Clinical Neurophysiology

INTRODUCTION

The brain normally produces low voltage electrical activity. This can be measured via the electroencephalogram (EEG), which is ordinarily recorded from the scalp with small surface electrodes. The precise origin of this electrical activity is unknown, but the prevailing belief is that most of the activity represents dendrite synaptic potentials in cortical pyramidal cells. Since there are normal EEG recordings characteristic of certain ages and states of consciousness, it is possible to recognize generalized malfunction of the brain with this modality, as well as localized or paroxysmal abnormalities.

The body also produces electrical activity outside the central nervous system, which can be measured in health and disease. Such measurements, performed via peripheral nerve conduction studies, electromyelograms, and neuromuscular function studies, can be used for diagnostic and prognostic purposes.
What is clinical neurophysiology?

Clinical neurophysiology is an area of medicine that is concerned with testing the electrical functions of the brain, spinal cord and the nerves in the limbs and muscles. This is done to help in the diagnosis of a wide range of conditions affecting these parts of the body. Clinical neurophysiology has close links with neurology, which deals with diseases of the nervous system and muscles. However, clinical neurophysiology is primarily diagnostic - that is to say it is used mainly to help diagnose diseases rather than treat them. It is also called Electrodiagnostics (EDX) by some rheumatologists and Electrophysiology, mainly by ophthalmologists.

The main types of test carried out in clinical neurophysiology departments are:

1. **EEG (electroencephalogram)**: a recording of the electrical activity of the brain.

The brainstem auditory evoked response test (BAER), is performed to help diagnose nervous-system abnormalities, hearing losses (especially in low-birth weight newborns), and to assess neurological functions. The test focuses on changes and responses in brain waves. The brain waves are stimulated by a clicking sound to evaluate the central auditory pathways of the brainstem.
Electroencephalography is the neurophysiologic measurement of the electrical activity of the brain by recording from electrodes placed on the scalp, or in the special cases on the cortex. The resulting traces are known as an electroencephalogram (EEG) and represent so-called brainwaves. This device is used to assess brain damage, epilepsy and other problems. In some jurisdictions it is used to assess brain death. EEG can also be used in conjunction with other types of brain imaging.

Neuroscientists and biological psychiatrists use EEGs to study the function of the brain by recording brainwaves during controlled behavior of human volunteers and animals in lab experiments. Theories to explain sleep often rely on EEG patterns recorded during sleep sessions. In addition, the procedure is used clinically to assist in the diagnosis of epilepsy.

During an EEG, highly sensitive monitoring equipment records brain activity through electrodes that are placed at measured intervals on a patient's scalp. The test is not painful. First, the head is measured, and then the electrodes are placed on the scalp with a paste-like substance. The principal role of the patient is to remain still, relaxed, and comfortable.

EEG has several limitations. Scalp electrodes are not sensitive enough to pick out individual action potentials, the electric unit of signaling in the brain, or whether the resulting electrical activity is releasing inhibitory, excitatory or modulatory neurotransmitters. Instead, the EEG picks up synchronization of neurons, which produces a greater voltage than the firing of an individual neuron. Secondly, EEG has limited anatomical specificity when compared with other functional brain imaging techniques such as functional magnetic resonance imaging (FMRI). Some anatomical specificity can be gained with the use of EEG topography, which uses a large number of electrodes to triangulate the source of the electrical activity.

EEG has several strong sides as a tool of exploring the brain activity. The time resolution is very high. As other methods for researching brain activity have time resolution between seconds and minutes, the EEG has a resolution down to sub-millisecond. The brain is thought to work through its electric activity. EEG is the only method to measure it directly. Other methods for exploring functions in the brain do rely on blood flow or metabolism which may be decoupled from the brain electric activity.

First EEG tracing, by Hans Berger (1929)
2. Electromyography

Electromyography (EMG) is a medical technique for measuring muscle response to nervous stimulation. EMG is performed using an instrument called an electromyograph, to produce a record called an electromyogram. An electromyograph detects the electrical potential generated by muscle cells when these cells contract.

Electromyography is a test that measures muscle response to nervous stimulation. A needle electrode is inserted through the skin into the muscle. Each muscle fiber that contracts will produce an action potential. The presence, size, and shape of the wave form of the action potential produced on the oscilloscope, provides information about the ability of the muscle to respond to nervous stimulation.

EMG can help to distinguish primary muscle conditions from muscle weakness caused by neurological disorders. It can be used to differentiate between true weakness and reduced use due to pain or lack of motivation. It is used to find causes of weakness, paralysis, involuntary twitching,
and abnormal levels of muscle enzymes. It can help diagnose neuromuscular disorders such as Motor Neuron Disease, neuropathy, nerve damage and muscle damage.

Electromyography is also used in biofeedback studies and training. Electromyography training is a kind of biofeedback in which patients learn to control muscle tension in the face, neck, and shoulders. For example, such training is sometimes given to migraine patients.

Muscle tissue at rest is normally electrically inactive. After the activity caused by the trauma of needle insertion subsides, the electromyograph should detect no action potential. When the muscle is voluntarily contracted, action potentials begin to appear. As contraction is increased, more and more muscle fibers produce action potentials. When the muscle is fully contracted, there should appear a disordersly group of action potentials of varying rates and amplitudes (a complete recruitment and interference pattern).

EMG may aid with the diagnosis of nerve compression or injury (such as carpal tunnel syndrome), nerve root injury (such as sciatica), and with other problems of the muscles or nerves. Less common medical conditions include amyotrophic lateral sclerosis, myasthenia gravis, and muscular dystrophy.

### 3. Evoked potential

When a sensory stimulation of any kind reaches the brain, this evokes characteristic sequences of waves in the EEG, **sensory evoked potentials**. They are different for each sensory modality and also depend on the stimulus intensity. They have a very reliable time relation to the stimulus.

Evoked potentials have very low amplitude and are drowned by the ordinary EEG rhythms. In order to see them, a large number of identical stimuli must be given, and the subsequent EEG curves stored in computer memory. After this, the computer averages these many curves, so that the ordinary EEG, which is not related to the stimulus "averages out" and only the evoked potentials remain.

Sensory evoked potentials are useful clinically. Damage to sensory tracts will obviously interfere with the evoked potentials. Careful analysis of the changes may also reveal more subtle information.

Signals can be recorded from cerebral cortex, brainstem, spinal cord and peripheral nerves. Usually the term "evoked potential" is reserved for responses involving either recording from, or stimulation of, central nervous system structures. Thus evoked CMAP (compound motor action potentials) or SNAP (sensory nerve action potentials) as used in NCV (nerve conduction studies) are generally not thought of as evoked potentials, though they do meet the above definition.
Types of evoked potentials

**Visual evoked potentials:**

Visual evoked potentials (VEPs), also sometimes referred to as visual evoked responses (VERs), are the electrical responses recorded from the scalp at the back of the head over the areas of the brain involved with vision. All evoked potential studies use electrodes placed on the scalp. These are just the same kind of electrodes as are used to record the EEG, but only a few electrodes, carefully positioned, are needed for evoked potential recording. The test is completely painless.

The stimulation most commonly used now for visual evoked potential testing is a black and white checkerboard pattern, with the black and white squares “reversing” repeatedly throughout the test, so that the black squares change to white and the white squares to black, and then back again. As you can imagine, this gives a sensation of movement of the squares.

![Checkerboard pattern](image)

The test is also useful in the investigation of a whole range of other disorders affecting any part of the visual system from the eye itself to the visual areas at the back of the brain. Visual evoked potentials are used by ophthalmologists (specialists in eye disease) as well as by neurologists.

**Auditory evoked responses:**

Auditory evoked responses (AERs) are also referred to as brainstem auditory evoked responses (BAERS) and brainstem auditory evoked potentials (BAEPs). The term brainstem is used because this area of the nervous system, which connects the base of the brain with the top of the spinal cord, is where the electrical responses recorded in this test are believed to originate.

During the test, the person sits in an easy chair or lies on a couch or bed in a quiet room and is made as relaxed and comfortable as possible. Unlike visual evoked potentials, AERs are not altered by sleep, and if anything, sleep may improve the quality of the recording. In some
departments, a mild sedative drug will be given before the test and this may be particularly helpful when recording from babies or small children. The person hears the sound stimuli through a pair of headphones. Various types of sound may be used, but clicks are the most common for investigating diseases of the nervous system. At the beginning of the test, the sound is turned up and down until the point at which the person can just hear the stimulus has been found. The sound is then increased slightly for the actual test.

A delay in the conduction of signals through nerve pathways in the brainstem may occur in multiple sclerosis and this can often be revealed by AER testing. It is also used to investigate a variety of other disorders affecting the brainstem and adjacent areas. As well as diseases of the nervous system, AERs can also be used to test hearing. In particular, AER testing is used in many hospitals in the assessment of hearing in premature or other sick newborn babies who may be at risk of hearing loss.

**Somatosensory evoked potentials:**

Somatosensory evoked potentials - SEPs or SSEPs for short – sound complicated but are really quite straightforward. SSEPs measure the electrical response in the brain and spinal cord when a nerve in an arm or leg is stimulated with a small electrical pulse. During the test, the person either lies on a couch or bed or sits in a comfortable armchair in a quiet room. Relaxation is encouraged as muscle tension or movement may interfere with the results of the test. As with AERs, a mild sedative drug is sometimes given if a person has difficulty relaxing. If the arms are being tested, a small repeating electric pulse is given to the skin over one of the large nerves, usually around the wrist. This usually produces a slight twitch in the thumb. The electrical pulse itself feels like a tapping sensation on the skin, which most people do not find too unpleasant.

In multiple sclerosis, there may be a delay in the passage of the signals up the spinal cord or through the brainstem. This will show up in the test, which may also give information about where in the nervous system this delay has occurred.

The test is also used to help with the diagnosis of a range of other disorders known to produce abnormal SSEPs. SSEPs are now increasingly being used during surgery to monitor the spinal cord during delicate operations on the vertebrate or the spinal cord itself. Many people believe that recording SSEPs during spinal surgery can reduce the risk of serious injury to the spinal cord during this type of operation.

**Motor evoked potentials:**

Motor evoked potentials are the electrical responses of muscles in the limbs to stimulation applied over the brain or spinal cord. The speed of these responses is also tested in some specialized departments. Magnetic stimulation is used to produce the responses. This is done by creating a magnetic field by sending pulses through a hand-held coil of wire covered in plastic. The magnetic field then activates the nerve cells. Magnetic stimulation is not uncomfortable and no special preparation is required. The coil is held over the scalp to stimulate the brain or over the neck to stimulate the spinal cord. The responses are recorded from electrodes placed over muscles in the
arms or legs. The responses may be delayed in a variety of conditions, including multiple sclerosis, disorders of the spinal cord, stroke and coma as well as a range of other less common neurological disorders. This technique is also used to monitor the spinal cord during surgery.

4. Polysomnography

Polysomnography refers to the collective process of monitoring and recording physiologic data during sleep. The specific variables monitored during center-based polysomnographic evaluation of sleep-related respiratory disturbances are listed.

The variables monitored and recorded during polysomnography include but are not limited to:

- global neural electroencephalographic activity (EEG) from electrodes placed on the patient's scalp;
- eye movements (electro-oculogram, or EOG) from electrodes placed near the outer canthus of each eye;
- submental electromyographic activity (EMG) from electrodes placed over the mentalis, submentalis muscle, and/or masseter regions;
- rhythm electrocardiogram (ECG) with two or three chest leads;
- respiratory effort, by chest-wall and abdominal movement via strain gauges, piezoelectric belts, inductive plethysmography, impedance or inductance pneumography, endoesophageal pressure, or by intercostal EMG;
- nasal and/or oral airflow via thermistor or pneumotachograph;
- oxygen saturation (SpO2) via pulse oximetry;
- body position via mercury switches or by direct observation;
- limb movements (arms and legs) via EMG;
- recordings of or vibration (frequency and/or volume) may be recorded;
- end-tidal CO2, transcutaneous CO2, esophageal pH, penile tumescence, and bipolar EEG are beyond the scope and intent of this guideline.

5. Intraoperative neurophysiology monitoring

Intraoperative Neurophysiology Monitoring (IONM) is the use of electrophysiological methods such as EEG, EMG, and evoked potentials to monitor the functional integrity of neural structures (brain, nerves, and spinal cord) during surgery. The most common applications are in spinal surgery; some brain surgeries; carotid endarterectomies; ENT procedures such as acoustic neuronal resection; and peripheral nerve surgery. Motor evoked potentials have also been used in surgery for TAAA (thoracic-abdominal aortic aneurysms).

These methods can be used to localize neural structures, for example to locate cranial nerves during skull base surgery; to test function of these structures; and for early detection of intraoperative injury, allowing for immediate corrective measures.
For example, during any surgery on the thoracic or cervical spinal column, there is some risk to the spinal cord. Since the 1970’s, SSEP (somatosensory evoked potentials) have been used to monitor spinal cord function by stimulating a nerve distal to the surgery, and recording from the cerebral cortex or other locations rostra to the surgery. A baseline is obtained, and if there are no significant changes, the assumption is that the spinal cord has not been injured. If there is a significant change, corrective measures can be taken; for example, the hardware can be removed.

More recently, transcranial electric motor evoked potentials (TCeMEP) have also been used for spinal cord monitoring. This is the reverse of SSEP; the motor cortex is stimulated transcranially, and recordings made from muscles in the limbs or from spinal cord caudal to the surgery. This allows direct monitoring of motor tracts in the spinal cord.

The Future of Clinical Neurophysiology

With the generalization of digital systems, the possibility of maintaining information that, eventually, we will not be able to recover is only the tip of the iceberg of a wide range of difficulties. Among these difficulties, we can include the incompatibility of transferring data between different systems (in the same department or between different departments), the difficulties to analyze signals with software not compatible and the impossibility of using general software in the treatment of neurophysiological signals.

The manufacturing of software and hardware as a unit could change in the future. On one hand, some companies that market conventional equipment also offer a free reader that allows the visualization of the signals in other computers. On the other hand there exist companies whose software run independently of the acquisition equipment with functions that span from visualization of EEG to specific analysis such as spike detection, sleep quantification, mapping, etc. As far as I know, this phenomenon is less developed in EMG or EP although it does not seem impossible that something similar happens.

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