CHAPTER 3

SIGNAL AVERAGING TECHNIQUE

Averaging is a time domain analysis to extract signals embedded in noise. As averaging progresses, the noise level reduces and the signal emerges. When averaging is carried out 'N' times, the regular and repetitive signal reaches the value equivalent to 'N' and the noise is reduced to root N times. The electrical data to be analysed for eliciting the evoked potential components comprising of the background electrical activity and the evoked potential. The evoked potential components occur at regular intervals with respect to the stimulus onset whereas the background electrical activities are changed in frequency and amplitude. For example the background noise signal with different sweeps are selected from a continuous waveform. If we take a specific point in time domain of all sweeps, the amplitude at that point, in the time domain of each sweep will vary, and when they are averaged, the mean level be less than the highest amplitude measured. Since the evoked potential respects in the same gap while it is averaged, the magnitude remains the same. So averaging technique is one of the important feature in the study of evoked potentials. An evoked potential is an electrical manifestation of the brain’s reception and response to an external stimulus. Most evoked potentials cannot be seen in routine EEG recordings. This is because of their low amplitudes (0.1-10 μv) and their admixture with normal background brain wave activity and various artifacts that together are from twenty to several hundred microvolts in amplitude.

Separation of the buried evoked potential waveform from the other electrical activity as discussed above is accomplished by signal averaging technique. In this method the stimulus is given many times and the brain
signals for the duration of interest immediately. Following are summed and then divided by the number of presentation to obtain the average evoked potential. This technique makes significant improvement of the signals to noise ratio and permits the recording of very small evoked potentials. This is conveniently done using computer by means of software. The amplitude of the brain wave is sampled at a series of consecutive discrete points in time shortly before and after the stimulus. The amplitude at each of these points in time are stored as numbers in particular locations. The sampling process is known as digitizing and is done with analog to digital converters. The more sampling is done on amplitude and time scale the more accurate will be the reconstruction of the brain wave from the digitized values. Each of the particular section of the digitized wave is called a trail and the number of trails is often referred to as N. The values are measured at corresponding time from the respective N trails and are added together to obtain the sum for each points. If the sum is divided by the number of trails, the average is obtained and is plotted as a graph against time. For a constant evoked potential the signal is mixed with background activity which varies from trial to trial (the noise). When a number of trials are added together and divided by N the evoked potential becomes the same as in each trial but the average of the background activity has decreased by the factor root N and the evoked potential is distinguished by the decreased background activity (Binnie et al., 1982).

In evoked potential recording the number of trails required in any particular average is primarily determined by the ratio of the amplitude of the expected response to the amplitude of the background activity, that is, the signal to noise ratio. For example when the response is small (1µv) and the background activity is large (40µv) the 1600 trails are needed to reduce the 40µv background activity to 1µv (√1600 = 40) and it is about the size as the residual noise and more trails will be necessary before the evoked potential can unequivocally be seen. The number of trails, selected for subcortical evoked potentials are from 1000 to 4000 and for cortical from 50
to 200. In Brainstem Auditory Evoked Potential (BAEP) recording to test waveform consistency at least averaging of 1000 trials are usually recommended and the test may be repeated two to four times to arrive at a good measure of response variability. Rowe, (1981), suggested that the variability between the test should be less than 0.1 to 0.2 m sec for interpeak latency measurements before the test can be considered technically satisfactory whereas Stockard, (1976) recommended 0.08 msec. Chaippa, (1978) reported the averaging between 1600 to 2500 trails will be adequate to produce good BAEPs. So, theoretically the number of responses required depends on the relative amplitude of the responses and of the noise. In practice, the number should be large enough so that the two successfully evoked average potentials can be superimposed without significant differences. The length of the interval to be averaged is usually 20 millisecond for early latency BAEPs which occurs within 10 milliseconds for the onset of stimuli. In principle the sweep should be long enough to include all important parts of the evoked potential with sufficient resolution of detail.

3.1 PRINCIPLE OF AVERAGING

Auditory evoked potentials are small and obscured by EEG, ECG, muscle activity and other noises. So individual response cannot be clearly distinguished and seem to fluctuate in repeated recordings. Averaging is done by giving auditory signals repeatedly and by collecting and adding each response to the proceeding ones and dividing the sum by the number of response. This procedure enhances the signals by reducing the noise towards minimum level. The period of analysis is started by a trigger pulse from the stimulator after the onset of the stimulus. The period and the size of signal must be long enough to include all the peaks under study.
3.2 AVERAGERS

3.2.1 Number of Channels

Most averagers have 2, 4, 8 or more channels from which the operator can select the number of channels needed for the Evoked Potential (EP) study. In most of the averagers the number of addresses per channel is constant. The multichannel option may be used to record evoked potentials either simultaneously from different areas or successively from the same area. Successive recordings are often made to evaluate the reproducing ability of EPs or to study Evoked Potentials to stimulation of both ears. Such recording can be compared directly by superimposing the EPs on the oscilloscope screen and measuring them with cursers.

3.2.2 Triggering

The average responses to successive stimuli, each epoch must be started at the same time with respect to the stimulus. There are three choices of starting points for the arrangement of transient EPs. Not all of them are available on every averager.

1. Triggering at the onset of the stimulus is the most commonly used method. It includes in the average most of the stimulus artifact and the earlier part of Evoked Potential.

2. Prestimulus triggering includes a period of recording before the stimulus.

3. Post stimulus triggering can be used to eliminate from the evoked potential a period between stimulus and the onset of the response. When this period is very long.
Steady state evoked potentials are most commonly averaged by triggering the computer at the onset of one of the repetitive stimuli. The responses to the first few stimuli may undergo adaptive changes before a steady state is reached. Therefore, collection of steady state evoked potential is started after several stimuli had been given.

3.2.3 Number of Responses to be Averaged

The number of responses is selected with a sweep counter. It stops the acquisition of data after a preset number of sweeps needed for an evoked potential. It can be determined on the basis of practical and theoretical considerations. In practice the number of responses collected should be large enough so that the average evoked potentials do not differ from each other. The number of epochs averaged equals the number of stimuli and of responses in case of transient EPs. But steady state EPs require large number of stimuli. Theoretically, the number of epochs required depends on the ratio of the amplitude of stimulus locked components in the recording of the signal or the noise. Long periods of recording should be avoided because they affect the characteristics of signal or noise. Each EP should be recorded at least twice. They are superimposed to ascertain and they resemble each other closely enough in latency, amplitude and shape.

3.2.4 Time and Amplitude Analysis

Time and amplitude are the major measurements in signal analysis. The choice of time analysis depends on the duration of evoked potential under study. The signal period under study must be long enough to include all the important peaks of the evoked potential. In the brainstem auditory evoked potential, the most common analysis periods are 20 milliseconds and the main requirement in selecting the time parameters (analysis period, number of bins and sampling rate) of analysis are given below:
1) The analysis period must be long enough to include the important peak of the evoked potential to be studied.
2) The sampling rate must be sufficient enough to resolve the highest frequency of evoked potential peaks.

In signal analysis amplitude is another parameter that may vary with different technical and physiological factors. In signal average the sampled signal from the output of digitizer or ADC is measured the number. However the amplitude of the signal reproduced digitally depends on the signal size end the number of discrete verticle measurements.

3.2.5 Recording Parameter

The type of equipment available to obtain an averaged evoked potential varies from large general purpose computers. They can average 16 or more channels simultaneously to small special purpose device that will produce a single average evoked potential. In this study the evoked potentials are recorded from the subjects using EEG setup and NICOLET evoked potential system with 16 channels. In case of BAEP recording, sometimes only one channel is used to record response between the vertex and stimulated ear. Then otherwise two channels between the vertex and stimulated ear, between vertex and nonstimulated ear. In this regard 2048 clicks, mostly rarefaction clicks and rarely, condensation clicks (discussed in detail in chapter 6) are applied to one or both the ears. The rate of stimulus in clicks per seconds are selected as 20 pulse per second. And about 5 to 100 pulse per second are selected in some application. The stimulus intensity used were 90 db in most recording and from 40 db to 90 db in some application. The contralateral ear is always masked with 25-30 db less then stimulated ear. It takes around 20 minutes to record during stimulation and overall the experimental period will takes nearly one hour for recording the response with two trials, including the patient and equipment preparation.
The number of trials required in any particular average is primarily determined by the ratio of the amplitude of the expected response to the amplitude of the background activities, that is the signal to noise ratio. In the case of evoked potentials where their amplitudes are less than 1 µv, about 2000 trials are needed to reduce the background activities of around 50 µv in amplitude. Among other factors to be considered in choosing the analysis time to average a particular evoked potentials are the duration of the evoked potential and the number of sampling points required faithfully to the higher frequency components. At the very least the sampling rate of the analog input should provide not less than two and half sampling points (Oppenheim et al., 1991) to define the period of the fast frequency. This critical sampling rate is called the nyquist frequency. The waves having a frequency of about 2000 Hz or more (as in BAEPs waveforms components, chapter 7) required a sampling rate of more than 4000 points per second. In practice, it is better to have a higher sampling rate than the theoretical one. If the sampling rate is not sufficient, the aliasing errors are likely to occur in which the factor frequencies in the analog input are apparently represented as slower frequencies in the digitized version. The present averagers can digitize at more than the needed rate. The system used in this work with a sampling rate of 8KHz is enough to avoid the aliasing error in the data. How well the amplitude of the evoked potential is digitally reproduced depends on the number of bits per sample in the computer's analog to digital converter. This fix the number of distinguishable voltage levels which can be recorded and is likely to be eight bit or more.

The data from the output of the analog to digital converter that is, the amplitude at each point in time are stored as the numbers in particular memory locations (address) in the averager. There is an address for each of the sample points. The number of samples for each trials are stored in the memory locations continuously. The amplitudes measured at the discrete time are not exactly a whole number, and it is rounded to the nearest number. So after starting the sampling, the values measured at
corresponding time point on each trials are added together to obtain the sum for each point and stored in separate memory location. After completion of the sum for N trials and all samples, the sum of each point is divided by the number of trials. The results are the average of each point corresponds to sample points on time scale. Two trials of this recording are needed, to be super imposed on each other to make sure that the recorded evoked potential is perfect.

3.3 AUDITORY STIMULATION

3.3.1 Methods of Applying Stimulus

Clicks are commonly used to test the integrity of the auditory pathway. In general, they tend to produce larger and well defined evoked potential than tone bursts or pips. The usual method of producing a click is to feed a short duration monophasic square wave into the earphone or loudspeaker. The earphones used are usually of moving coil or electrodynamic type which has low impedance at high stimulus intensities. It generates electromagnetic fields which induce stimulus artifacts that may require shielding of earphone (Boston et al., 1979) with mu metal Hughes et al (1980) with a piezoelectric earphone observed a wave peak of 0.7 msec before wave I which they suggested that this wave might be a cochlear or auditory nerve potential. The coupling between earphone and ear can significantly change the BAEP wave form and that is reported by Coats et al (1980).

3.3.2 Stimuli Details

The stimulation of the ear in clinical application and experimental studies were reported by various workers (Portman et al., 1983, Aran et al., 1983). In auditory evoked potential several types of stimulus are used (Davis, 1976, Arlinger, 1981). The preferred stimulus for the clinical neurologic investigation of cochlear nerve and brain stem auditory pathway is a click. It is produced by delivering an electrical square pulse of 100 to
200 µsec. duration into a standard audiometric earphone having a relatively flat frequency spectrum (Coats et al., 1980) thus, deflecting in the earphone membrane. The earphone membrane reacts to the square pulse and generates a pressure change. This conversion from the electric square pulse into an acoustical waveform results in sound pressure wave which consist of a major wave, followed by smaller highly damped oscillations of alternating polarity that may last upto 2 msec. or longer with a peak acoustic frequency of 500 to 4000 Hz which depends on the pulse duration and mode of earphone. In this work a NE555 monolithic timing circuit is used to generate the square pulse, which is highly stable controller, capable of producing accurate time period. Two potentiometers are used to adjust the click intensity and rate whenever necessary.

The use of click stimuli is very satisfactory for neurological studies because they produce sudden excitation resulting in a well defined evoked potentials. However clicks are not very suitable for audiological studies because they contain a wide range of tone frequencies. They act mainly by the virtue of their high frequency content and do not test the lower frequency range which is important for speech. Stimulation with tone of lower frequency is desirable for audiological purposes but creates several problems and remain a poor stimulus for elicitation of BAEPs. The receptors for low tones are located in the apical part of the cochlea and are not easily exposed by BAEP method. This is due to the longer travel of sound waves to the apex of the cochlear, response to low tones are elicited later than responses to high frequencies, which excite basal part of the cochlea. And also due to low frequency sound waves which have a long duration. The responses are dispersed in time and have low amplitude. Response to the low frequency contents of an auditory stimulus are therefore easily observed by the earlier and large response components generated by the more basal parts of the Cochlea. Study on the effect of click intensity on different portion of auditory pathway is one of the main objective of this study which is explained in detail in later chapter.