during deep sleep stages and in infants as irregular activity; Theta (4–7 Hz) rhythm which is encountered in early sleep stages and drowsiness; Alpha (8–12 Hz) rhythm which is the typical rhythm during relaxed state with eyes closed (it is suppressed with eye opening); Beta (13–30 Hz) rhythm which is prominent during stressful situations and Gamma (> 30 Hz) rhythms, which are believed to be involved in higher order functions of the brain.

In usual practice, EEG signals are recorded on multiple locations on the scalp using electrodes placed at specific points. The International Federation of Societies for Electroencephalography and Clinical Neurophysiology has recommended the 10–20 system of electrode placement, which consists of 19 actives electrodes plus two reference (linked to earlobes or mastoids). The distance between each electrode is either 10% or 20% of the total edge distances (e.g. nasion-inion), hence the name 10–20.

Figure 7 shows the 10–20 system of electrode placement, where the letters A, C, F, O, P, and T denote auricle, central, frontal, occipital, parietal, and temporal, respectively4. Odd and even numbering are used for the left and right sides, respectively. Midline electrodes are numbered with Z, representing zero. Nowadays, it is common to extend this 10-20 system by placing electrodes in between thus arriving at 32, 64, 128 and even 256 channels!.

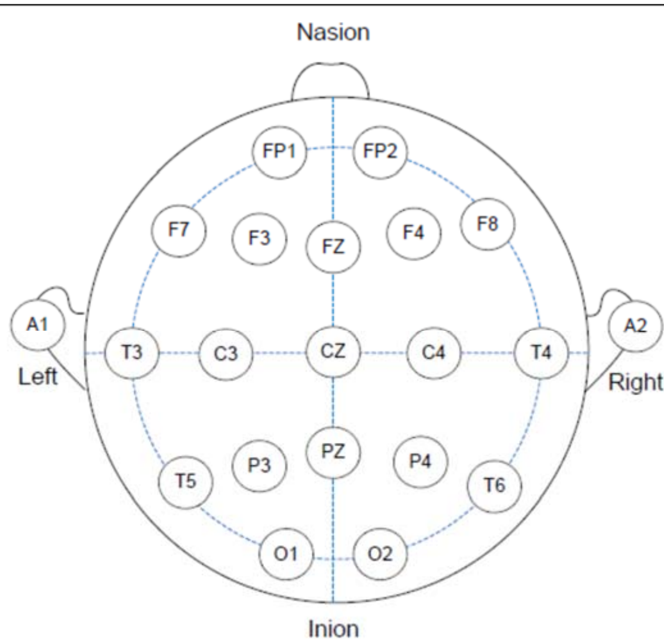
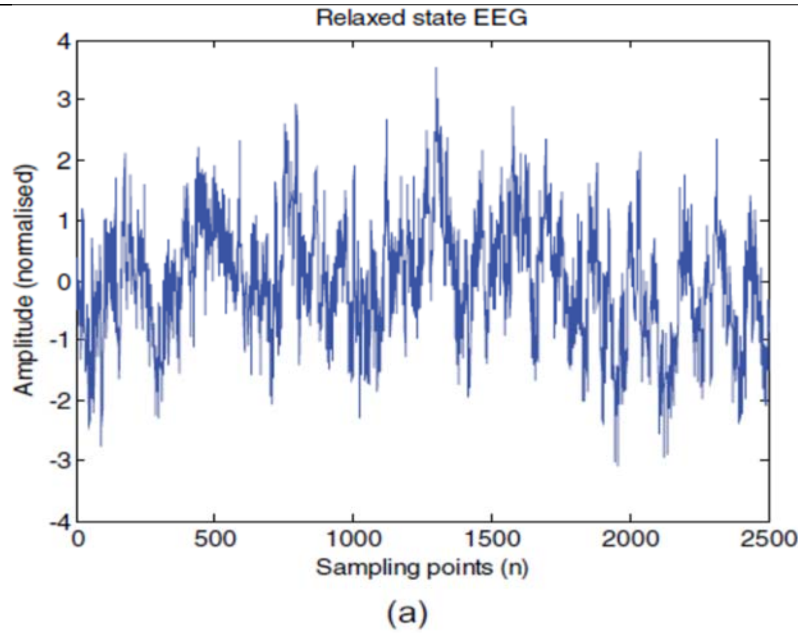


Figure 7: Neuron and its interconnections.

Figure 8 shows examples of EEG signals extracted from a subject while resting and performing an active mental task (non-trivial computing task). Visually, both these signals appear to be just noise but in later chapters, it will be shown that both these signals can be discriminated effectively for use in a brain-computer interface application.



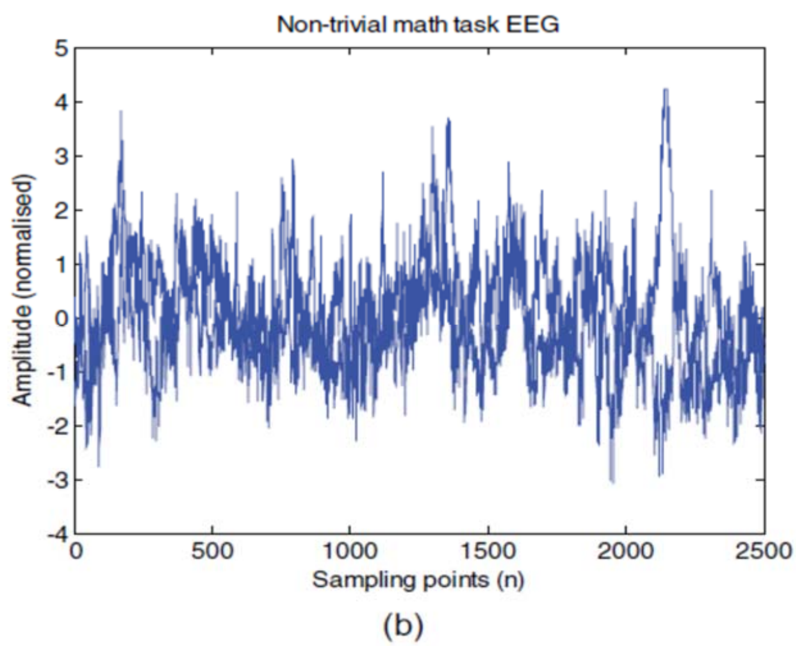


Figure 8: EEG signals during: (a) relaxed state (b) non-trivial math task.

Electromyogram: -

Electromyogram (EMG) is recorded by an electromyography device, which measures the muscle's electrical potential. The central nervous system consisting of the brain, spinal cord and peripheral nerves controls the action of the muscle fibers that typically results in movements. Muscle is composed of specialized cells that are capable of contraction and relaxation and is controlled by simulations from innervated motor units (neurons).

EMG can be recorded by two methods: surface EMG (SEMG, which records EMG using electrodes placed on the skin) which is more popular than intramuscular EMG (a needle electrode is inserted in the muscle) as it is non-invasive. SEMG measures the muscle fiber action potentials of a single (or more) motor unit, which are known as the motor unit action potentials (MUAPs). The actual potential is about 100 mV but due to the layers of connective tissue and skin, the SEMG is a complex signal with much less amplitude (typically about 5 mV). Figure 1.14 shows an example of a SEMG signal.

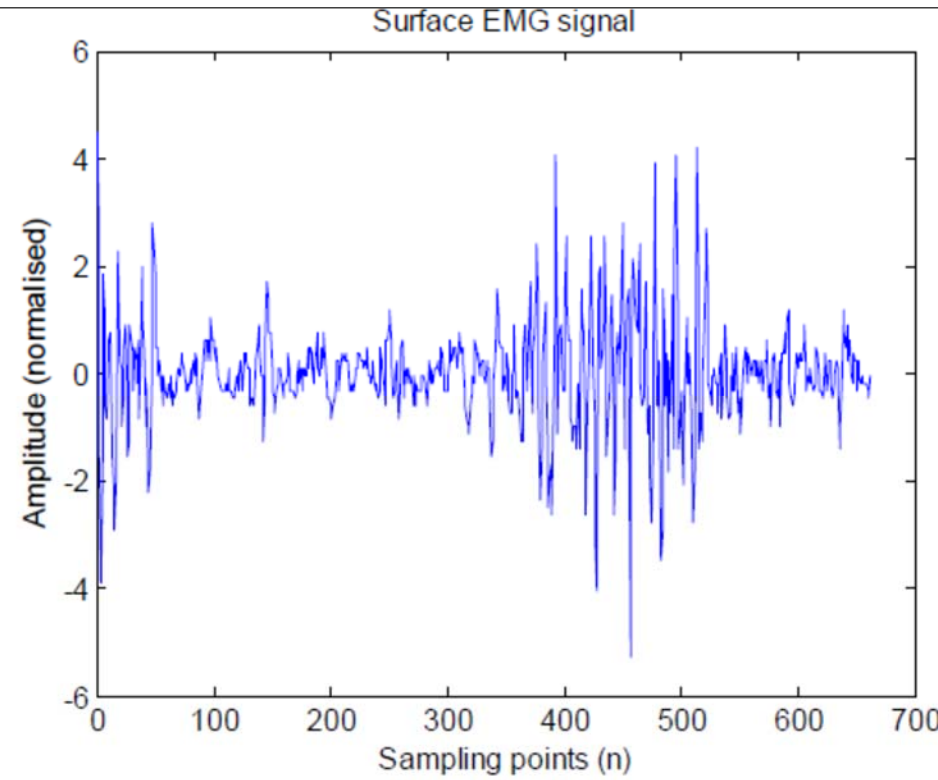
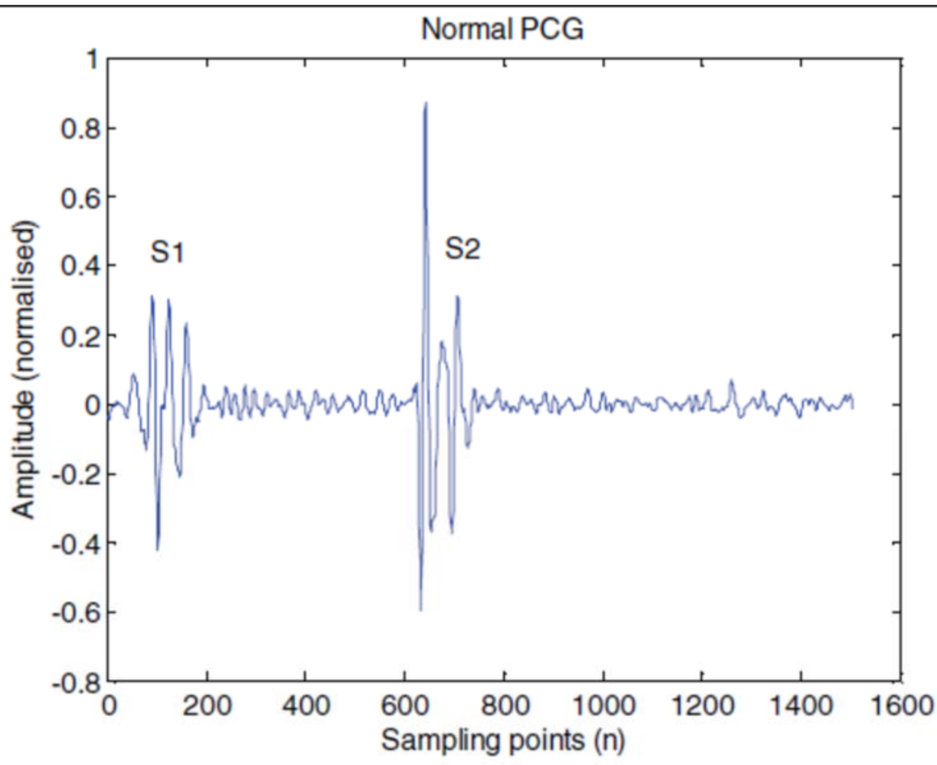


Figure 9: Typical surface EMG signal.

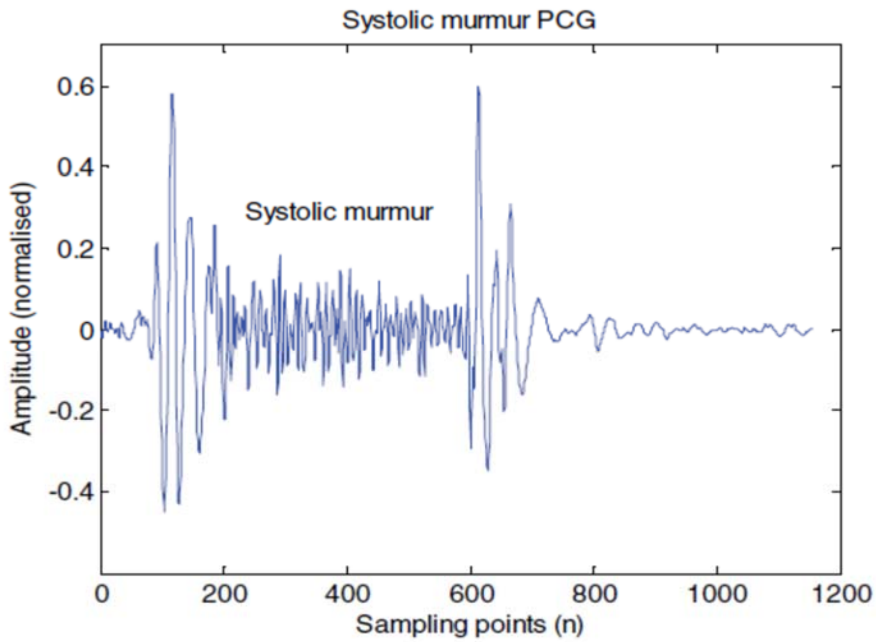
Phonocardiogram

Phonocardiography is the vibration or sound of the heart when it pumps blood. Though the common cardiac analysis centers on ECG, phonocardiography can provide complementary valuable information concerning the function of heart valves and the hemodynamics of the heart as ECG can only detect faults in heart's electrical system.

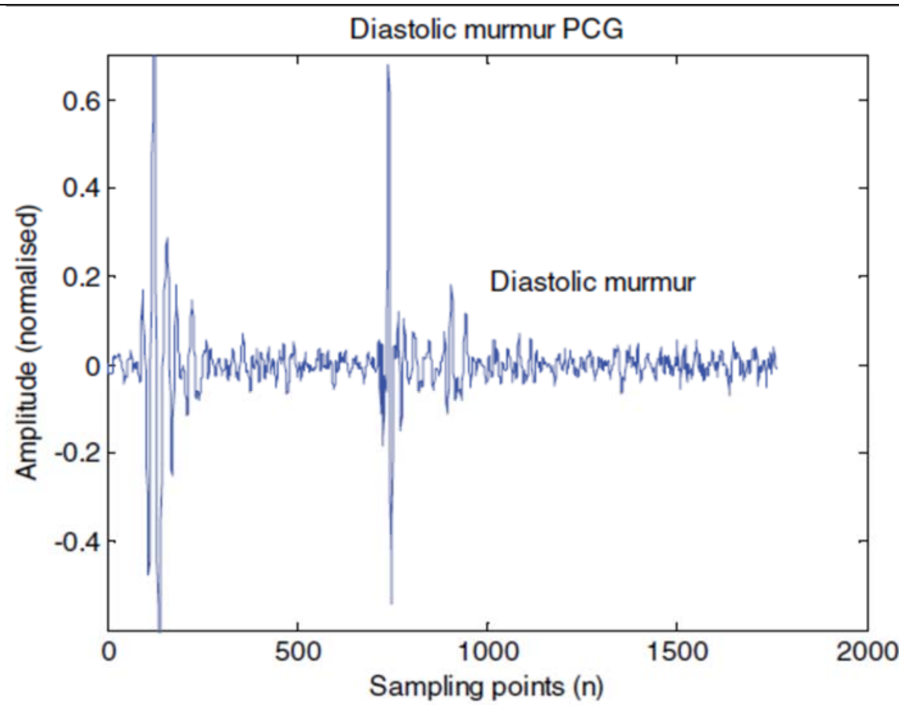
The phonocardiography of a normal heart comprises of two distinct activities namely the first heart sound, S1 and the second heart sound, S2, which correspond to the 'lup' and 'dup' sounds, respectively. An abnormal heart, on the other hand, includes several other activities between S1 and S2 sounds. These abnormal sound activities (like S3, S4, murmurs, clicks and snaps) are useful in diagnosing heart diseases. Nowadays, the sound waves produced by the heart are not only heard using a stethoscope but also observed as phonocardiogram (PCG) signals on a monitor screen. Figure 10 shows PCG signals for a normal heart, systolic murmur (SM) and diastolic murmur (DM).



(a)



(b)



(c)

Figure 10: Typical surface EMG signal.

Other Biological Signals: -

There are many other biological signals such as arterial blood pressure signals (ABP, shown in Figure 11) generated by changes in blood pressure which are recorded on the upper arm (units-mmHg); electrooculogram (EOG) signals, which measure the eye movements and oxygen saturation (SpO2) signals which measures the level of oxygen in blood. It is common to perform a multimodal signal analysis, where more than one signal modality is recorded. This is useful to perform a more thorough diagnosis. Figure 12 shows a typical example where three ECG leads, arterial pressure, pulmonary arterial pressure, central venous pressure, respiratory impedance, and airway CO2 signals are recorded from a subject.

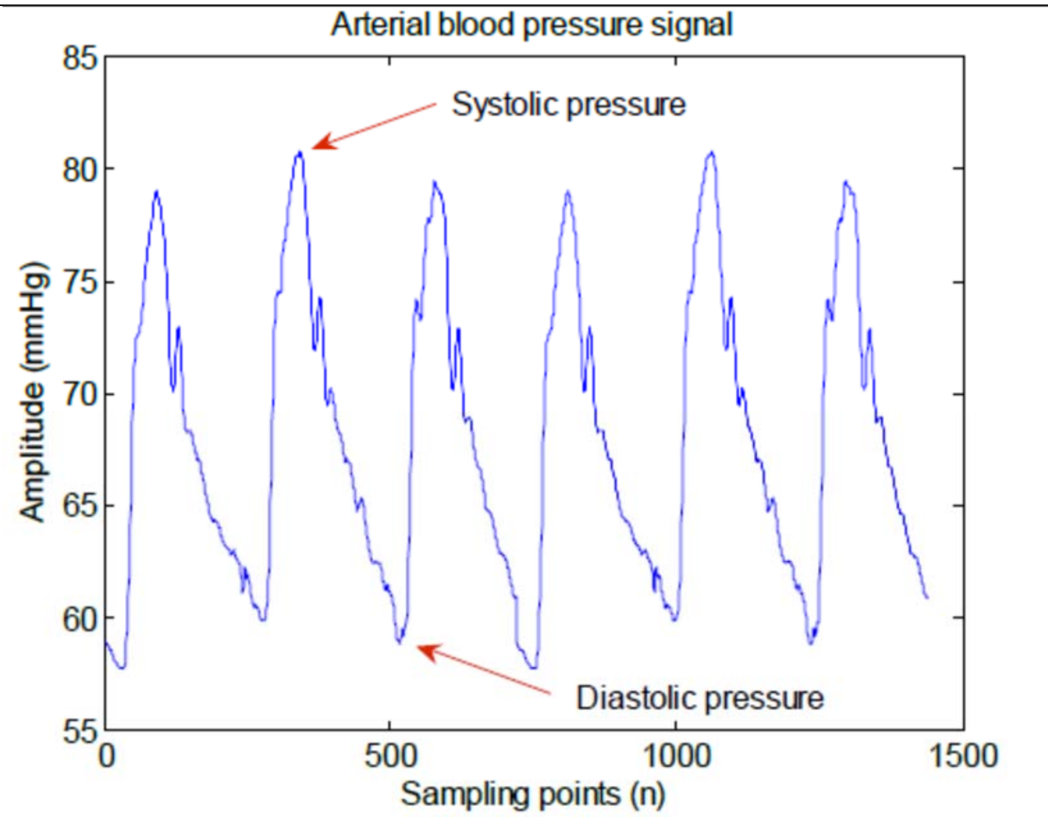


Figure 11: Arterial blood pressure signal.

Figure 12: Multimodal data from MGH/MF database.

References:-

1. "Biological Signal Analysis" by Ramaswamy Palaniappan.
2. "BIOMEDICAL SIGNAL ANALYSIS" by RANGARAJ M. RANGAYYAN.