands by repetitive visual and audio stimuli. For making the training more effective, biofeedback methods were involved. Originally, changes in finger skin resistance or temperature were monitored. EEG biofeedback or neurofeedback uses EEG signal for feedback input. It is suggested that this learning procedure may help a subject to modify his or her brainwave activity. One of the methods involved in neurofeedback training is the so-called frequency following response. Changes in the functioning of the brain in desired way, e.g. increase in alpha activity, generates appropriate visual, audio, or tactile response. Thus, a person can be aware of the right direction of the training.

Some researchers assume that subjects can improve their mental performance, normalize behaviour, and stabilize mood through the positive or negative feedback loop, while others are sceptical on these controversial issues. There are some findings indicating applications to certain range of conditions, as *attention deficit disorder, depression, epilepsy,* and *alcoholism*.

3. EEG recording techniques

Encephalographic measurements employ recording system consisting of

- electrodes with conductive media
- amplifiers with filters
- A/D converter
- recording device.

Electrodes read the signal from the head surface, amplifiers bring the microvolt signals into the range where they can be digitalized accurately, converter changes signals from analog to digital form, and personal computer (or other relevant device) stores and displays obtained data. A set of the equipment is shown in Figure 2.

Scalp recordings of neuronal activity in the brain, identified as the EEG, allow measurement of potential changes over time in basic electric circuit conducting between signal (active) electrode and reference electrode [12]. Extra third electrode, called ground electrode, is needed for getting differential voltage by subtracting the same voltages showing at active and reference points. Minimal configuration for mono-channel EEG measurement consists of one active electrode, one (or two specially linked together) reference and one ground electrode. The multi-channel configurations can comprise up to 128 or 256 active electrodes.

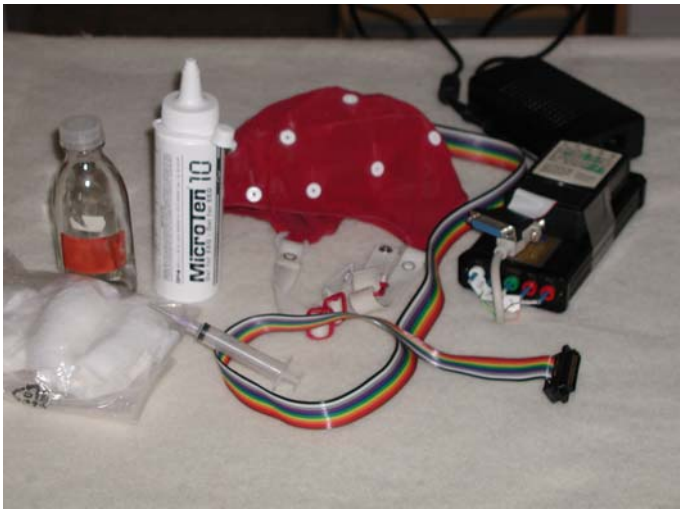

Figure 2. Equipment for EEG recording: amplifier unit, electrode cap, conductive jelly, injection, and aid for disinfection.

Recording electrodes

The EEG recording electrodes and their proper function are critical for acquiring appropriately high quality data for interpretation. Many types of electrodes exist, often with different characteristics. Basically there are following types of electrodes:

- disposable (gel-less, and pre-gelled types)
- reusable disc electrodes (gold, silver, stainless steel or tin)
- headbands and electrode caps
- saline-based electrodes
- needle electrodes

For multichannel montages, electrode caps are preferred, with number of electrodes installed on its surface (Figure 3). Commonly used scalp electrodes consist of Ag-AgCl disks, 1 to 3 mm in diameter, with long flexible leads that can be plugged into an amplifier [7]. AgCl electrodes can accurately record also very slow changes in potential [9]. Needle electrodes are used for long recordings and are invasively inserted under the scalp.

Skin preparation differs, generally cleaning of the skin surface from oil and brushing from dried parts is recommended. With disposable and disc electrodes, abrasive paste is used for slight skin abrasion. With cap systems, abutting needle at the end of injection is used for skin scraping, which can cause irritation, pain and infection. Especially when person's EEG is measured repeatedly and cap is mounted for the same electrode points, there is a threat of certain pain and bleeding. That is why the right hygiene and safety protocol should be kept.

Using the silver-silver chloride electrodes, the space between the electrode and skin should be filled with conductive paste also helping to stick. With the cap systems, there is a small hole to inject conductive jelly. Conductive paste and conductive jelly serve as media to ensure lowering of contact impedance at electrode-skin interface.

In 1958, International Federation in Electroencephalography and Clinical Neurophysiology adopted standardisation for electrode placement called 10-20 electrode placement system [13]. This system standardized physical placement and designations of electrodes on the scalp. The head is divided into proportional distances from prominent skull landmarks (nasion, preauricular points, inion) to provide adequate coverage of all regions of the brain. Label 10-20 designates proportional distance in percents between ears and nose where points for electrodes are chosen. Electrode placements are labelled according adjacent brain areas: F (frontal), C (central), T (temporal), P (posterior), and O (occipital). The letters are accompanied by odd numbers at the left side of the head and with even numbers on the right side (Figure 4). Left and right side is considered by convention from point of view of a subject.

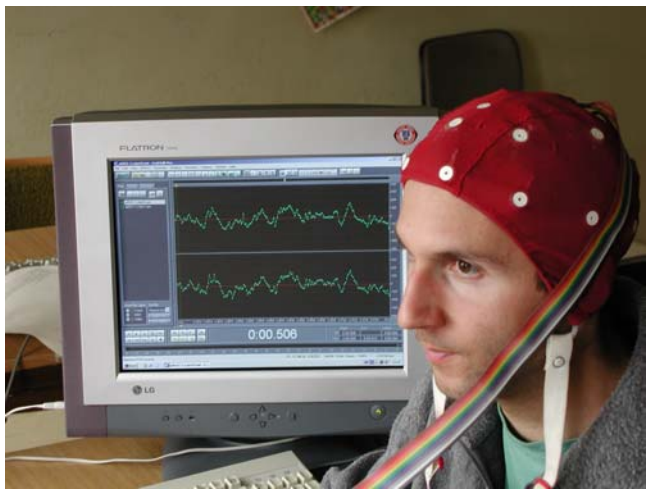

Figure 3. Electrode cap with electrodes placed after 10-20 electrode placement system.

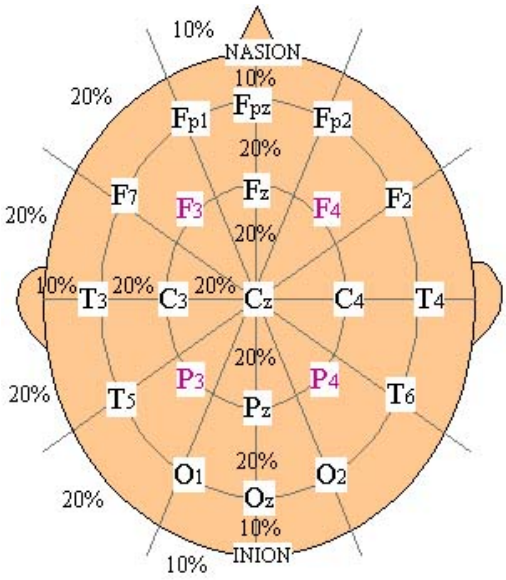

Figure 4. Labels for points according to 10-20 electrode placement system.

As it is known from tomography different brain areas may be related to different functions of the brain. Each scalp electrode is located near certain brain centres, e.g. F7 is located near centres for rational activities, Fz near intentional and motivational centres, F8 close to sources of emotional impulses. Cortex around C3, C4, and Cz locations deals with sensory and motor functions. Locations near P3, P4, and Pz contribute to activity of perception and differentiation. Near T3 and T4 emotional processors are located, while at T5, T6 certain memory functions stand. Primary visual areas can be found bellow points O1 and O2. However the scalp electrodes may not reflect the particular areas of cortex, as the exact location of the active sources is still open problem due to limitations caused by the non-homogeneous properties of the skull, different orientation of the cortex sources, coherences between the sources, etc. [4].

High impedance can lead to distortions which can be difficult to separate from actual signal. It may allow inducing outside electric frequencies on the wires used or on the body. Impedance monitors are built in some commercially available EEG devices. In order to prevent signal distortions impedances at each electrode contact with the scalp should all be bellow 5 K Ohms, and balanced within 1 K Ohm of each other. Similar standard is required for clinical use of the EEG and for publication in most reputable journals. Practically, impedance of the whole circuit comprising two electrodes is measured, but built in impedance checks usually display results already divided by two. Control of all impedances is desirable also after finishing every single measurement.

Several different recording reference electrode placements are mentioned in the literature. Physical references can be chosen as vertex (Cz), linked-ears, linked-mastoids, ipsilateral-ear, contralateral-ear, C7 reference, bipolar references, and tip of the nose. Reference-free techniques are represented by common average reference, weighted average reference, and source derivation. Each technique has its own set of advantages and disadvantages. The choice of reference may produce topographic distortion if relatively electrically neutral area is not employed. Linking reference electrodes from two earlobes or mastoids reduces the likelihood of artificially inflating activity in one hemisphere. Nevertheless, the use of this method may drift away "effective" reference from the midline plane if the electrical resistance at each electrode differs [14]. Cz reference is advantageous when it is located in the middle among active electrodes, however for close points it makes poor resolution. Reference-free techniques do not suffer from problems associated with an actual physical reference. Referencing to linked ears and vertex (Cz) are predominant.

With modern instrumentation, the choice of a ground electrode plays no significant role in the measurement [15]. Forehead (Fpz) or ear location is preferred [16], but sometimes wrist or leg is also used. The combination of all active electrodes with reference and ground electrode compose channels. The general configuration is called montage.

Amplifiers and filters

The signals need to be amplified to make them compatible with devices such as displays, recorders, or A/D converters. Amplifiers adequate to measure these signals have to satisfy very specific requirements. They have to provide amplification selective to the physiological signal, reject superimposed noise and interference signals, and guarantee protection from damages through voltage and current surges for both patients and electronic equipment. The basic requirements that a biopotential amplifier has to satisfy are [17]:

- The physiological process to be monitored should not be influenced in any way by the amplifier.
- The measured signal should not be distorted.
- The amplifier should provide the best possible separation of signal and interferences.
- The amplifier has to offer protection of the patient from any hazard of electric shock.
- The amplifier itself has to be protected against damages that might result from high input voltages as they occur during the application of defibrillators or electrosurgical instrumentation.

The input signal to the amplifier consists of five components:
The desired biopotential, undesired biopotentials, a power line interference signal of 50/60 Hz and its harmonics, interference signals generated by the tissue/electrode interface, and noise. Proper design of the amplifier provides rejection of a large portion of the signal interferences. The desired biopotential appears as the differential signal between the two input terminals of the differential amplifier [17].

The amplifier gain is the ratio of the output signal to the input signal. In order to provide optimum signal quality and adequate voltage level for further signal processing, the amplifier has to provide a gain of 100-100,000 [17] (the highest need not to be the best, combination of more parameters is involved, e.g. the range of the A/D converter, sampling rate, noise of the used elements) and needs to maintain the best possible signal-to-noise ratio. In order to decrease an impact of electrically noisy environment differential amplifiers must have high common-mode rejection ratios (at least 100 dB) and high input impedance (at least 100 M Ohms). The common-mode rejection ratio is the ratio of the gain of differential mode (wanted signal) over the gain of the common mode (original input signal between the inputs and ground).

Special electrically shielded rooms minimize the impact of urban electric background, in particular 50/60 Hz alternating current line noise. For usual medical purposes, shielded room is not necessary. For research purposes when maximal amount of information is desired, shielded room is used. Then amplifiers run on batteries and an optical cable leads to the PC standing outside from the shielded space. In addition to the optical cable, electrical/optical and optical/electrical converters are necessary. Usually information of interest lies bellow this line noise and we can use low-pass filters with cut-off bellow 50/60 Hz, or for keeping higher frequency bands a notch filter can be applied, that is able to reduce only a narrow band around 50/60 Hz (but distorts phases).

When computers are used as recording devices, channels of analog signal are repeatedly sampled at a fixed time interval (sampling interval), and each sample is converted into a digital representation by an analog- to-digital (A/D) converter. The A/D converter is interfaced to a computer system so that each sample can be saved in the computer's memory. The resolution of the converter is determined by the smallest amplitude that can be sampled. This is obtained by dividing the voltage range of the A/D converter by 2 raised to the power of the number of bits of the A/D converter [7]. A/D converter usually uses minimally 12 bits (discerning 4,096 value levels). Ability to resolve 0.5 μV is recommended [18]. Sufficient sampling rate is required, at least double of the highest frequency component of our interest.

Analog (hardware) filters have to be integrated in the amplification unit. A high-pass filter is needed for reducing low frequencies coming from bioelectric flowing potentials (breathing, etc.), that remain in the signal after subtracting voltages toward ground electrode. Its cut-off frequency usually lies in the range of 0.1-0.7 Hz. To ensure that the signal is band limited, a low-pass filter with a cut-off frequency equal to the highest frequency of our interest [7] is used (in the range from 40 Hz up to less than one half of the sampling rate). Analog low-pass filters prevent distortion of the signal by interference effects with sampling rate, called aliasing, which would occur if frequencies greater than one half of the sampling rate survive without diminishing.

Once data are stored, digital filtering can be used. The strength of the analog filters is limited thus for displaying and processing of the signals further decreasing of DC components is usually needed. It is possible to choose from linear (FIR, IIR) filtering or novel non-linear filtering methods. The choice should be done according to the objectives put on the signal processing. Predominantly finite impulse response (FIR) filters are used which do not distort wave phases. The data points width typically range on the order of 1000 and one of the window function (Blackman, Hanning, Hamming, or rectangular) should be chosen. Filters should be designed in a way to influence useful signal properties minimally.

Before performing the final measurements the whole EEG system should be tested. Inter-channel calibrations with known wave signal parameters should not display significant discrepancies. The output noise (referred to input) consists mainly from the noise caused by the analog amplifier circuitry and by A/D converter circuitry. Noise value should be consistent with manufacturer information, about 0.3-2 μV pp. (range from negative peak to positive peak) but this value depends on the way of noise estimation and on the system configuration (low-pass filter, sampling rate, choice of circuitry). The noise can be determined by connecting the inputs of the amplifier together, or abased them into a salty solution, or "short-circuiting" the inputs, and then measuring the output of the amplifier. The number of useful information bits can be counted as a power of two from the ratio of average EEG signal amplitude over the noise amplitude (e.g. 50μV/1μV results in over 5 bits).

One of the limitations of recordings is due to storage requirements. For example, 1 hour of eight channels 14-bit signal sampled with 500 Hz occupies 200 MB of the memory. There exist portable recording systems used for longer monitoring of a subject without limiting movement of a person. Some of the commercial EEG recording systems comes from following suppliers: Lexicor, Electrical geodesics, Biosemi, NeuroScan, Sigma Medizin, Contact Precision Instruments, Stellate, Thought Technology, Xltek.

Artefacts

Among basic evaluation of the EEG traces belongs scanning for signal distortions called artefacts. Usually it is a sequence with higher amplitude and different shape in comparison to signal sequences that doesn't suffer by any large contamination. The artefact in the recorded EEG may be either patient-related or technical. Patient-related artefacts are unwanted physiological signals that may significantly disturb the EEG. Technical artefacts, such as AC power line noise, can be decreased by decreasing electrode impedance and by shorter electrode wires. The most common EEG artefact sources can be classified in following way:

Patient related:
- any minor body movements
- EMG
- ECG (pulse, pace-maker)
- eye movements
- sweating

Technical:
- 50/60 Hz
- impedance fluctuation
- cable movements
- broken wire contacts
- too much electrode paste/jelly or dried pieces
- low battery

Excluding the artefact segments from the EEG traces can be managed by the trained experts or automatically. For better discrimination of different physiological artefacts, additional electrodes for monitoring eye movement, ECG, and muscle activity may be important.

Notes on experimental set-up

For data acquisition of suitable quality, a choice of the right representative group of volunteers with appropriate spectrum of demographic data and other parameters should be considered. The position of subjects during the EEG measurements should be comfortable enough to avoid unwanted activities, a lying position diminishes the occurence of some artefacts caused by feeble motion, on the other hand it may lead towards sleeping, especially when a darkened noiseless room is designed. Keeping of the same conditions and instructions for the subjects for the whole length of the experiment period is desired.

Conclusion

Electroencehalography belongs to electrobiological imaging tools widely used in medical and research areas. EEG measures changes in electric potentials caused by a large number of electric dipoles formed during neural excitations. EEG signal consists of different brain waves reflecting brain electrical activity according to electrode placements and functioning in the adjacent brain regions. For using EEG techniques, the following recording system components are necessary:

- Electrode cap with conductive jelly or Ag-AgCl disc electrodes with conductive paste.
- Amplifiers with overall amplification gain between 100-100,000, with input impedances at least 100 M Ohms, and common-mode rejection ratio at least 100 dB.
- Analog filters integrated in the unit with high pass filter with cut-off frequency in the range of 0.1-0.7 Hz and low pass filter with cut-off frequency less than one half of the sampling rate. In fact, frequencies above 50 Hz are rarely involved as they contribute negligibly to power spectrum of EEG.
- At least 12 bit A/D converter with accuracy lower than overall noise (0.3-2 μV pp.), and sampling frequency usually between 128 – 1024 Hz.
- Sufficiently quick PC for taking over data for recording and eventually for online analysis, with adequate volume of hard disc.
- Digital high pass FIR filter with similar cut-off frequency as analog high pass.

The general quality of recording equipment depends on the right combination of the mentioned parameters. Before further data processing, raw EEG signal should be checked for artefacts.

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