EE 791
EEG -1b

Recording the EEG

To record either evoked or ambient neural activity we can use an assembly of surface electrodes placed at standardized locations on the scalp known as the 10-20 system as shown in the following figure 4.28. The positions are measured on the scalp relative to the known skull landmarks, from the front at the nasion to the inion at the back of the head and side to side from the two ear canals. This allows researchers and clinicians in different labs to know standardize their measurements and reporting. The electrodes are from 5 to 10 mm diameter and for the macro recording of EEG electrode size in this range is not a factor in determining signal characteristics.
If one wants to record from the cortical surface of the brain, the dura or covering layer, or even within the cortex or deeper structures, a variety of multi-channel electrodes are available such as the shallow "pin cushion" and needle electrodes shown in the next figure. These are fabricated using microelectronic techniques and record from a single to a small number of neurons at each electrode.

Instrumentation (EEG Electrodes)

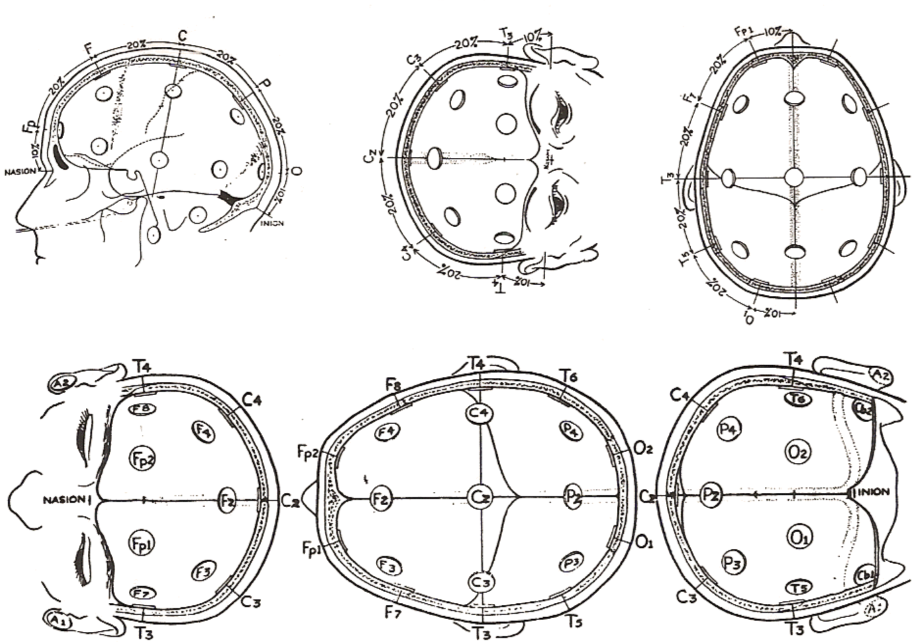


Figure 4.28 The 10-20 electrode system This system is recommended by the International Federation of EEG Societies. (From H. H. Jasper, "The Ten-Twenty Electrode System of the International Federation in Electroencepha-

From Webster (1998)

Cortical Electrodes

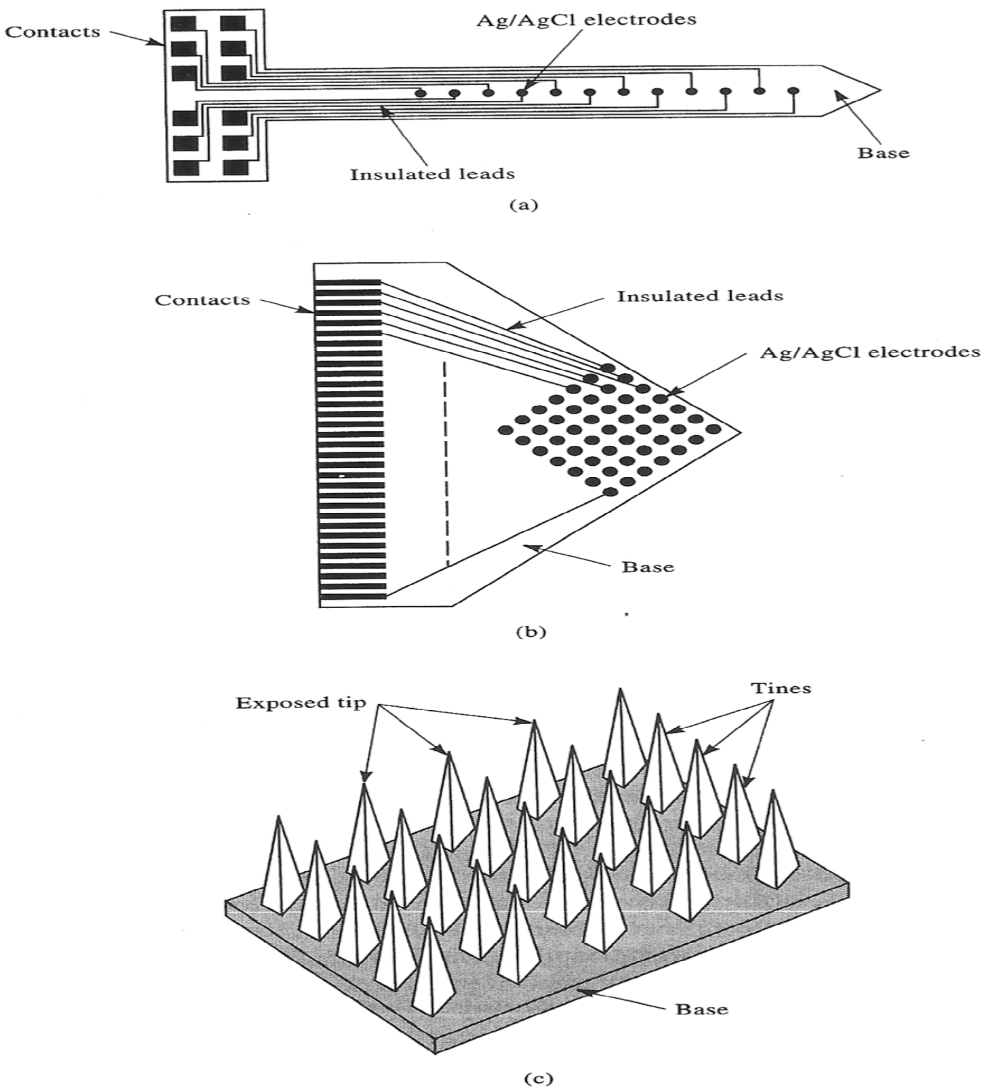


Figure 5.16 Examples of microfabricated electrode arrays. (a) One-dimensional plunge electrode array (after Mastrototaro *et al.*, 1992), (b) Two-dimensional array, and (c) Three-dimensional array (after Campbell *et al.*, 1991).

From Webster (1998)

The surface EEG signals are recorded in a multi-channel fashion using differential preamplifiers and band limiting low pass filters (0.5 Hz to e.g. 70Hz) as shown in the next figure. Since there can be very large common mode 60 Hz signals on the scalp, differential recording techniques are required with a second channel as reference and a third electronically grounded electrode attached at the neck (not shown). In the past the EEG signals were recorded on paper and analysed visually. Today they are acquired by computer (usually a PC) with a sample rate of typically 200 Hz, but still analysed mostly visually. The computer screen has only replaced the paper page. Development of signal processing techniques to extract features, and multi-channel pattern classification algorithms are ongoing areas of EEG research.

Amplifier Connections

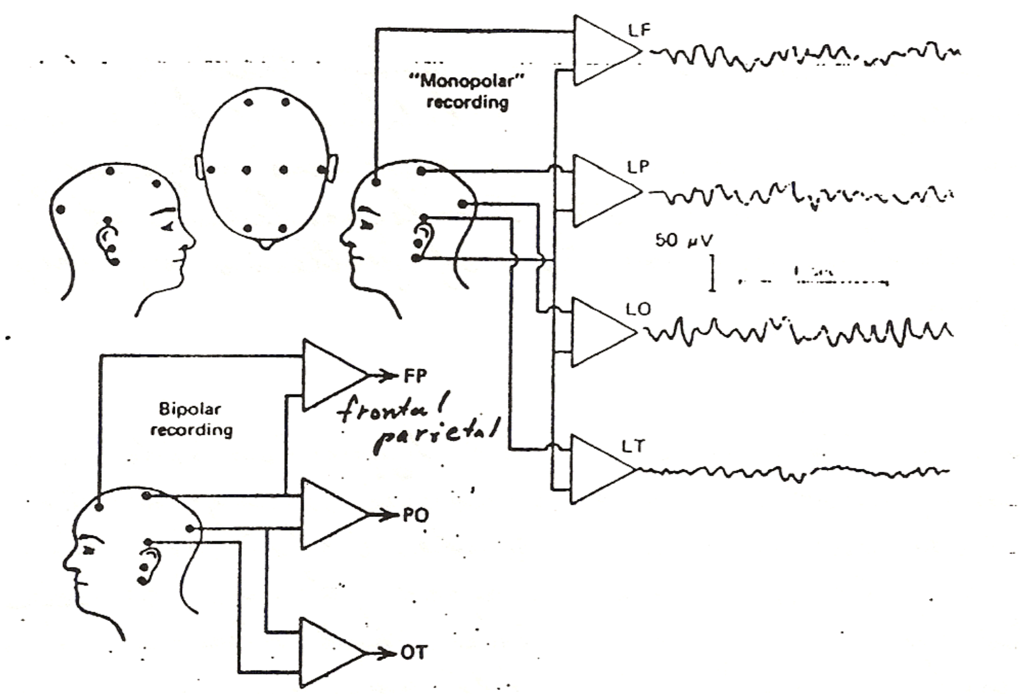


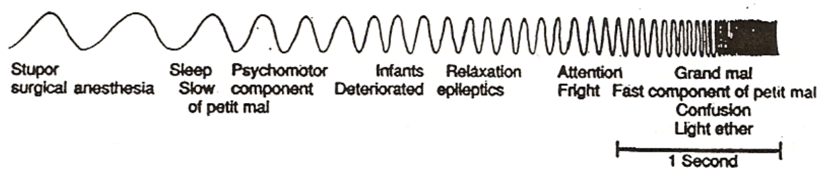
Figure 11-52. Method of connecting the recording channels for "monopolar" and bipolar recording. With "monopolar" recording, the reference electrode is on the earlobe, chin, or neck

From Webster (1998)

As a first approximation the information in spontaneous EEG is in its frequency content with the very slow components indicating depressed cortical function such as in a stupor or under anesthesia (or deep sleep, following figure) and the faster components indicating intense neural activity such as beta activity or even pathologies such as epileptic seizures. It must be stressed that in clinical applications the bandwidth characteristics and a neural state are associative and little is understood how such clinical states result in the recorded EEG. This question is a very fruitful area of further research, and new single and multi-channel signal processing and pattern recognition strategies should shed some light.

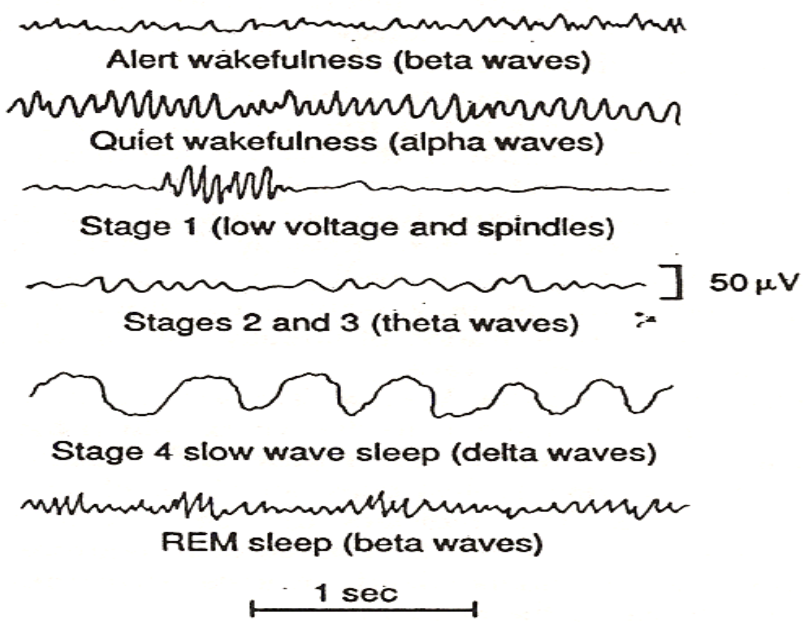
Clinical Applications (Spontaneous EEG)

Figure 59–3. Effect of varying degrees of cerebral activity on the basic rhythm of the electroencephalogram. (From Gibbs and Gibbs: Atlas of Electroencephalography, 2nd Ed. Vol. I. Reading, Mass., Addison-Wesley, 1974. Reprinted by permission.)



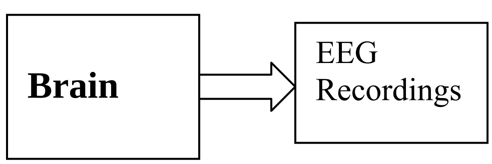
- Identify presence of lesions (historical)
- Diagnosis and monitoring of epilepsy (seizures)
- Sleep staging
- Estimation of depth of anesthesia
- Other organic brain disease
- Neuropsychiatry (depression, schizophrenia, Altzheimer)

Sleep Staging

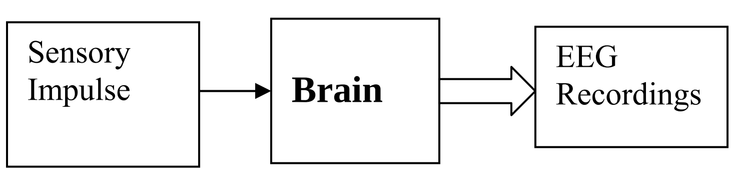


Brain Evoked and Event Related Potentials

These are special uses of the EEG signal and are not limited to the bandwidth of normal EEG (1 Hz – e.g. 70 Hz) recorded while the subject sits still. In engineering terms EEG is just monitoring a multi-output system with no controlled inputs.



Evoked potentials use the more common approach where you determine the transfer function (characteristics) of a system by driving it with a known input (physiological impulse) and measuring the output. We can use the sensory inputs to the brain to stimulate it with one input, hopefully keeping the other inputs constant or 0.



Brain Stem Auditory Evoked Potential (BSAEP)

The complete auditory response is shown in the following figure, with the BSAEP in the first 10 msec, and the more cognitively affected event related potentials (ERP) shown in the 100's of msec range. This evoked potential (EP), is the output of the auditory pathways of the brainstem (auditory nuclei) to supra threshold "clicks" presented to the ear of the subject. It is a subset of the entire brain auditory response shown in the following figure and occurs within approximately the first 10 ms. Because of this very short latency, it is not confounded by any auditory cognitive processing and is therefore considered a true EP and assumed to be deterministic, changing neither in shape or time of occurrence relative to the time of the stimulus. However, because it is generated by the brainstem it has a very small amplitude, typically less than500 nV due to the small size of the auditory nuclei and the distance between the brainstem and the scalp surface at C_z. The later components of the auditory response (latency > 10 ms) are generated by the auditory cortex and therefore have longer durations and higher amplitudes as shown.

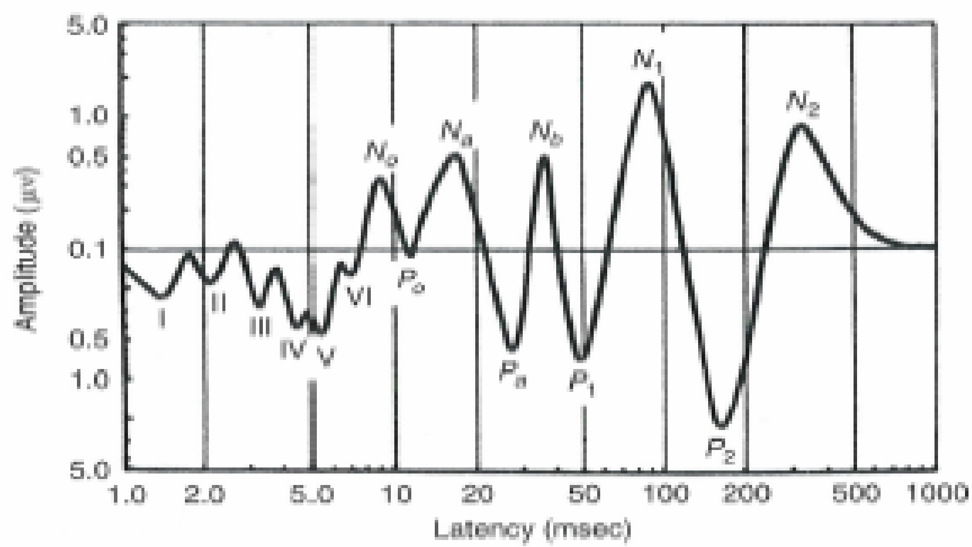
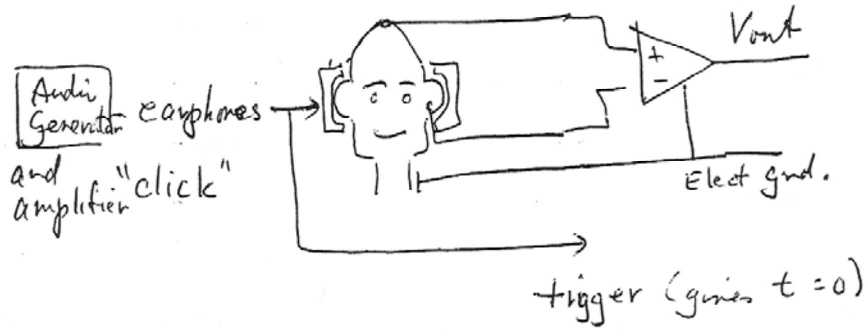
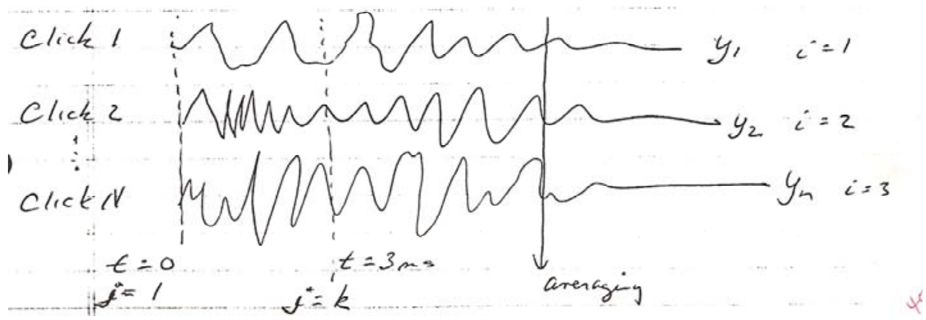


Figure 1-17 The auditory evoked potential waveform as recorded from the human scalp. A subject is presented with a series of up to several thousand tones or clicks and the time-locked EEG is averaged over the stimuli to remove the (much larger) spontaneous EEG. The first few ms of the waveform is also known as the brainstem averaged evoked response (BAER). Physiologists have assigned standard labels to each peak (N_1, P_2, and so forth). Reproduced with permission from Picton et al. (1974).

From Nunez and Srinivasan 2006



Clicks are sent to the ear at amplitudes above threshold where increases in the click amplitude do not affect the BSAEP amplitude or shape. They are delivered at a rate of 10 Hz. For each click the auditory signal is conducted along the cochlear (auditory) nerve to the brainstem which lies deep in the skull under the cerebrum. It is then sent on via additional synapses and pathways to the auditory cortex in the superior gyrus (fold) of the temporal lobe. The BSAEP is used to determine the health of the brainstem in those patients with neurological disease or suffering from neural trauma such as a stroke or head injury. It is also used to determine if the hearing apparatus, including the cochlea is healthy, and since the test requires no cognitive response from the subject can be performed on very young children in the first months of life to determine deafness. This is very important since the best results when implanting hearing technology such as the artificial cochlea are achieved when the implant is done at a very ealy age when the auditory cortex is still developing in the child. V_{out} in the above figure is a sum of the BSAEP, physiological noise such as cortical EEG, and environmental and instrumentation noise. The BSAEP has a bandwidth of 150 Hz to 2500 Hz (well above the bandwidth of ambient EEG but is in the amplitude range of hundreds of nanovolts, which is well below the input instrumentation noise of all amplifiers. Even by filtering out most ambient cortical EEG and any remaining environmental noise (almost all 60 Hz is removed by the differential amplifier by its common mode rejection) using a bandpass filter from 100 Hz to 3 KHz, we are still left with the broadband instrumentation noise in the µvolt range. Therefore the signal to noise ration in db is negative. There are no sophisticated signal processing techniques available to reliably extract the BSAEP from the much larger noise signal. The current commercial technique is ensemble or synchronous averaging. This requires that the clicks are repeated over time (BSAEP clicks at 10 Hz) and the response recorded for each click as shown below.



Each click i , i = 1 – N, results in the recorded signal y_i which contains both the BSAEP and noise. Time 0 is the time of the click or impulse. Averaging requires that the signal be sampled over time, using a sample rate of 50 KHz resulting in approximately 500 samples for the 10 msec of recording. The sample index j then goes from 1 at time 0 to 500.

The output for click i can be represented by

$$y_i = s_i + n_i$$

where s_i is the BSAEP and n_i is the additive noise. In the sampled data response we can write

$$y_{i,j} = s_{i,j} + n_{i,j}$$

where $y_{i,j}$ is the jth sample for the ith response.

If we ensemble average the N responses we get

$$1/N\sum_{i=1}^{N} y_{i,j} = 1/N\sum_{i=1}^{N} s_{i,j} + 1/N\sum_{i=1}^{N} n_{i,j} \qquad \text{eqn 1}$$

If we make the following assumptions:

- the BSAEP is deterministic and invariant for any i ($s_{i,j}$ is constant for each i)
- the noise is random for each i and uncorrelated from stimulus to stimulus
- the noise has zero mean (usually valid for instrumentation noise since the signal is high pass filtered

Then the $n_{i\,j}$ term in equation 1 goes to 0 if N is large enough and the $s_{i,j}$ terms becomes simply s_j . The ensemble average of the recorded output then is only the BSAEP. Notice, no assumptions have been made about the noise characteristics or statistical properties other than it is random and uncorrelated. We do not know whether the BSAEP is constant from stimulus to stimulus since single BSAEP have not been measured except in rare occurrences. Studies using sequential ensembles of 100 have shown that there can be small variances in the average BSAEP but these changes are not consistent with time. The assumption of a deterministic BSAEP is consequently still generally accepted. In general, instrumentation noise and the background high frequency EEG have zero mean, and are random and uncorrelated so most of our assumptions are valid. However, in other applications of ensemble averaging of electrophysiological signals, the stimuli can be delivered by electrical or magnetic pulses and $n_{i,j}$ then may include the stimulus

artefact which is not random and is correlated to the desired EP. Ensemble averging will not remove the stimulus artefact and indeed has no effect on it. Other means have to be found to remove this artefact.
Although the averaging technique is very robust because it makes few assumptions, it is also quite inefficient requiring a great many stimuli if the SNR is very poor. In the case of the BSAEP, N is usually 2048 requiring more than 200 seconds of 10 Hz clicks. If the noise is assumed to be Gaussian zero mean, the SNR improves with $\sqrt{N}$. For non Gaussian noise such as large muscle or other artefacts, the performance is seriously degraded. However, large artefacts can be detected by an amplitude discriminator and that particular y_i then discarded prior to including it in the average.

Evoked responses associated with the other sensory systems, such as visual and somatosensory can also be derived using ensemble averaging with N determined by the SNR. Other EPs or ERPs can be obtained by directly stimulating regions of the brain using magnetic stimulation and this field is just beginning.