**BME 620L - Applied Electrophysiology**

# *Transcutaneous electrical nerve stimulation using EEG*

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## Abstract

Transcutaneous electrical nerve stimulation (TENS) is a non-pharmacologic treatment for pain relief. TENS has been used to treat a variety of painful conditions. Evidence continues to emerge from both basic science and clinical trials supporting the use of TENS for the treatment of a variety of painful conditions while identifying strategies to increase TENS effectiveness.

EEG remains a major technique for investigation of the brain. Its main applications are in assessment of cerebral function rather than for detecting structural abnormalities. Abnormalities in EEG reflect general pathophysiological processes, raised intracranial pressure, oedema, epileptogenesis etc, and show little specificity for a particular disease.

This study aims to develop a wireless EEG system to record information about brain electrical activity during pain and stimulate the TENS unit to treat the painful condition. A novel dry electrode, which can be installed rapidly, is used to acquire EEG from the scalp. A wireless data link between the electrode and a data port (on the TENS unit) is established based on the Bluetooth technology.


## Background

Sitting in an office chair for prolonged periods of time can definitely cause low back pain or worsen an existing back problem. This is because sitting in an office chair, is a static posture that increases stress in the back, shoulders, arms, and legs, and in particular, can add large amounts of pressure to the back muscles and spinal discs. When sitting in an office chair for a long period, the natural tendency for most people is to slouch over or slouch down in the chair, and this posture can overstretch the spinal ligaments and strain the discs and surrounding structures in the spine. Over time, incorrect sitting posture can damage spinal structures and contribute to or worsen back pain. TENS therapy typically uses electrodes on small, sticky pads attached via wires to a battery operated device. The electrodes are placed over the area in pain, and current is sent through the electrodes, stimulating the sensory nerves and creating a tingling sensation that reduces the feeling of pain.

## Introduction

The CNS consists of the brain and spinal cord. The brain is an important organ that controls thought, memory, emotion, touch, motor skills, vision, breathing, temperature, hunger, and every process that regulates our body. The brain can be divided into the cerebrum, brainstem, and cerebellum. Cerebrum is the largest part of the brain and divided into four lobes. The four lobes of the brain are parietal, occipital, temporal and limbic lobe and all are associated with different brain functions.

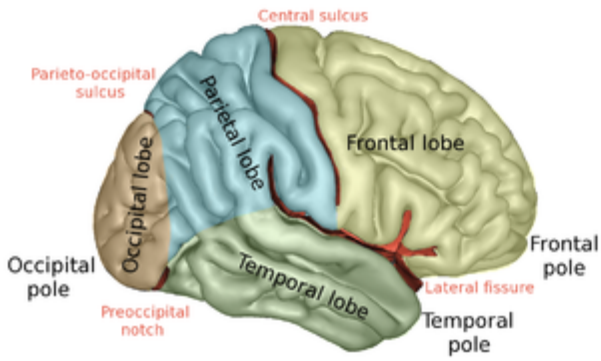


**Figure 1: Four Lobes of the brain**

Multiple pathways in the CNS are involved in pain processing. Human brain imaging studies have revealed cortical and subcortical networks are activated by pain. The brain areas most commonly activated by noxious stimuli in human brain imaging studies are the primary somatosensory cortex (S1), secondary somatosensory cortex (S2), anterior cingulate cortex (ACC), insula, prefrontal cortex (PFC), thalamus and cerebellum. Neural activation in these areas is consistent with anatomical and electrophysiological studies that show possible afferent nociceptive connectivity to these regions.

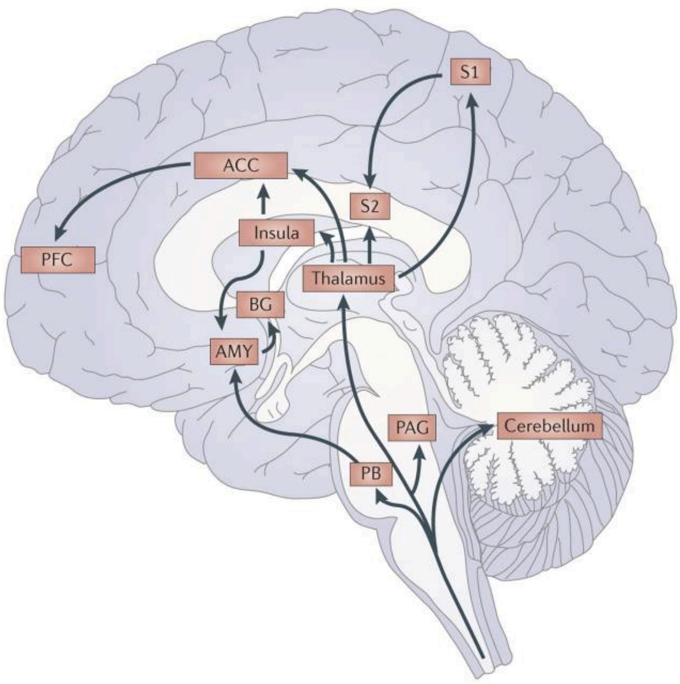


**Figure 2: Afferent pain pathways include multiple brain regions**

Brain responses to pain, assessed through positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) are reviewed. Functional activation of brain regions are thought to be reflected by increases in the regional cerebral blood flow (rCBF) in PET studies, and in the blood oxygen level dependent (BOLD) signal in fMRI. rCBF increases to noxious stimuli are almost constantly observed in second somatic (SII) and insular regions, and in the anterior cingulate cortex (ACC). Activation of the lateral thalamus, SI, SII and insula are thought to be related to the sensory-discriminative aspects of pain processing.

Transcutaneous electrical nerve stimulation (TENS) is used in the treatment of acute and chronic pain conditions. These small battery-powered devices deliver alternating current via cutaneous electrodes positioned near the painful area. It can be applied with varying frequencies, from low (< 10 Hz) to high (> 50 Hz). Intensity may also be varied from sensory to motor intensities. Sensory intensity is when the patient feels a strong but comfortable sensation without motor contraction. High intensity usually involves a motor contraction but is not painful. In general, higher-frequency stimulation is delivered at sensory intensity, and low-frequency stimulation is delivered at motor intensity. Regardless of intensity, different frequencies activate central mechanisms to produce analgesia i.e, the inability to feel pain.

## Design and Implementation

The EEG system consists of three components: a set of EEG electrodes, a central control unit, and a data port. The electrodes record EEG signals; the central control unit amplifies the signals and wirelessly transmits them to the data port which is used to process the acquired information and deliver a shock. In the current configuration, three electrodes (i.e., a ground, a reference, and a signal electrode) are used to acquire an EEG signal.

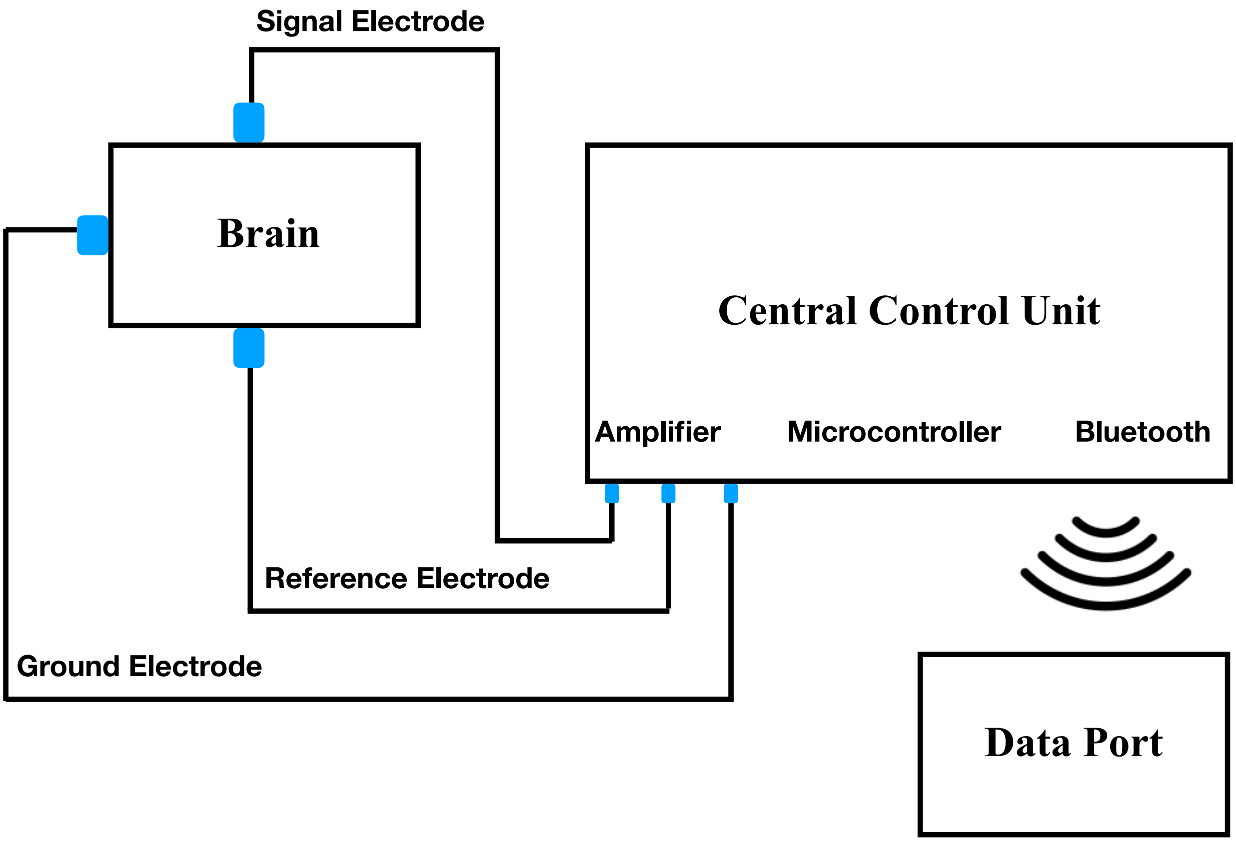


**Figure 3: EEG signal and the system transmits data wirelessly to a data port**

## Skin Screw Electrode

Our skin screw electrode has a cylindrical shape (approximately 1cm in both diameter and height) with micro teeth along the bottom. When the electrode is twisted clockwise, these teeth can penetrate hair and hook on the painless top layer of the scalp. This kind of electrode does not require the application of electrolyte, and can be applied to or removed from the scalp very quickly.

## Central Control Unit

The role of the central control unit is to acquire and transmit the EEG signal to the data port wirelessly. The major electronic function blocks inside the unit are: (a) a high-impedance, low noise differential amplifier; (b) a micro controller; and (c) a Bluetooth wireless communication circuit.

## Data Port

The data port is used for data storage, and triggering the TENS unit. The EEG data is processed and recorded on a flash memory card.

## TENS Unit

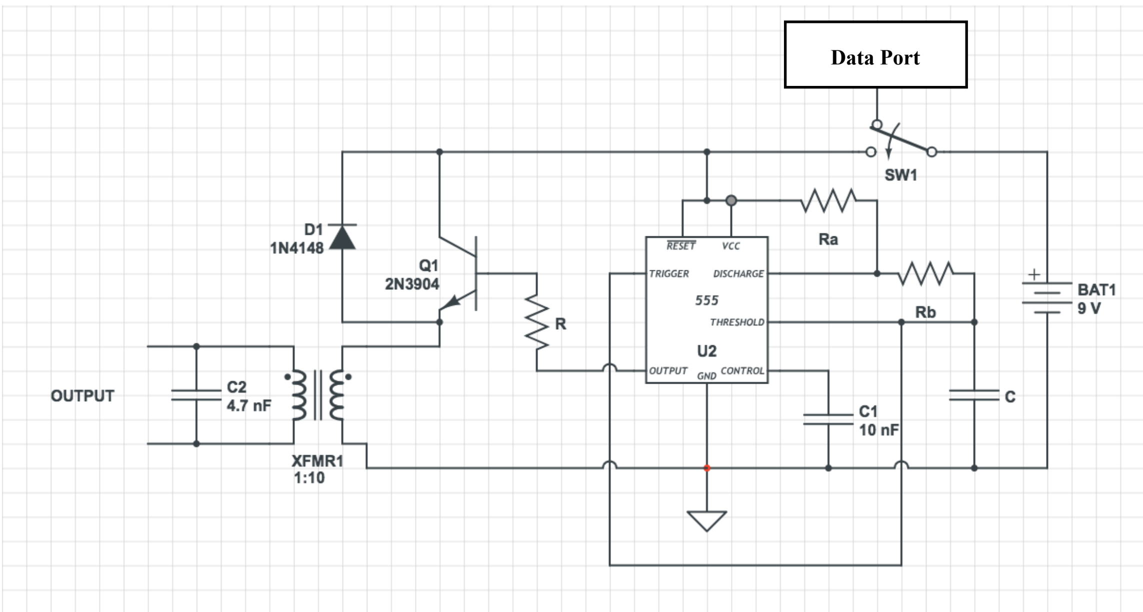


**Figure 4: Transcutaneous Electrical Nerve Stimulator (TENS) Circuit**

The circuit uses a CMOS 555 timer to produce a brief pulse which feeds a 1:10 step up transformer. Together with a 4.7 nF capacitor the transformer makes a parallel resonant circuit; the resonance leads to a considerable increase in the output voltage. The pulse width can be adjusted using Ra, Rb, C and here they are combined with the on-off switch. Wider pulses produce higher output voltages. Since a peak voltage of up to 200 V can be produced, the transformer must have adequate insulation.

Any socket used for data communications might be called a data port. In the above figure output of data port controls switch S1 opening and closing which in turn triggers the monostable circuit. By controlling the switching action with the output of data port, monostable would produce an output square pulse when pain is detected and fed back through the EEG signal into the data port. This in turn is going to produce the necessary output to treat the pain.

## Localised Pain Detection

It is important that the EEG picks up the pain which arises from the receptors from the back and distinguishes with the information received from other nociceptive receptors. Improper detection can rise to unnecessary  stimulation of the back i.e the TENS unit delivers a shock inappropriately since it is activated. Therefore it is essential to identify localised pain and create stimulations when required.

### Is there an EEG pattern for chronic pain?

The main objective of this research was to determine EEG patterns in the presence of chronic pain. Findings show that there is a general trend towards increased power at lower EEG frequencies in patients with chronic pain at rest.

Changes in EEG activity associated with chronic pain have been observed in different brain regions, including frontal, parietal, and occipital, or sensoriomotor and somatosensory regions. This widespread distribution of changes in brain processing is in agreement with findings provided by neuroimaging studies including functional Magnetic Resonance Imaging, Positron Emission Tomography, and Magnetoencephalography in patients with pain. Despite the heterogeneity in the type of pain and clinical characteristics of the participants included in the reviewed studies, one thing is common; abnormalities in sensory and motor information processing in patients with chronic pain.

### Accuracy of EEG Pattern

The device consists of electrodes positioned at several locations so that it collects data from primary somatosensory cortex (S1), secondary somatosensory cortex (S2), anterior cingulate cortex (ACC), insula, prefrontal cortex (PFC), thalamus and cerebellum. EEG activity can be seen in these regions individually which confirms that there is pain. This helps us in differentiating back pain from other body pains since all the above mentioned regions do not show a change in EEG activity collectively. Also by doing this we can predict pain despite the fact that the EEG pattern is going to change for different users.

### Advantages and disadvantages of the EEG technique

#### Advantages:

- Provides data on brain electrical behavior in individuals with pain
- Portable and low cost device
- Easy to use
- No restrictions for the use of metallic implants in the body, enabling the evaluation of individuals with prosthetic devices.

#### Disadvantages:

- EEG discriminating location power
- Adequacy of the environment where the examination is performed.
- Intensive training on acquired data

### Conclusion

Increased alpha and theta power at spontaneous EEG and low amplitudes of ERP during various stimuli seem to be clinical characteristics of individuals with chronic pain. Quantitative EEG can be a simple and objective tool for studying the mechanisms involved in chronic pain, identifying specific characteristics of chronic pain conditions and providing insights about appropriate therapeutic approaches. However more studies are necessary before drawing any conclusion on the utility of qEEG on chronic pain.

## TENS activation and pain treatment

Fixed-site high-frequency TENS (FS-TENS) devices are designed for placement at a pre-determined location, which enables development of a wearable device for use over extended time periods. The device is designed for a pre-determined location rather than according to the patient's pain distribution.

### Mechanism of sensory nerve stimulation for pain relief

Activation of sensory nerves (Aβ fibers) closes a pain gate in the spinal cord that inhibits the transmission of pain signals carried by nociceptive afferents (C and Aδ fibers) to the brain. Anatomic pathways and molecular mechanisms that may underlie the pain gate have been identified. Sensory nerve stimulation activates the descending pain inhibition system, primarily the periaqueductal gray and rostroventral medial medulla located in the midbrain and medulla sections of the brainstem respectively. The periaqueductal gray has neural projections to the rostroventral medial medulla, which in turn has diffuse bilateral projections into the spinal cord dorsal horn that inhibit ascending pain signal transmission.

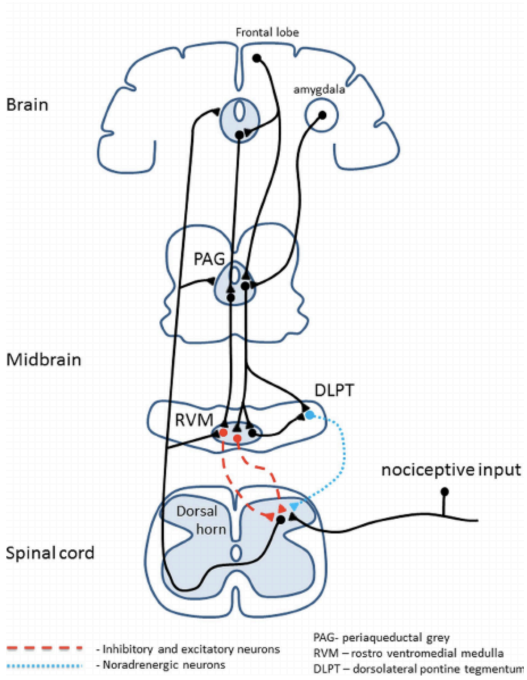


**Figure 5: Pain Modulating System**

## <u>Tens Electrode Placement</u>

A stimulation lead wire consists of 2 electrodes/pads:

. A negative electrode: **black** connection
. A positive electrode: **red** connection

The tens unit electrodes/pads are embedded to a belt and this can be placed virtually anywhere on the back. Usually we place the first electrode pad directly where you are feeling pain. The second pad is needed to complete the circuit and can be placed horizontally or vertically from the first pad. For general lower back pain, you will want to place a pad on each side of the spine. If the pain is isolated and in one area, then you can place the second pad directly next to the first pad or just above or below the first pad.

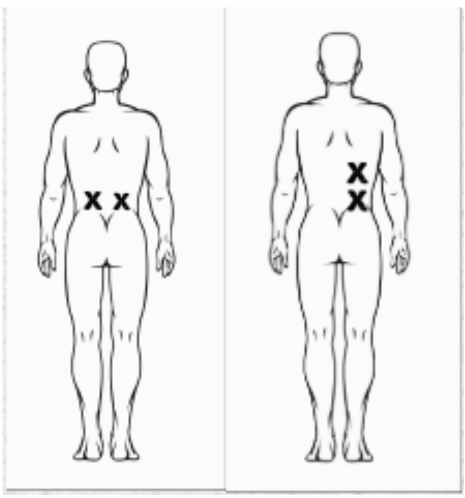

**Figure 6: Placing the TENS Electrode**

A portable TENS unit is a great non-invasive, drug-free treatment for all types of back pain. These can be worn on basically any part of the back and are designed to combat both acute and chronic back pain. A TENS machine can be used anytime you are in pain and typically 10-30 minutes is all that is needed to experience noticeable relief. It is safe to use every day, the amount of relief one will experience is different for everyone. Pad placement is easy and intuitive: electrode pads are placed in the area where you are experiencing pain. The one area you want to avoid when using a tens unit on the back is directly on the spine, which typically feels uncomfortable.

## Device

This is a wearable device which can be worn for long periods of time. Also the EEG electrodes are embedded into a hat which contains the bluetooth chip to transfer information obtained through the electrodes to the data port located on the back. The TENS unit is attached to a belt that is worn around the back. The entire device can be designed in  a way which is comfortable for the user and wouldn't have any discomfort while wearing for long time..

### Precautions before using the device

Be sure to follow directions carefully and take these precautions:

- Use TENS only for the reason your doctor orders it. Let your doctor know if your condition changes.
- Do not leave electrodes in place for long periods of time without checking and cleaning the skin beneath them.
- If a rash or burn develops beneath the electrodes and lasts more than six hours, stop TENS. Also call your doctor or physical therapist.
- Do not place electrodes on broken or irritated skin.
- Do not drive while using the device.
- Do not use the device in the shower or bathtub.
- Do not use the device while sleeping.

### Design

### Band

The band is worn around the back. It would feature a durable fabric and robust velcro closure designed for longer wear. The ends are rounded to prevent overlap of the velcro onto the user's clothing and a fully enclosed pocket keeps the TENS device secure in the band.

### Cap

The cap can connect wirelessly and sets up fast. It is battery operated and designed to be rechargeable. It  transmits data wirelessly at 128 or 256 Hz, so you can record high resolution brain data outside of the laboratory and without being tethered to a computer. The cap would be integrated with 9 axis motion sensors so that it can detect head movements.

**Figure 7: EEG Cap and Wearable TENS unit**

## Conclusion

Through my technology the problem of experiencing a back pain in office due to prolonged period of sitting can be eliminated. The user must however ensure that the precautions are followed before using the device.

## Discussion

Extracting EEG signal for back pain is going to be a challenge. By conventional EEG technique we need to visualise the changes in alpha and theta waves. Next we have to see the difference in the frequency spectrum since there is no use in measuring the amplitude due to the fact that it is going to be different for different users. Also we need to see the EEG pattern while recording it at several locations, calculate the change in frequency and average those values to get a number which can be set as a threshold for detecting back pain.

We need to set a range of values about the average so that if there is a change in the EEG frequency spectrum within that range we can assume that there is pain. The challenge is to set the range since a large range can lead to erroneous values resulting and in wrong stimulation and if the range is small then we might miss the pain signals and the user might not experience a shock to treat his back pain.

In the TENS side, it is going to deliver a shock within the safe limit to provide instantaneous pain relief. However the nature of pain is unknown, the user might be experiencing a severe discomfort and this stimulation pulse wouldn't be strong enough to treat it. The amplitude of EEG comes into the picture now and it would be great if there can be a way of interpreting the EEG amplitude to deliver pulses. Given the uncertain nature of amplitude it is going to be tough in using it to vary the intensity of pulses to treat the pain.

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