NON INVASIVE MODALITIES OF NEUROCOGNITIVE SCIENCE USED FOR BRAIN MAPPING: A REVIEW

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Abstract

The brain plays a pivotal role in the study neurocognitive science. It is the seat of intelligence and is a complex organ which is being widely studied. Although mapping different areas of the brain has been carried a lot still remains for the study of cognition. Various non invasive modalities used for brain mapping are classified according to the measurement techniques used. Electromagnetic Technique uses two modalities for studying electromagnetic and electrical activity of the brain EEG (Electroencephalography) MEG (Magnetoencephalogrphy).Whereas hemodynamic technique uses recording of hemodynamic activity of the brain, these modalities are MRI (Magnetic Resonance Imaging).fMRI (functional Magnetic Resonance Imaging) PET (Positron Emission Tomography), SPECT (Single Photon Emission Computed Tomography) NRIS (Near Infrared Spectroscopy). Hemodynamic techniques like MRI, fMRI, PET and SPECT provide excellent spatial resolution while electromagnetic modalities provide excellent temporal resolution .This paper explains various noninvasive modalities, their working principle and a comparative study of all the modalities.

Index Terms: *modalities, spatial and temporal resolution, Radionuclide, Artifacts*

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1. INTRODUCTION

Development of research methodology, especially non-invasive structural and functional neuroimaging methods, plays a pivotal role in cognitive neuroscience. In 1924 German neurologist recorded EEG signals. He used the word electroencephalogram for brain signals.EEG imaging technique is simple economical. Clinical applications of EEG [1-4] (a) monitor health, coma and brain death; (b) phrenological studies of head injury, stroke, tumor, etc.; (c) brain mapping by evoked potentials (d) monitor cognitive engagement (e) produce biofeedback situations, study of alpha waves etc.; (f) control anesthesia depth ("servo anesthesia"); (g) investigate epilepsy and locate seizure origin; (h) test epilepsy drug effects; (i) assist in experimental cortical excision of epileptic focus; (j) monitor human and animal brain development; (k) test drugs for convulsive effects; (l) investigate sleep disorder and physiology.

Brain imaging is developed in 1990's and has helped in observing changes with patient's brain for various physical activity as well as stimulus [11]

In MRI precession frequency of hydrogen atom is used to trace the image of tissue [1][5] .MRI provides excellent anatomical as well as pathological structure of the brain. It used as a diagnostic tool for stroke haemorrhages and tumor, lesion studies

Functional imaging techniques like fMRI and PET provide excellent functional mapping of brain hence is widely used in phrenological and cognitive studies of the brain. fMRI uses magnetic properties of blood oxygenation [1-5] whereas in PET and SPECT scan, image of a part of the body is obtained by detecting gamma rays emitted from a particular portion of the body after the patient is injected with a radioactive tracer[6][13] In case of NRIS image is obtained by light modulation due to blood flow in the tissue[12]

2. Electroencephalogram Signal

The cerebral cortex is 4-5mm thick .All activities such as language, sensation, consciousness, movement, originate in the folded region of the cerebral cortex. Electrodes placed on the scalp are used to record the electrical activity of the brain. These signals are EEG signals

2.1 Recording of EEG signals

In medical practice several channels of EEG signals are recorded from various locations of the scalp for a comparative analysis of activity of different parts of the brain. The International Federation's Society of Electroencephalography and clinical Neurophysiology recommend 10-20 Electrode recording system which is shown in fig.1(10% and 20% of distance between nasion and anion, and distance between two ear lobes) [3] Fig.2 shows various regions of the brain

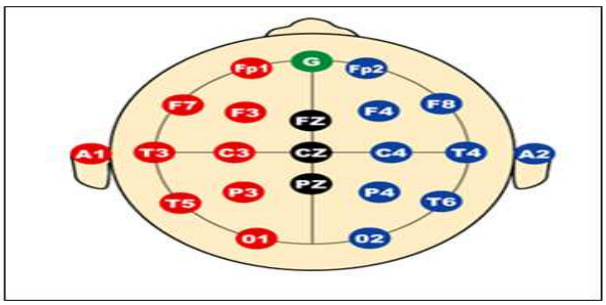

Fig -1: Placement of Electrodes
F- Frontal, T-Temporal-Central P-Parietal, O-Occipital Z-Electrode placed in middle

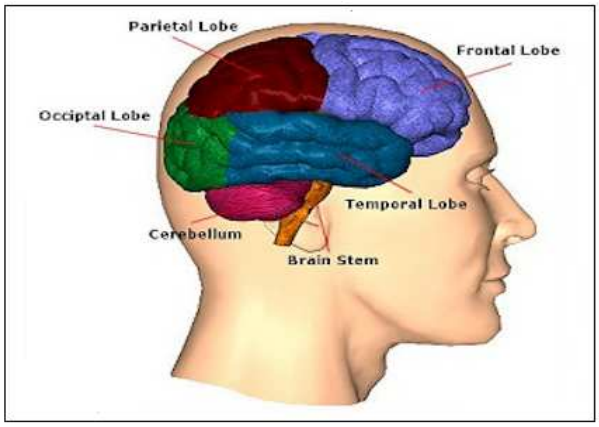

Fig -2: various lobes of brain

2. 2 Classification of EEG signals

EEG signals are stochastic signals and are in the frequency band of 0-50 Hz with amplitude in the range of μ V. The EEG signals generated are classified as **[1--4]**

- Alpha wave
- Delta wave
- Beta wave
- Theta wave
- Gamma wave

The classification of EEG signal is tabulated in Table: 1 with area of its generation

Table -1: Classification EEG signals

Waves	**Amplitude Range in μ V**	**Frequency range in Hz**	**Source of Origination**	**Function**
Alpha wave	50-200	8-13	Parietal and occipital lobe	Alertness consciousness
Beta	5-10	>13	Frontal and central	Analysis logical thinking
Theta	10	4 -8	Thalamic region	Drowsiness,deep sleep and meditation
Delta	20-200	0.5 -4	Occipital lobe	Appear during deep sleep,
Gamma (Fast Beta wave)	5-10	>30	Visual cortex	Appears during mediation and concentration

Other than the rhythm mentioned in table 1 there are waves with frequencies much higher than the normal activity range of EEG have been found in the range of 200-300 Hz. They are localized in the cerebellum and do not play any role in clinical neurophysiology. Most of the above rhythms may persist up to several minutes, while others occur only for a few seconds, such as the gamma rhythm. These rhythms are Phi (ϕ), Kappa (κ), Sigma (σ), Tau (τ), Chi (χ), Lambda (λ) and transient waveforms are associated with two sleep states, commonly referred to as a) REM –sleep (Rapid Eye Movement) b)Non-REM and also there are vertex waves, sleep spindles, and Kcomplexes[1-4] Fig.3 shows normal EEG rhythm

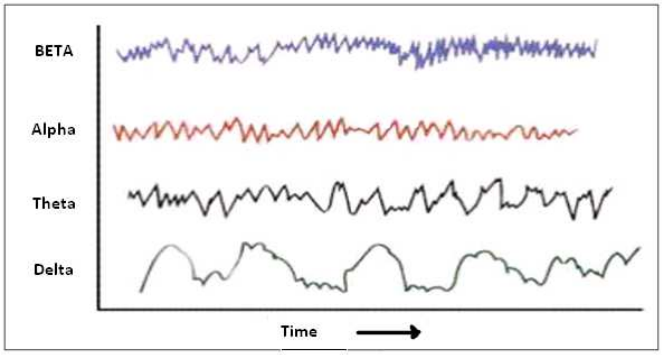

Fig -3: Normal EEG waveforms

It is usually difficult to interpret EEG rhythm and waves from scalp however filtering enables separation of the desired waveforms. There are two categories of EEG signals

a) Spontaneous brain activity
b) Background EEG, where potentials are evoked by giving various sensing and cognitive stimuli.

2. 3 Artifacts of EEG signals

As Bandwidth of EEG signals is 0.5Hz to 40 Hz and their amplitude is in the range of few μ volts. The signals are susceptible to external noise. Noise due to internal signals

generated from other parts of the body. These artifacts are classified as physiological and Nonphysiological [4]

- **Physiological**

They usually arise from generator sources within the body but not necessarily the brain; for example, eye movements; electrocardiographic and electromyographic artifacts, galvanic skin response and so on. Biological generators present in the body may produce artifacts when an EEG recording is made directly from the surface of the brain.

- **Nonphysiological**

These Artifacts come from a variety of sources such as instruments and digital artifacts (electronic components, power lines, inductance, etc.), electrode artifacts, environment, etc. With the addition of a variety of equipments in hospitals, artifacts may cause serious misinterpretation

3.0 MRI

MRI Uses a strong magnetic field and radio waves to obtain images of soft tissue of the brain. It provides excellent contrast detail between different tissues. The subject is placed inside a large cylindrical Magnet which has an aperture area of 11" to 26" (see figure 4) .During examination a radio signal is turned on and off intermittently there are two or six sequences lasting 2 to 15 minutes .The radio waves are absorbed by the body and the echoes are continuously measured by the scanner. Figure 4 shows open MRI

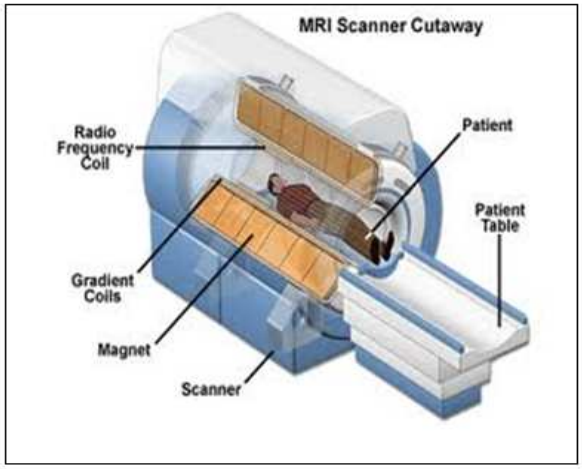

Fig -4: Schematic of a close system MRI Unit

Fig -5: Open system MRI Unit

When the radio signal is beamed through the body, hydrogen in the water molecules of the body absorbs the energy. The excited spins enter into resonance and align in a direction different from that of the magnet. This is called magnetic resonance. When the radio wave subsides the spins return to the previous direction of the magnetic field. They producing a small radio signal which is picked by the scanner

3.1 Working Principle

Spinning of hydrogen atom produces a small magnetic field. When placed in a magnetic field it tends to align itself with the main field, like a spinning top. The alignment is not complete but, forms an angle with the field and rotates about the axis of the main field (see fig.6)

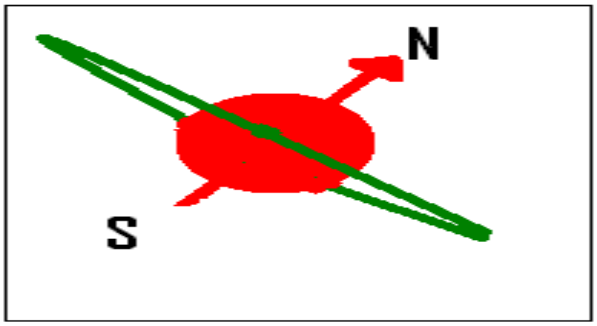

Fig -6 Spinning of Hydrogen Atom

This rotation is called precession and the angular frequency of precession is called the Larmor frequency and designated ω_0 [5]

$\omega_0 = 2\pi f_0 = \gamma B_0$ or $f_0 = \omega_0 /2\pi = \gamma B_0/2\pi$

Where γ is called gyromagnetic constant. For hydrogen it is 2.68×10^8 rad/s/Tesla. From equation 1 Larmor frequency is a function of the Magnetic field strength

Table 2: Magnetic field and Resonance frequency [5]

Magnetic Field in Tesla	Frequency in MHz
0.5	21.3
1.0	42.6
1.5	63.9
2.0	85.2
3.0	127.8

An increase in the magnetic field causes small increase in frequency. Nuclear magnetic resonance is observed in many nuclear isotopes as mentioned below table 2

Table 3: Nucleus and Resonance frequency [5]

. Nucleus	Frequency in MHz
^{1}H	63.9
$^{19}F1$	60.1
^{23}Na	16.9
^{31}P	25.9

In general the nuclear spins do not all align with the magnetic field because of thermal energy associated with the body. Hydrogen has only two spin quantum states, either aligned, in the direction of the field, or anti-aligned, in the opposite direction (see fig. 7).

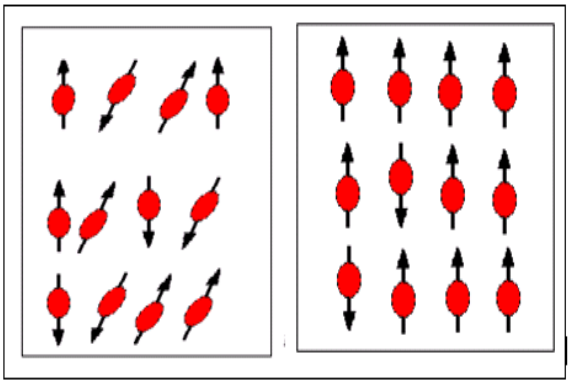

Fig -7: Schematic diagram showing alignment of Hydrogen atom with out and with external magnetic field

The anti-aligned spins have slightly more energy than the aligned spins and this energy difference is proportional to the thermal energy of the body. The spins are almost evenly distributed among the two energy levels. An image of the body is obtain from the slight energy difference in anti aligned and aligned spins [1][5]

3.1.2T1, T2 and T2* component

When the radio signal is turned off, magnetization will go back to rest by re-emitting the energy absorbed. The return to equilibrium is not instantaneous and it can be resolved in two components, one along the direction of the main field, other in the plane perpendicular to the main field. These components return separately to their equilibrium states as shown in figure 6. Both vary exponentially. The longitudinal component increases exponentially with a characteristic time known as T1 and the transverse component decreases exponentially with a characteristic time known as T2.Different tissues have different relaxation times. T1 and T2 contain tissue information.[5]

The net magnetization is the sum of the magnetic moments of all the spins. It produces the MR signal. Magnetization is treated as a single varying vector rather than the behavior of the individual spins.

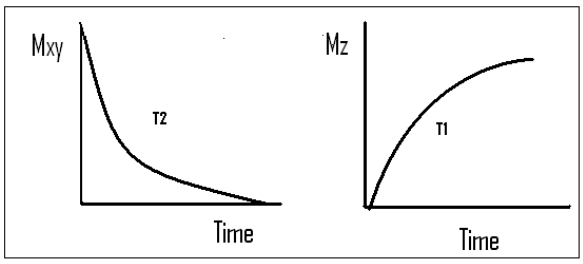

Fig -8: Relaxation speed

4.0 Functional Magnetic Resonance Imaging

Functional Imaging in MRI is a technique that gives functional information rather than just anatomical information. Flow, perfusion, diffusion, tagging and brain activation belong to this category.

The indirect method used by fMRI helps understand physiological events describe it. When a set of neurons fire, there is a local increase in glucose consumption which in turn produces an increase in oxygen consumption. This induces an increase in regional cerebral blood flow and an increase in regional cerebral blood volume with a consequent increase in blood velocity. In the blood there is a decrease in oxygen extraction fraction producing an increase in oxyhemoglobin and a decrease in deoxyhaemoglobin. For this sequence of events the most common approach used in fMRI is the **B**lood **O**xygen **L**evel **D**ependent (BOLD) contrast. The decrease in deoxyhaemoglobin, because of its high paramagnetism, produces a decrease in local microscopic field gradients, which in turn produces an increase in T2*. This corresponds to an increase in signal, which is measured by the MR equipment (see fig.9).

In fMRI oxygen level of blood supplied to various parts of the brain is mapped. Oxyhemoglobin and deoxyhemoglobin can be mapped from the fact that deoxyhemoglobin has high paramagnetism which increases T2 component which can be measured by MRI

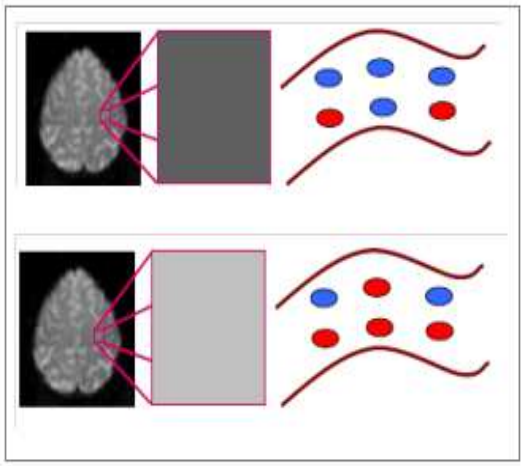

Fig- 9 : Increased proportion of deoxyhaemoglobin MRI signal lower image is darker and Decreased proportion of deoyhaemoglobin MRI signal brighter, Red circle indicate oxyhaemoglobin while blue one deoyhaemoglobin

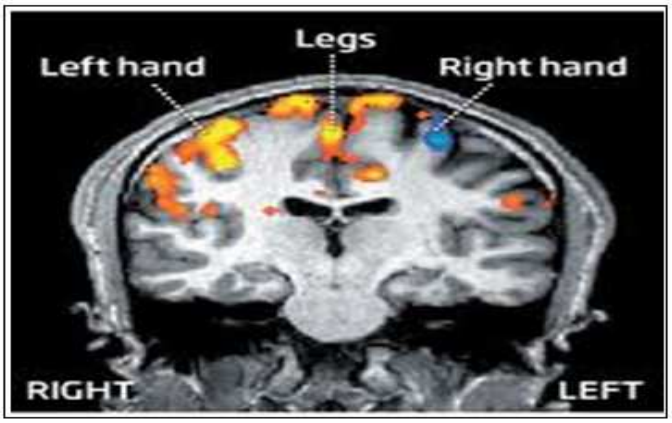

Fig- 10 :fMRI image

5.0 POSITRON EMISSION TOMOGRAPHY

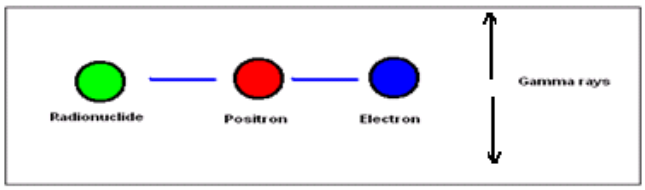

Fig-11: Emission of Gamma ray

In PET scan, image of a part of the body is obtained by detecting gamma rays is emitted by a particular portion of the body after the patient is injected with a radioactive tracer. When a positron emitted by a radioactive substance bombards an electron in the tissue, two gamma rays are emitted in opposite direction as shown in figure 11 these rays are detected by detector, when gamma rays strikes the detector it emits light which is amplified by a photomultiplier amplifier and the signal goes to the computer (see fig.12).

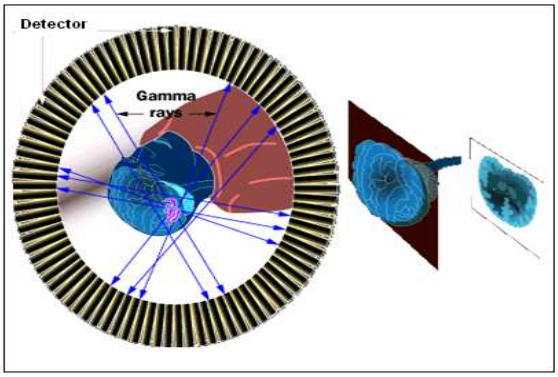

Fig- 12: PET scan Detector

Procedure

The patient is injected with a radiopharmaceutical in the vein of the arm Radiopharmaceutical is radionuclide combined with sugar, flurodeoxygulcose radionuclide are given the Table 3 gives different pharmaceuticals used in PET .More sugar gets attached to tumor cell as compare to healthy cells. The patient is placed in a ring of detectors in PET as shown in figure 12. A pair of detectors is placed symmetrically at 180°.Since scintillation is mapped; the process is also called scintigraphy. The patient is not allowed to eat or drink 8 to 12 hours before test

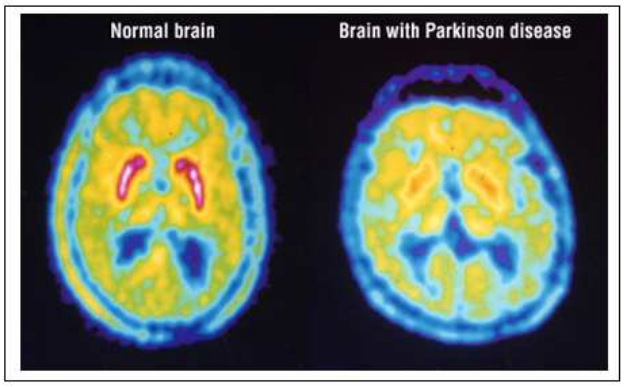

Fig-13: figure showing PET images of brain for normal and with Parkinson disease

Table 4: Radiopharmaceuticals Used in PET [1]

Radioactive Atom	Half life(in minutes)
Carbon 11	20
Fluorine 18	110
Nitrogen	10
Oxygen	2

5.1 PET Instrumentation System

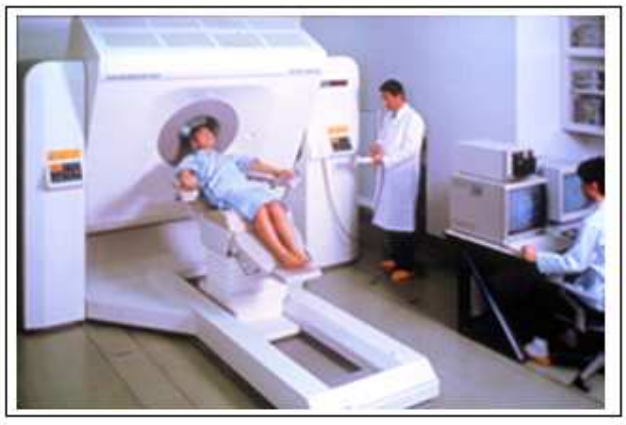

Figure 14: PET scan(Source: mentalhealthnews.org)

The PET instrumentation system consist of (see fig.14)

1. Cyclotron
2. Bio-Synthesizer
3. Scanner Detector and
4. Computer

Cyclotron is machine which is used to produce radio isotopes which are then used in Bio- synthesizer to produce radiopharmaceutical

Bio-synthesizer: It attaches FDG (flurodeoxygulcose) to radionuclide to form a radiopharmaceutical for the study of the brain O.15 and water is used C-11 or O-15 carbon monoxide is used for cerebral volume C-11 or F-18 N-Methylspiperone is used for mapping dopamine and serotonin

6.0 Single Photon Emission Computed Tomography (SPECT)

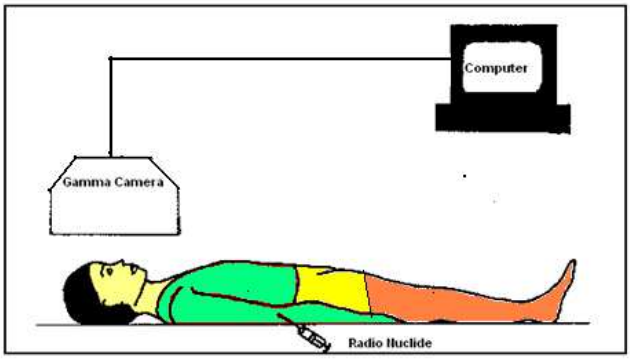

Fig.15: Schematic diagram of the production of radionuclide using gamma camera

The SPECT scan is similar to PET scan except that the radio nuclide is different and has large decay time. In this scanning the radioactive used is Iodine -123, Xenon 133 and Technetium 99. When positron strikes an electron it emit a single gamma ray instead of two rays at 180°.Hence for each ray there is only one detector. The image obtained with SPECT gives fewer details as compared to PET

SPECT images are produced from multiple 2D projections by rotating one or more gamma cameras around the body to achieve complete 360° angular sampling of photons from the body. Reconstruction using methods similar to those used in x-ray CT provides 3D data sets allowing the tracer Biodistribution to be displayed in orthogonal planes.[8]

7.0 Near infrared Spectroscopy

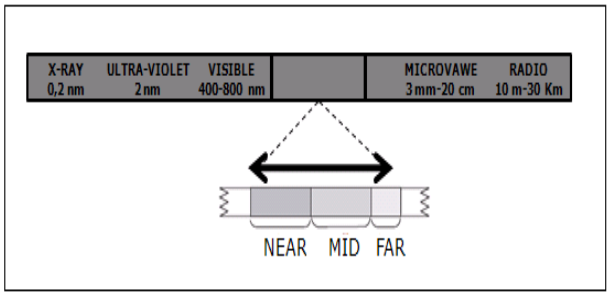

Fig-15:: Optical and Electromagnetic Spectrum

Near infrared spectroscopy (NIRS) is a noninvasive optical technology that relies on the relative transparency of biological tissues to near infrared light (700-900 nm). It Is used to determine tissue oxygenation. Oxy and deoxy hemoglobin and cytochrome aa_3 possess distinct absorption characteristics in the near infrared spectrum. By monitoring absorption at wavelengths where oxy- and deoxy-hemoglobin and cytochrome aa_3 differ, it is possible to determine the concentrations of oxyhemoglobin, deoxyhemoglobin, total hemoglobin, and oxy-deoxy cytochrome aa_3. By determining the concentrations of oxyhemoglobin, deoxyhemoglobin, and total hemoglobin, hemoglobin-O_2 saturation can also be calculated.

As with other forms of oximetry, NIRS relies on the Beer-Lambert law which describes a relationship between light behavior and concentration of a compound:

$$\log (I/I_o) = L\,C$$

Where I is the measured power of light at the detector, after it passes through the tissue and I_o is the measured power of light at the emitter before it enters the tissue, L is the path length of the light from emitter to detector, and C is the concentration of the absorbing compound in the tissue. For the brain, the light absorbing compounds are mainly oxyhemoglobin (HbO_2) and deoxyhaemoglobin (Hb), and to a much lesser extent, water and cytochrome aa_3 [12]

8.0 Comparison of various Modalities

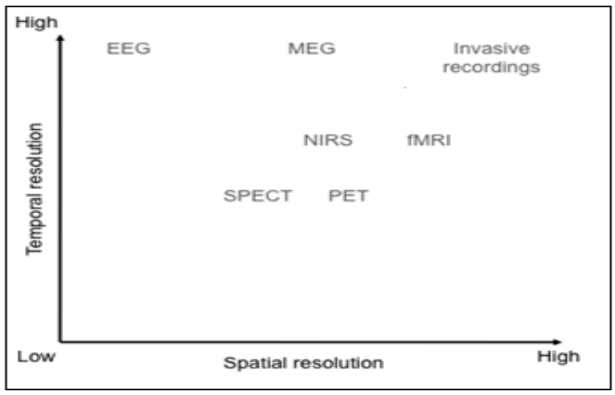

Fig16:-Temporal Vs Spatial resolution of various modalities

Table5: Comparison of Various Modalities

Imaging Methods	Temporal Resolution	Spatial Resolution	Application	Advantages	Disadvantages
EEG	Excellent 1msec	Poor Approximately 1cm	Study of various rhythms, epilepsy, preoperative mapping, degenerative disorder	Non invasive, no ionizing radiation widely used, low cost	Low spatial resolution
MEG	Excellent 1msec	Poor Approximately <1cm	Study epilepsy	Non invasive, no ionizing radiation widely used ,low cost	Low spatial resolution
PET	Very Poor 30-40 sec	Very Good 4 mm	Functional mapping	Silent as compared with MRI	Subject has to take Radionuclide
fMRI	Poor 8-10 sec	Very Good 3-6 mm	Preoperative mapping functional mapping	Non invasive, can perform functional imaging	Noisy ,signal loss due to field in homogeneities, unsuitable for claustrophobic
NIRS	poor	poor	Functional mapping	Non invasive, no ionizing radiation	Low spatial resolution
SPECTS	Average	poor >1cm	Functional mapping	Silent as compared to MRI	Subject has to take Radionuclide

8.0 CONCLUSION

As technology progresses the modalities of brain mapping are getting sophisticated day by day and play a pivotal role in revealing brain functions and cognition

All modalities have their own advantages and disadvantages. EEG modality is very economical than other modalities but artifacts make it difficult to interpret the

Signal. EEG has excellent temporal resolution but badly suffers in spatial resolution.

MRI and fMRI play a paramount role in anatomical and functional mapping of the brain. It is costlier but has excellent spatial resolution

PET and SPECT have relatively poor spatial and temporal resolution that fMRI. . PET and SPECT are not noisy as compared to fMRI. In PET and SPECT there are chances of radioexplosure .In NIRS there is no exposure to radiation

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BIOGRAPHIES

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Nandini Jog received her B.Tech(Hons.) in Electrical Engineering from IIT Bombay in 1966. Later on she completed her Master's and PhD (Technical) from Bombay University. Her PhD topic was Electronic Music wherein she developed a music tutor for studying 20 ragas in Indian classical music using various computer programmes. She has published twenty papers in interdisciplinary topics